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Engineering Secure and Reliable Systems – A French-German Workshop

Proceedings

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French-German Institute for Environmental Research (DFIU)

Preface

Abstract

The French-German Workshop on Engineering Secure and Reliable Systems is an educational and scientific workshop on cross-border risk management. The workshop took place in Sophia-Antipolis, Antibes, France. From 26th to the 28th of June 2023 researchers and practitioners from France, Italy, and Germany came together to exchange current research outcomes within the research field on Engineering secure and reliable systems. Approximately ten researchers attended the event. During the workshop, four keynote speeches were scheduled. The French-German Workshop on Engineering Secure and Reliable Systems accepted three papers for inclusion in the post-proceedings.

Résumé

Le French-German Workshop on Engineering Secure and Reliable Systems est un atelier éducatif et scientifique sur la gestion des risques transfrontaliers. L'atelier a eu lieu à Sophia-Antipolis, Antibes, en France. Du 26 au 28 juin 2023, des chercheurs et des praticiens de France, d'Italie et d'Allemagne se sont réunis pour échanger les résultats de leurs recherches dans le domaine de l'ingénierie des systèmes sûrs et fiables. Environ dix chercheurs ont participé à l'événement. Au cours de l'atelier, quatre discours étaient prévus. Le French-German Workshop on Engineering Secure and Reliable Systems a accepté trois articles pour inclusion dans les actes de l'atelier.

Zusammenfassung

Der French-German Workshop on Engineering Secure and Reliable Systems ist ein Bildungs- und Wissenschafts-Workshop zum Thema des länderübergreifenden Risikomanagements. Der Workshop fand in Sophia-Antipolis, Antibes, Frankreich, statt. Vom 26. bis 28. Juni 2023 kamen Forscher und Praktiker aus Frankreich, Italien und Deutschland zusammen, um aktuelle Forschungsergebnisse im Bereich der Entwicklung sicherer und zuverlässiger Systeme auszutauschen. Etwa zehn Forscher nahmen an der Veranstaltung teil. Während des Workshops waren vier Hauptvorträge geplant. Der French-German Workshop on Engineering Secure and Reliable Systems akzeptierte drei Artikel zur Veröffentlichung.

Engineering Secure and Reliable Systems – A French-German Workshop

Not only does the COVID-19 pandemic show the importance of cross-border cooperation, but the first lockdown in Europe was characterized by border closures and lengthy controls so that (essential) goods could only be transported solely with long delays. However, demand for urgently needed goods increased significantly due to the pandemic. This phenomenon was particularly noticeable in the case of medical items, including medicines and protective equipment. Therefore, a central question for improving future health care is how individual countries' cooperation should be structured to distribute the required medical goods according to their needs optimally. This topic was examined from different perspectives during the workshop.

The workshop pursued the two goals of training doctoral students in cross-border resilience and initiating a dialogue between networking participants in cross-border cooperation, as it is becoming increasingly important that complex issues are tackled and solved in interdisciplinary teams.

The workshop was structured to encompass various formats, fostering dynamic discussions and yielding valuable outcomes. Specialized insights were shared through keynote speeches and interactive sessions on diverse topics, enabling the exploration of innovative ideas. Subsequently, these proceedings were collaboratively developed in interdisciplinary teams as post-proceedings stemming from the workshop.

Content

Public-Private Partnerships in Disaster Management: A Systematic Review of Incentives and Challenges

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Abstract

In times of crisis, the seamless functioning of supply chains, the preservation of business operations, and the provision of essential goods to the population are shared concerns for both public and private entities. However, the primary responsibility for ensuring an adequate supply to the population rests with the government and its authorities. In a complex and unpredictable environment marked by scarce resources and limited data availability, fulfilling this responsibility alone becomes a nearly unsolvable challenge. Consequently, active participation from private actors, such as logistics service providers, becomes essential since their expertise and resources play a pivotal role in collectively ensuring operational continuity. Hence, there is a growing trend towards establishing Public-Private Partnerships to enhance the resilience of supply chains and critical infrastructure. Despite their potential, the implementation remains limited due to existing barriers and conflicting perspectives, which hinder effective crisis response in these collaborative efforts. Consequently, we present a comprehensive framework to tackle these challenges, offering enablers and incentives to facilitate and enhance long-term partnerships.

Keywordse: Collaboration; Resilience; Decision-support; Preparedness; Risk management

1 Introduction

Effective disaster management is crucial amid infrastructure damage, economic setbacks, health issues, and social vulnerabilities caused by natural disasters and humanitarian crises. The urgency stems from the interconnectedness within global supply chains, emphasizing the need for comprehensive disaster preparedness and response efforts. Public-Private Partnerships (PPPs) offer a promising approach, combining expertise and resources to enhance preparedness, response, and recovery efforts.

Despite the growing recognition of PPPs in disaster management, a significant gap exists in understanding the complex dynamics of these collaborations, especially in an uncertain

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environment. Time constraints, possible infrastructure damage, varying demand, numerous stakeholders, and limited resources make organizing an efficient ad-hoc response challenging [1]. Moreover, the existing literature often lacks a systematic and descriptive analysis of these issues, making it difficult for policymakers, researchers, and practitioners to derive practical insights and recommendations.

Therefore, this study explores the enablers, incentives, challenges, and decision-making mechanisms inherent in PPPs in a systematic review using the following research question to grasp the details of these collaborations and maximize their effectiveness:

> RQ: What are the key enablers, challenges, and incentives for public and private sector stakeholders in establishing and sustaining effective disaster management PPPs?

We contribute a practical framework derived from our research findings, which captures insights from the reviewed papers. This structured foundation aims to shape future resilience strategies in disaster management. Drawing from past PPP initiatives, the framework serves as a practical guide, addressing challenges, identifying enablers, and highlighting incentives to enhance preparedness for upcoming disasters. Consequently, the outcomes of our study facilitate informed decision-making and enhance the overall effectiveness of disaster management efforts, particularly amid uncertainties.

The remainder of this work is structured as follows. Section 2 covers the role of uncertainty in disaster management and the theoretical concepts of PPPs. Section 3 presents the methodology of the applied systematic literature review. Subsequently, Sections 4 and 5 present and discuss the obtained results.

2 Theoretical Background

2.1 Uncertainty and challenges in disaster management

The environment of humanitarian disasters is highly dynamic and uncertain. The characteristics of humanitarian logistics also indicate the challenges relief supply chains face, including uncertainty about the occurrence of disaster [2], irregularity in demand [3], poor logistics infrastructures [4], slow coordination and response [5], and a lack of adequate resources [6].

Although each disaster is unique, most exhibit similarities in the logistical response and specific challenges or critical success factors that should receive constant and careful attention [7]. Based on the research of [5], [8], [9], and [7], those critical success factors comprise efficient network design, information management and technology, coordination and collaboration, and strategic transport decisions and last mile operations.

In particular, a lack of coordination and collaboration is often cited as one of the most significant challenges in relief operations (e.g., [10, 11, 12]). Hence, fostering public-private collaboration is crucial for effectively addressing the barriers and challenges arising from the uncertainty and complexity of disaster environments.

2.2 Collaboration and Public-Private Partnerships

Relief logistics requires fast and efficient actions from multiple participants in the humanitarian supply chain, including procurement, transportation, and warehousing [13]. Collaboration can occur between different actors intending to develop solid and beneficial relationships. These actors have different interests, capacities, and logistics expertise [12]. Consequently, PPPs are crucial for leveraging synergies between the private and public sectors to advance and improve disaster relief and logistics [13].

As per the definition provided by the German Federal Ministry for Economic Cooperation and Development, PPPs are defined as collaborations between the public sector and private businesses in the design, planning, construction, financing, management, operation, and exploitation of public services previously provided solely by the state [14]. There are multiple ways in which collaboration or PPPs can take place depending on the level of engagement, phase of the disaster relief operation, financial agreement, or logistics activities [15].

For instance, some companies such as Walmart Inc., Home Depot Inc., Lowe's Companies Inc., the Coca-Cola Company, Chick-fil-A Inc., or British Airways engage routinely in collaborations to make resources and services available to public actors [12, 16, 17]. Even though there are many different types and concepts of collaboration or partnerships, [18] highlight long-term partnerships as an opportunity for increased knowledge transfer and better strategic collaboration.

Although the idea of PPPs is intensively discussed, a significant gap exists in understanding how these collaborations can effectively benefit all stakeholders and what essential factors are required for integrating them seamlessly into complex networks. Therefore, we outline the theoretical potential and practical mechanisms necessary to adopt PPPs across diverse supply chain environments successfully.

3 Methodology

The study employs a systematic review of scientific literature to answer the underlying research question. The systematic method ensures a thorough exploration of the current knowledge. It identifies potential areas for future research, enabling detailed analysis and providing valuable insights into PPPs. The systematic review methodology was implemented based on [19, 20] to guarantee future reproducibility and comparability. The applied process is illustrated in Figure 1.

In the initial phase of the study, we carefully considered establishing precise search parameters and selecting an appropriate database and keywords central to the study. We chose Scopus, a reputable and widely used scientific database, to ensure the inclusion of all relevant literature.

Subsequently, an iterative process was employed to formulate an effective search string, aligning with the central research question and the field of study. Relevant keywords were identified and tested in various combinations using Boolean operators, enabling the analysis of corresponding results. This iterative process provided valuable insights into search patterns and associated keywords, resulting in the selection of the following search string to query the aforementioned scientific database:

TITLE-ABS-KEY(("public-private" OR "cross-sector" OR "partnership") AND "disaster" AND ("incentive" OR "challenge" OR "decision"))

The search took place on October 13, 2023, yielding 506 articles. We screened these publications based on specific inclusion and exclusion criteria to extract relevant articles and maintain the reliability of the systematic process. The review includes studies directly relevant to PPPs and the determined research question encompassing peer-reviewed journal articles published in English. Our review excludes studies that do not primarily focus on PPPs or fail to provide substantial information on the underlying research aim. Non-academic sources, such as news articles, opinion papers, and blog posts, are not included due to their informal nature.

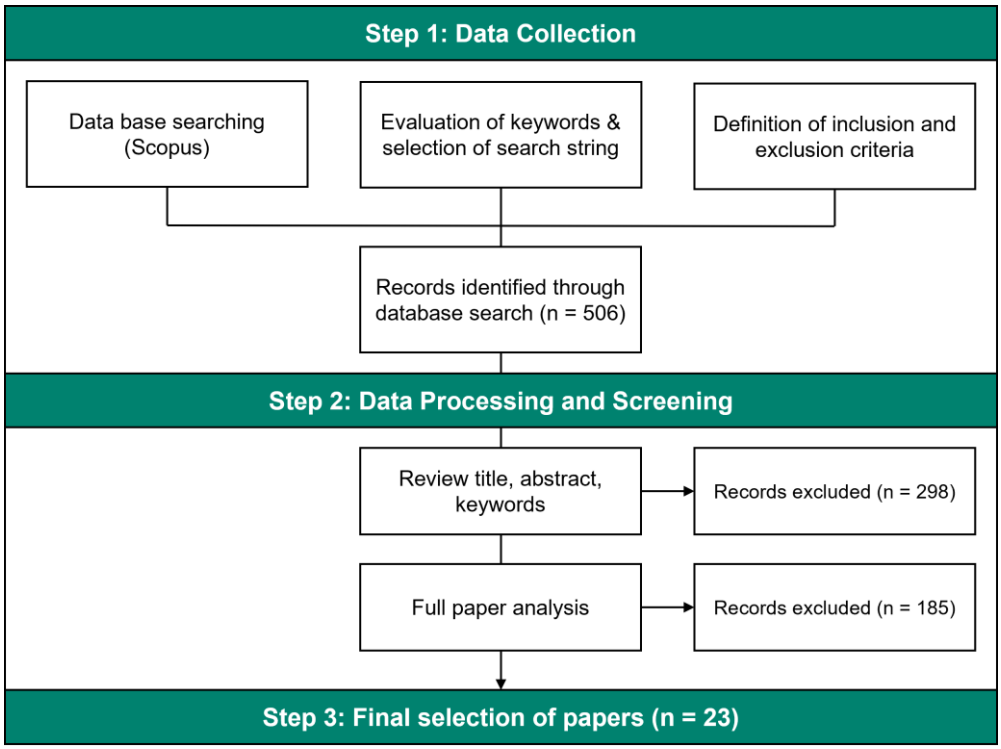

Figure 1: Schema of literature review

In the next step, articles were initially screened based on their titles and abstracts following the established criteria. To manage the volume of papers, topics regarding insurance, sustainability, construction, and specific case studies were excluded. We closely examined each article, extracting relevant information to address the research question. Furthermore, we coded specific sections in the papers using a classification scheme to develop the framework. Subsequently, these coded sections were assigned to their respective categories in alignment with the established framework. The following sections offer detailed insights into the descriptive and thematic findings from the remaining 23 articles.

4 Results

4.1 Descriptive analysis of the reviewed articles

In the last decade, as illustrated in Figure 2, there has been a notable rise in papers focusing on collaborations between public and private actors. Furthermore, the three-year moving average indicates a consistent upward trend, highlighting a growing interest in this field. Table 1 outlines the methodologies of the chosen articles from the systematic review and specifies the journals to which they are affiliated. The five journals with the highest number of contributions (count in parentheses) are: International Journal of Disaster Risk Reduction (5), Journal of Humanitarian Logistics and Supply Chain Management (3), Journal of Disaster Research (2), International Journal of Production Economics (2), and International Journal of Environmental Research and Public Health (2). Moreover, the widespread distribution of individual articles across diverse journals underscores the broad significance of collaborations in various domains and sectors.

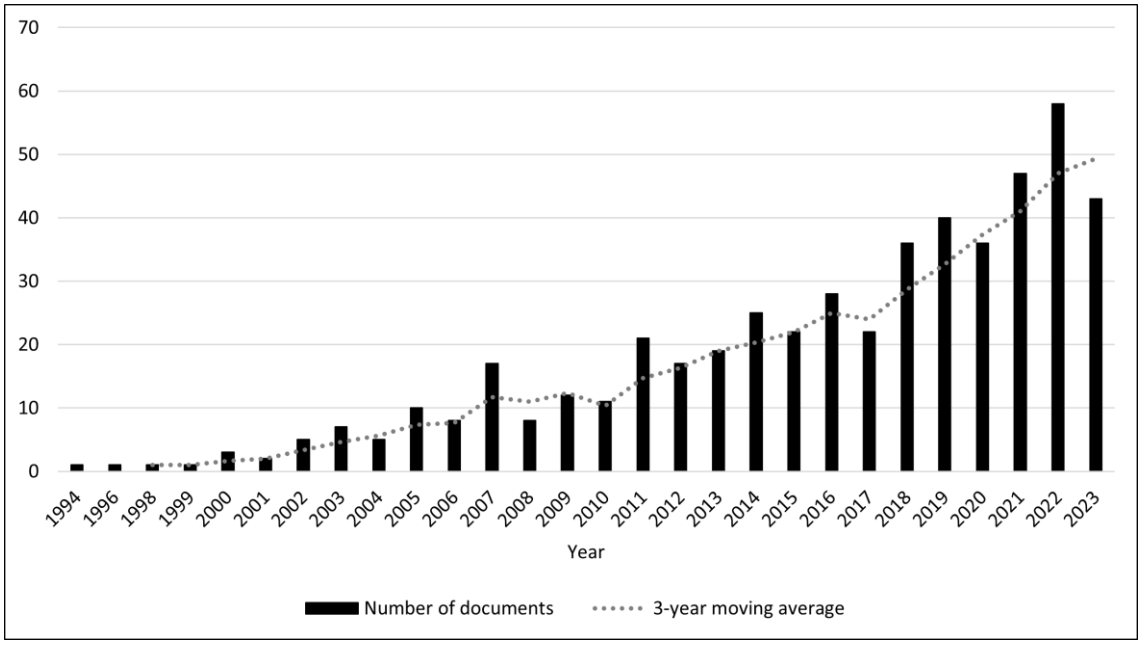

Figure 2: Number of documents by year

Examining the research methods employed in these journals, it is evident that qualitative empirical analysis is the primary approach. This methodical preference among disaster risk reduction and humanitarian logistics researchers might be the case since qualitative empirical approaches offer detailed insights and contextual knowledge. Quantitative methods also play an essential role, emphasizing statistical analysis and interpretation of numerical data. While researchers widely employ empirical methods, the limited use of mathematical and analytical models underscores the unique nature of the topic, emphasizing the significance of real-world observations and human-centered approaches.

Table 1: Number of documents by journal and methodology

Journal	Methodology	Articles
International Journal of Disaster Risk Reduction (n = 5)	Empirical Analysis (Qualitative)	2
	Empirical Analysis (Quantitative)	1
	Empirical Analysis (Qualitative & Quantitative)	1
	Analytical/ Mathematical	1
Journal of Humanitarian Logistics and Supply Chain Management (n=3)	Empirical Analysis (Qualitative)	1
	Empirical Analysis (Qualitative & Quantitative)	1
	Analytical/ Mathematical	1
Journal of Disaster Research (n = 2)	Empirical Analysis (Qualitative)	1
	Empirical Analysis (Qualitative & Quantitative)	1
International Journal of Production Economics (n = 2)	Empirical Analysis (Qualitative)	1
	Empirical Analysis (Qualitative & Quantitative)	1
International Journal of Environmental Research and Public Health (n=2)	Empirical Analysis (Qualitative)	2
Transportation Research Record (n =1)	Empirical Analysis (Qualitative)	1
Transportation Journal (n = 1)	Empirical Analysis (Qualitative)	1
SCM Journal of Homeland Security and Emergency Management (n=1)	Empirical Analysis (Qualitative)	1
International Journal of Production Research (n = 1)	Empirical Analysis (Qualitative)	1
International Journal of Emergency Management (n=1)	Analytical/ Mathematical	1
HSO Management, Leadership and Governance (n = 1)	Empirical Analysis (Qualitative)	1
Decision Analysis (n = 1)	Analytical/ Mathematical	1
American Review of Public Administration (n = 1)	Empirical Analysis (Qualitative)	1

4.2 A decision-support framework for public and private actors

We developed a robust decision-support framework based on the selected review papers to understand PPPs and manage the complexity of these relationships. The framework presented in Figure 3 identifies critical enablers, challenges, incentives, and practical examples that guide stakeholders toward successful collaboration. The following subsections elaborate on the primary categories of the framework.

4.2.1 Enablers

Identifying the factors that enable successful PPPs is crucial to implement them efficiently. According to the reviewed papers, these enablers encompass: Information & knowledge sharing [21, 22, 23, 24, 25, 26], collaboration & communication mechanism [27, 28, 21, 29, 30, 31, 22], framework agreements [32, 24, 23, 30, 21], alignment of interests [28, 22, 33], trust-building [28, 21, 30], infrastructure & technology [31, 26, 21, 24, 23, 22, 28], quality of services [27], training [21, 22, 31], and management commitment [22, 26].

In particular, sharing information & knowledge and collaboration & communication mechanisms were often cited as critical success factors in effective partnerships. According to [21], a clear legal basis, platforms for information sharing, mechanisms for acquiring and sharing critical resources, and regular communication mechanisms are essential. One possible solution is to

collaborate based on legal framework agreements (FAs) established before disasters or through intermediary agencies to support coordination [32, 30].

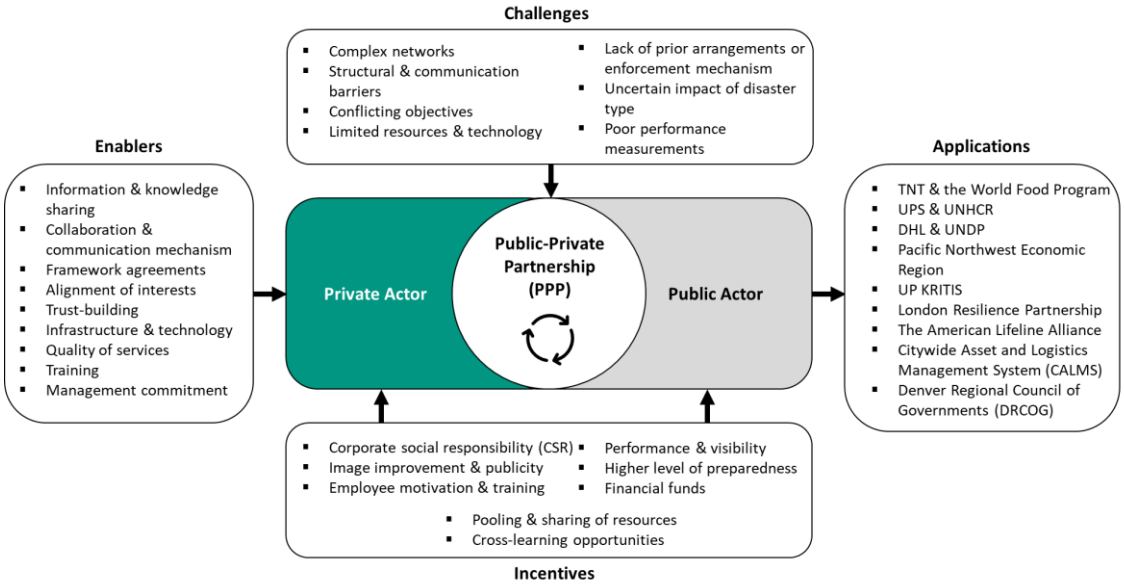

Figure 3: Framework for Public-Private Partnership

In addition, it is vital to define a common goal, align the interests of all stakeholders, build trust, create compatibility, and ensure the availability of critical infrastructure, technology, and resources to carry out the necessary actions. Both sides should specify the expected performance quality, which can be ensured, for example, through collaborative exercises and adequate commitment.

4.2.2 Challenges

While PPPs offer numerous benefits, they also come with significant challenges. Overcoming these challenges is crucial for long-term success and the smooth functioning of operations.

The main challenges highlighted in the examined articles can be summarized as follows: Complex networks [34, 35, 36], structural & communication barriers [27, 25, 30, 37], conflicting objectives [35, 31, 38], limited resources & technology [34, 32, 39, 24], lack of prior arrangements or enforcement mechanism [40, 36, 32], uncertain impact of disaster type [31, 35], and poor performance measurements [27, 36].

Humanitarian relief networks typically involve multiple stakeholders with diverse and conflicting objectives, protocols, perspectives, and a strong inclination towards asserting control and maintaining independence. This diversity often leads to duplicated efforts, unidirectional communication, ill-defined decision-making, and unknown accountability, making the relief process less effective and coordinated.

Furthermore, conducting humanitarian relief operations is complex due to constrained resources and a political atmosphere marked by urgency and unpredictability. Additionally, there are fluctuating needs and diverse impacts on the population and infrastructure. According to [40], prior arrangements with private service providers are essential to supply a critical response

component during an emergency. However, failure to honor the contractual agreement can have intense and widely dispersed impacts on human health and well-being, with little room for adequate contract enforcement.

Therefore, a long-term basis of building trust, elaborated measures to ensure performance even under exceptional circumstances, a constant exchange of critical information, and fostering close collaboration during non-crisis periods are essential prerequisites.

4.2.3 Incentives

Building effective PPPs requires careful balancing of incentives for private and public actors to maintain long-lasting relationships. Private actors are generally motivated by their shareholders' interests and the importance of generating profit as a corporation [24].

However, Corporate Social Responsibility (CSR) [27, 31, 37, 41], image improvement & publicity [28, 36], as well as employee motivation & training [27, 36], play an essential role in attracting customers and staying competitive. Although there may not be a direct financial gain, social engagement can result in indirect economic advantages. Companies engaging in CSR initiatives and sharing core competencies and resources can enhance employee motivation and improve the company's image and visibility. Consequently, these efforts can attract a broader customer base and lead to an expansion of market share. In contrast, public entities prioritize the population's welfare and strive to maximize the level of service. Therefore, incentives primarily involve enhancing the performance of relief operations and increasing visibility among the population [38, 31], improving disaster preparedness [28, 29], and ensuring the availability of financial funds [36].

Both public and private organizations have valuable resources and knowledge to share during emergencies [27, 24, 23, 42, 34, 36]. For example, public entities can provide crisis expertise, special privileges, and permits, such as transit options for employees, and coordinate the distribution of goods to minimize the risk of stock-outs and maintain business continuity. Meanwhile, private organizations can provide technical and operational expertise, access to data, rapid response capabilities, and financial resources.

4.2.4 Application examples

PPPs have been widely and successfully utilized across various sectors and industries to cope with unforeseen events and leverage the strengths of both actors. In the reviewed articles, various application examples are provided, such as the logistics company TNT Express NV & the World Food Program [31], UPS Inc. & UNHCR [27], DHL Paket GmbH & UNDP [31], the Pacific Northwest Economic Region (PNWER) [30], the public-private cooperation UP KRITIS [35], the London Resilience Partnership (LRP) [25, 30], the American Lifeline Alliance (ALA) [30], the Citywide Asset and Logistics Management System (CALMS) [24], or the Denver Regional Council of Governments (DRCOG) [24].

For example, the ALA is a PPP project funded by the Federal Emergency Management Agency (FEMA). Its objective is to mitigate risks to essential services like transportation systems during hazardous events. The UP KRITIS working group in Germany represents a collaboration between critical infrastructure operators, their associations, and relevant government agencies [43]. The aim is to safeguard critical infrastructure through PPPs.

At the city level, the LRP, comprising more than 170 organizations, assigns distinct roles to each entity for emergency preparedness and response. Moreover, this partnership involves diverse organizations and communities, fostering a holistic approach to emergency management [44]. Likewise, the Logistics Management System CALMS comprises a database of private assets and resources provided by the New York City Office of Emergency Management (NYC OEM) to enable potential opportunities for sharing resources within the community during emergencies [45]. These examples demonstrate the versatility of PPPs, showcasing their ability to address various needs and promote resilience structures.

5 Conclusion

In conclusion, PPPs benefit significantly from the synergies of resources and knowledge by leveraging public and private assets and expertise. This synergy is particularly evident when private or public entities can deliver a service more efficiently than their counterparts, especially when resources are scarce and time is limited. Preparing for and responding to disaster situations is highly challenging due to the unpredictable nature of their extent.

While overcoming every barrier may be challenging, consistent communication and collaborative training are critical to building trust and effectively resolving differences. Consequently, it is essential to define common objectives during the preparation phase. This process involves creating awareness, emphasizing the importance to all stakeholders, anticipating limited resources, and establishing potential arrangements or communication platforms. Nevertheless, partnerships, especially long-term partnerships in disaster relief, are still rare, and the collaborative challenges faced by public and private actors represent some of the key reasons why companies may be hesitant to commit to such relationships [27].

Therefore, our comprehensive decision-support framework is valuable in managing the complexity and uncertainty of disaster management and collaborative partnerships. It helps address the underlying challenges and promotes long-term partnerships. A structured decision-making process can be developed by incorporating identified enablers, mitigating challenges, and reinforcing incentives. Moreover, insights gained from successful and challenging experiences in PPPs can influence the course of collaborative efforts. Integrating these lessons can pave the way for more resilient, responsive, and sustainable partnerships between public and private stakeholders.

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SoK: Mitigation and Adaptation Strategies for Heat Waves

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Abstract

Heat waves pose significant challenges to human health, infrastructure, and ecosystems, necessitating effective mitigation and adaptation strategies. This paper provides a systematization of knowledge focusing on advices presented by the international red cross and red crescent movement aimed at both lessening the impacts of heat waves and enhancing resilience in the face of rising temperatures with a special focus on human health and wellbeing. Mitigation strategies encompass technological innovations, urban planning, and behavioral change. Adaptation strategies include heat early warning systems, community engagement, infrastructure modifications, and policy frameworks designed to safeguard vulnerable populations. By examining these strategies, this paper aims to offer insights into holistic approaches for addressing the complex challenges posed by heat waves and engineering more resilient societies in a warming world.

Keywords: Climate change adaption; Literature review; Red cross; Humanitarian aid

1 Introduction

Climate change is considered to be the greatest public health challenge of the 21st century [1], and is easily and more frequently seen in increasing average temperatures on land and at sea, extreme temperatures, heat waves, severe floods, and droughts with unpredictable effects on humans. In this context, heat waves are amongst those effects most frequently named. Especially the 2003 heat wave in France and, more latterly, the 2023 heat waves affecting large areas of Europe have raised awareness of the risks involved [2]. Furthermore, these events showed the increasing dimensions of heat waves and their growing potential to lead to severe disaster situations even in temperate latitudes. Hence, heat waves need to be considered an extremely important phenomenon for risk management.

For this reason, disaster risk reduction as a disciplinary field and its set of measures is necessary to reduce vulnerabilities and disaster risks in the society, both in terms of preparedness (emergency plans, response and warning capabilities) and long-term risk prevention.

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It is in this context that civil protection organizations, and more particularly the Red Cross as an auxiliary to the public authorities, delivers valuable insights to disaster risk operations in face of heat waves and information on decision support for climate adoption and mitigation strategies once confronted with heat waves.

The information available supports the intuition that numerous measures can be taken to cope with heat waves, prepare for them and reduce their harmful impact. However, to be effective, most actions must be taken well before disasters occur, and must continue long after heat waves have passed by strengthening individual and collective resilience in the face of future hazards, by learning lessons from the previous heat wave. The aim of this article is to provide a systematization of knowledge (SoK) regarding mitigation and adoption strategies for heat waves. The work hereby analyses and systematizes white papers published by public institutions with a special focus on humanitarian action and medical aid i.e. the international Red Cross and Red Crescent Societies (IFRC).

2 Background and related literature

According to the definition given by the World Meteorological Organization, heat waves are characterized by a period of unusually hot weather in terms of average, maximum, minimum and daily temperatures, in a given region persisting for at least three consecutive days, during the hot period of the year, with thermal conditions exceeding certain threshold [3].

2.1 Effects of heat waves

During a heat wave, a person is exposed to a high outside temperature for a long period of time, without sufficient cool periods to allow the body to recover. The persistent exposition to heat during heat waves can lead to severe health issues. In this way, heat waves can have serious repercussions on human health, as the body's ability to regulate temperature is exceeded, thus leading to serious complications such as heatstroke, increased risk of accidents (drowning, work-related), and brain strokes. Also, new diseases linked to heat may emerge, or pre-existing pathologies may be exacerbated (allergies, respiratory diseases). These health aspects are closely linked to those of civil security, water and energy supplies.

Furthermore, collateral effects of heat waves are multiple, and if large-scale, require exceptional action. Inter alia systemic dimensions of these heat waves can be seen in their correlation with other cascading risks such as flooding, forest fires, drought, and landslides. In this sense, heat waves also affect infrastructures, causing difficulties in the supply of drinking water and electricity, as well as the saturation of hospitals.

2.2 Relevance of taking adaptive measures

The public exposed to the risks of heat waves depends on the one hand on the severity of the meteorological phenomenon, on the other hand, it also depends on the constitution of prople. While people known to be vulnerable (elderly people, children, pregnant women, chronic illnesses, people with disabilities) are particularly at risk, people who are overexposed should not be forgotten (people living in precarious housing, homeless people, people living in dense urban

areas, exposed workers, prisoners). This is, due in part to climate change and rising temperatures, but also to population growth and demographic change, the population's exposure to heat has been steadily increasing in recent years [2].

Furthermore, heat waves are also highly interrelated with increasing urbanization, reinforcing and multiplying their effects, due to the enclosure between buildings, the absence of vegetation, additional diffuse heat sources or even pollution mists [4]. These factors can influence the heat pollution and hence the exposition to heat. This demands for strategic actions and reactions on this observed trend. Given the scale of the heat wave phenomenon itself and the associated risks to people, goods and the environment, disaster risk reduction is essential. Initiatives to reduce the effects of disastrous situations as a cause of heat have been initiated by diverse actors. This is, a number of institutional, health and risk-reduction measures have been taken. However, through practice and measurement, a number of positive signs suggest that heat has been managed more effectively over the past 20 years, but recent heat management does not always meet the increased demands posed by the heightened exposure of the population.

2.3 The international Red Cross and Red Crescent Societies in fighting the effects of heat waves

Associations such as the IFRC play an essential role in anticipating a heat wave, preventing it and limiting its effects, in particular by defining the actions to be taken at local and national level, and by adapting prevention and management measures.

For example, the French government has a heat wave plan that is systematically activated from 01 June to 15 September each year (with the possibility of extension or activation outside this period, depending on temperatures). It defines four alert levels with their associated actions, from seasonal watch to maximum mobilization in the event of an exceptional heat wave. The French Red Cross's heatwave plan is modelled on the government's heatwave plan and is addressed to establishments and regional delegations. It is organized around three alert levels and details the actions that can be taken in terms of prevention, preparation, and response. Hereby, the French Red Cross contacts elderly and disabled people living at home, organizes home visits, sets up water distribution points, etc. This is, during the seasonal watch period, Red Cross establishments play a key role in preparing for intense climatic episodes to limit the health effects of a heat wave as much as possible: raising awareness of the risks and how to recognize the signs of dehydration, the possibility of opening day or temporary shelters for vulnerable people who are not residents of the establishment.

The actions taken at the local level depend on the resources available to the French Red Cross at the time and can be linked to those already put in place as part of other ongoing crises. At national level, the inter-ministerial crisis cell can request the opening of the French Red Cross Operations Centre, chaired by its Director General. At local and national level, the French Red Cross is in contact with the other players involved in preparing for and responding to heat waves: prefectural crisis units, municipalities, public services (emergency medical services, fire and rescue services), private operators (motorways, railways), civil security associations, etc. Beyond the aspects relating to preparedness and crisis management, the Red Cross has a more general and essential role to play in raising awareness of climate change and the human impact on it. In fact, too many people, including the media and Red Cross volunteers, still treat these heat waves and the

phenomena associated with them as “separate” cases, unconnected with the notion of climate change. The Red Cross therefore has a duty of accountability to its volunteers, the people it assists and the general public to raise awareness and provide training on the impact of its actions on global warming, which is the cause of the intense phenomena mentioned above.

3 Methodology

3.1 Systematic information search

The information search was focused on information provided by the international IFRC and the national societies. We searched within the web pages of the national societies for information on heat related action taking. Furthermore, we included information found on international joint webpages such as web page of the IFRC and especially the IFRC Climate Centre. As inclusion criteria we defined the emergence of the term “heat” or “climate” within the title of the resource.

3.2 Information extraction

The information found within the material is analyzed qualitatively. We hereby applied the procedures of a systematic literature analysis. The material is analyzed with a deductive approach. Applying this approach, we separate information to on of the two categories “Proactive measures” or “Reactive measures”.

4 Results

Although sometimes inter-twinned, we separated reactive and proactive measures within this SoK. For efficiently responding to heat waves, frequently, preparedness is essential for effective responding to the extreme situation. In this sense, proactive actions need to be taken for being able to launch many reactive measures and be able to help citizens in the most effective way. We will first discuss these proactive measures and in a second step have a look at reactive measures.

4.1 Proactive measures

One of the most important proactive measures named is awareness training [5]. At a time when society is becoming increasingly digital and confidence in the authorities is fading, the digital sphere represents as many assets as challenges, particularly when it comes to managing and raising public awareness of recent and upcoming heat waves. The digital infrastructure can hereby be used to provide integrated warning and response systems. This is, information sharing can play a key role in preparing for and anticipating future heat waves. Training people to be prepared and informing the general public will help to develop a culture of risk and safety and increase public awareness of the potential dangers and associated vulnerabilities. Fostering the awareness of the importance of heat wave the Austrian Red Cross advises to keep informed on the weather situation and informs on the right health relevant behavior when facing a heat wave such as managing the exposure to heat by staying indoors, reducing activity, drinking enough, and eating food that is easy to digest [6]. The German Red Cross furthermore advises to use protective clothing [7].

Moreover, the Red Cross of Luxembourg adds to these advises to reduce alcohol and caffeine consumption and taking showers or partial baths to cool down the body [8]. Communication on the actions taken, both in terms of response and prevention, is essential, in order to share the right messages and ensure visibility. Social media and the digital sphere as a whole have a role to play here.

Furthermore, urban planning has a vital role in heat wave management. Spatial planning and development can help to accommodate increasing urbanization, especially as people living in dense urban areas are overexposed in the event of a heat wave. These measures inter alia include cool islands and water provisioning by public water wells.

For taking proactive measures and prepare for upcoming heat waves, moreover, climate forecasts are an important means. These forecasts can help medical facilities in preparing for the special needs of patients suffering from heat induced medical conditions [5]. Fine granulated information on the weather conditions can in this way help to improve preparedness and improve planning. The information can be a source to support decision making of the affected risk managers.

4.2 Reactive measures

First aid practices such as reducing heat exposure, providing electrolyte-containing drinks, and positioning are the most important measures to know when it comes to taking reactive measures when dealing with heat induced emergency situations [7].

Furthermore, in-situ and mobile cooling centers can be implemented and run in heat waves as a reaction on the extreme weather [5]. For example, ventilators, cooling fans and ice tanks can refresh exposed people and reduce health impacts.

Even housing conditions can be adapted with short term, reactive measures. Such means can be using sprinklers and shading of roof tops and windows [5].

5 Conclusion

Managing heat waves is a topic of increasing relevance given the heightened exposure of people around the globe. This development is fueled by increasing frequency of heat days and rising population densities. Furthermore, demographic changes contribute to this development. The problem of extreme heat waves and its management are thereby also relevant for decision makers in temperate regions such as France or Germany.

In an effort to improve visibility of this topic, a trans-boundary perspective was taken in this work leveraging on the experiences of the IFRC. With regard to this topic, the presented work aims at providing a brief overview on mitigation and adaption measures that should be discussed when dealing with heat waves. We present both reactive and proactive measures focusing on efficiently managing heat waves and their effects on society.

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From Data Fragmentation to Integration – Data Management for Engineering Cross Border Disaster Resilience: A Systematic Literature Review

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Abstract

In recent years, an increasing frequency of natural disasters has posed significant threats to human life and property. The effects of disasters are severe and spread across national, geographical, political, or cultural borders. To respond to disasters effectively, timely and reliable information of multiple actors involved is required. However, in the case of cross-border disaster management, this is impeded due to several challenges regarding the fragmentation of data and a lack of interoperability of inter-organizational data. Hence, this study aims to investigate the current state of the art of challenges and solution approaches to data integration in cross-border disaster management. Therefore, a systematic literature review is conducted. By providing a comprehensive quantitative and qualitative analysis that identifies and categorizes challenges across multiple technological, organizational, legal, and cultural dimensions, a comprehensive systematization of knowledge is given, and further research directions on data integration in disaster management are outlined.

Keywords: Cross-border collaboration; Data heterogeneity; Data interoperability; Data sharing

1 Introduction

In 2022, 387 natural disasters were reported worldwide, resulting in the loss of 30,704 lives and affecting more than 185 million other people [1]. According to the International Disaster Database (EM-DAT), the impact of disasters has caused US$ 223 billion in economic losses, a number that has quadrupled since the 1980s [1]. Among all global risks, extreme natural events such as earthquakes, floods, or tsunamis are perceived among the most likely and most potentially damaging threats overall [2]. Disasters spread across national, geographic, political, or cultural borders, confronting the affected regions with significant challenges due to multiple actors

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involved in disaster management practices. A border can be defined as a space between two distinct entities, but it can also be approached as a process of social division [3].

To cope with these disasters, gaining high levels of disaster resilience is essential for individuals, companies, societies, and systems to absorb shocks and to "bounce back" quickly to a viable state after a hazard [4]. Resilience includes transformative, adaptive, and absorptive capacities to enhance a community's ability to withstand and manage disasters and to reduce the vulnerability of systems towards crises [5]. However, to respond to disasters in an efficient and effective manner, timely and reliable information is required [6, 7]. This information includes data on local and national levels and, in case of a cross-border disaster, data from several countries and organizations. Furthermore, data standardization and interoperability must be ensured to provide a reliable foundation for decision-makers [8]. In the context of cross-border regions, efforts towards integration can come at odds with divergences that are inherent to borders. Practically, integrating and sharing information across traditional organizational boundaries requires complex interactions between technical and organizational processes, such as overcoming challenges regarding different platforms where information is stored, managing legacy systems, highly variable data quality, and multiplicity of and sometimes incompatibility of database structures, database designs, and network infrastructure [9]. Initial research shows successful approaches to developing integrative strategies addressing data interoperability in cross-border disaster management. For instance, Dao et al. [10] propose an integrated framework for information integration between diverse infrastructure systems by integrating multiple-source heterogeneous data in a common data format. Kamissoko et al. [11] discuss an improved model for resilience assessment by integrating multiple data sources and stakeholders.

However, scientific research still lacks a comprehensive overview and systematic identification of approaches addressing data fragmentation issues. Nevertheless, this knowledge is crucial, as it is a precondition and determinant to engineer resilient systems. Hence, the present paper aims to identify and summarize the current state of the literature regarding data integration in disaster management, focusing on inter-organizational data integration in cross-border disaster management practice. Therefore, the following research questions are posed:

1. *What are data integration challenges in cross-border disaster management?*
2. *Which technological approaches are applied to solving issues regarding data integration to increase cross-border disaster resilience?*

Overall, this study contributes to the understanding of cross-border disaster management by providing a comprehensive quantitative and qualitative analysis that identifies and categorizes challenges across multiple technological, organizational, legal, and cultural dimensions. This work highlights solutions proposed in scientific literature and provides valuable insights for decisionmakers to improve the effectiveness of data integration in cross-border disaster management.

The remainder of this work is structured as follows. Section 2 covers the basic foundations of disaster management, resilience, and data integration. In Section 3, the methodological procedure of the literature review is presented. Following, the results are presented in Section 4. Section 5 provides a discussion and draws conclusions.

2 Theoretical background

2.1 Disaster management and resilience

According to the International Federation of Red Cross and Red Crescent Societies (IFRC), disasters can be defined as "serious disruptions to the functioning of a community that exceeds its capacity to cope using its own resources" [12]. Disasters, as a force of natural or human-induced calamity, disrupt the functioning of societies and cause widespread destruction [12]. Thus, identifying threats, understanding vulnerabilities, and developing strategies to mitigate the impact is at the core of the management of disaster risks [13]. The disaster management process characteristically involves four phases: mitigation, preparedness, response, and recovery [14]. The response phase takes place right after the impact of a disaster, involving activities that directly address the immediate need to provide relief and reduce the impact of disasters. A disaster response requires specific predefined actions and immediate communication and coordination of the involved actors [14]. After the response phase, measures within the recovery phase are taken to return the affected's lives to a normal state. All measures taken before a disaster to prevent, prepare, and detect future hazards are included in the mitigation and preparedness phase [14]. Taking all together, the disaster management cycle is dedicated to preventing the occurrence of disasters, reducing their impacts, and thus, improving the resilience of complex technological systems, societies, or economies [15].

This process is supported by conceptualizing the broad term resilience that has its origins in diverse areas [16]. Regarding its etymology, the term 'resilience' is traced back to the Latin word 'salire', meaning to climb or to jump, and more specifically to its derivative 'resilire', which signifies the ability to rebound or recover [17, 16]. In scientific terms, the concept of resilience is rooted in two different research streams. Holling [18] originally introduced resilience as a concept to understand the robustness of an ecological system and its ability to persist within a particular state when disturbances occur. In contrast, resilience has been defined in psychology as the ability to deal with stressful life events or adversity [19]. Today, resilience is understood broadly and applied in many fields, such as engineering, sociology, economics, and organizational studies [17]. In this paper, we adopt a system approach, referring to resilience as the capacity of a system (may it be one or several organizations, a territory, or even a society) to absorb shocks [4].

2.2 From data fragmentation to integration

Data on disasters and their impact is highly heterogeneous, both structurally and semantically [20]. Particularly in the case of transboundary disasters where multiple actors and organizations are involved, different data formats, data characteristics, and different data sources exist. In this work, we refer to this problem as data fragmentation, a term that originates in database management but has been applied in different cases such as external storage, processing, or data sharing applications [21]. In the context of cross-border disaster management, data fragmentation refers to several challenges regarding diverse and heterogeneous datasets collected by various international actors jointly responding to disasters [22]. This results from differences at multiple levels, attributable to the use of differing data formats, collection mechanisms, reporting standards, or sharing practices among countries and organizations involved in disaster management [23]. The accompanying lack of standardization hampers efficient data utilization

for timely decision-making in cross-border disaster management [24]. Therefore, addressing data fragmentation is crucial to overcoming interoperability issues, enhancing coordination among the respective actors, and ensuring more effective and unified disaster management efforts.

Overall, this results in the need for data integration [20]. According to Lenzerini [25] data integration refers to the problem of combining data resulting from different data sources, thus providing the user with a unified view of these data. Integrating data from multiple sources through assembling and sharing helps to produce consistent and richer information across distinct organizational entities to achieve a collective outcome [26]. It implies that data sources can be technically bridged. However, bridging data requires organizations that produce these data collaboratively to plan the respective sharing and technical operability between servers, which depends on their capacity to develop mutual trust in the long run [20].

3 Methodology

To answer the research questions, a systematic literature review was conducted, allowing the identification, evaluation, and interpretation of all available research data on the given topic to present a comprehensive, exhaustive summary of current evidence of the research field [27]. Rather than an empirical study, we addressed the research questions by thoroughly investigating the literature. Our rationale was that data fragmentation was researched from multiple stances. Findings did exist and required to be assembled in a comprehensive mode. Practically, to search for papers, a search term was defined based on the key terms of the overarching research field and extracted from the research questions. The selection of keywords for the search term was combined by relying on Boolean operators. Considering different compositions and spellings of the selected keywords, the search term as given in Table 1 was determined. As a database, the interdisciplinary database Elsevier Scopus of peer-reviewed scientific literature was selected to ensure a comprehensive coverage of all publications across multiple research fields of high-quality scientific journals and research articles. Based on paper collection and selection, we completed a quantitative and qualitative analysis of the literature on the core topic of our study.

Table 1: Details on the search term and respective inclusion criteria for the systematic literature search

Database	Scopus
Content	Title, Abstract, Keywords
Searchterm	(data OR information OR knowledge) AND (disaster) AND (integrat* OR fragment* OR interoperab* OR unif*) AND (border OR frontier OR boundar* OR "inter$organ*")
Type	Proceeding OR Journal Article
Language	English

The literature search was conducted in September 2023 and yielded 463 documents. According to the PRISMA Flow diagram and systematic procedure of literature selection according Page et al. [28], the initial set was iteratively reduced based on defined exclusion and inclusion criteria (see Figure 1). The resulting set of articles was reduced to Journal articles and Conference

proceedings written in English. Thereby, books, book series, trade journals, and titles of conference proceedings were removed. Thus, a set of 330 publications was used for quantitative analysis and subjected to the screening process based on titles and abstracts. Following further refined exclusion and inclusion criteria, all studies that neither examined a disaster event nor covered a cross-border region were excluded from the literature base. Alongside this, a particular focus has been placed on studies addressing data fragmentation and integration in a cross-border setting. Hence, the set was finally reduced to a selection of 25 articles which have subsequently been used for the following qualitative content analysis. In sum, all the papers included in the sample provide information about data integration (or fragmentation) and disaster management in cross-border regions.

During the qualitative literature analysis, all information needed to answer the research questions was collected. In addition to general information on the articles, such as publication year, source, or author(s), relevant data on the specific disaster type, study region, data integration challenges, and solution approaches are categorized and analyzed.

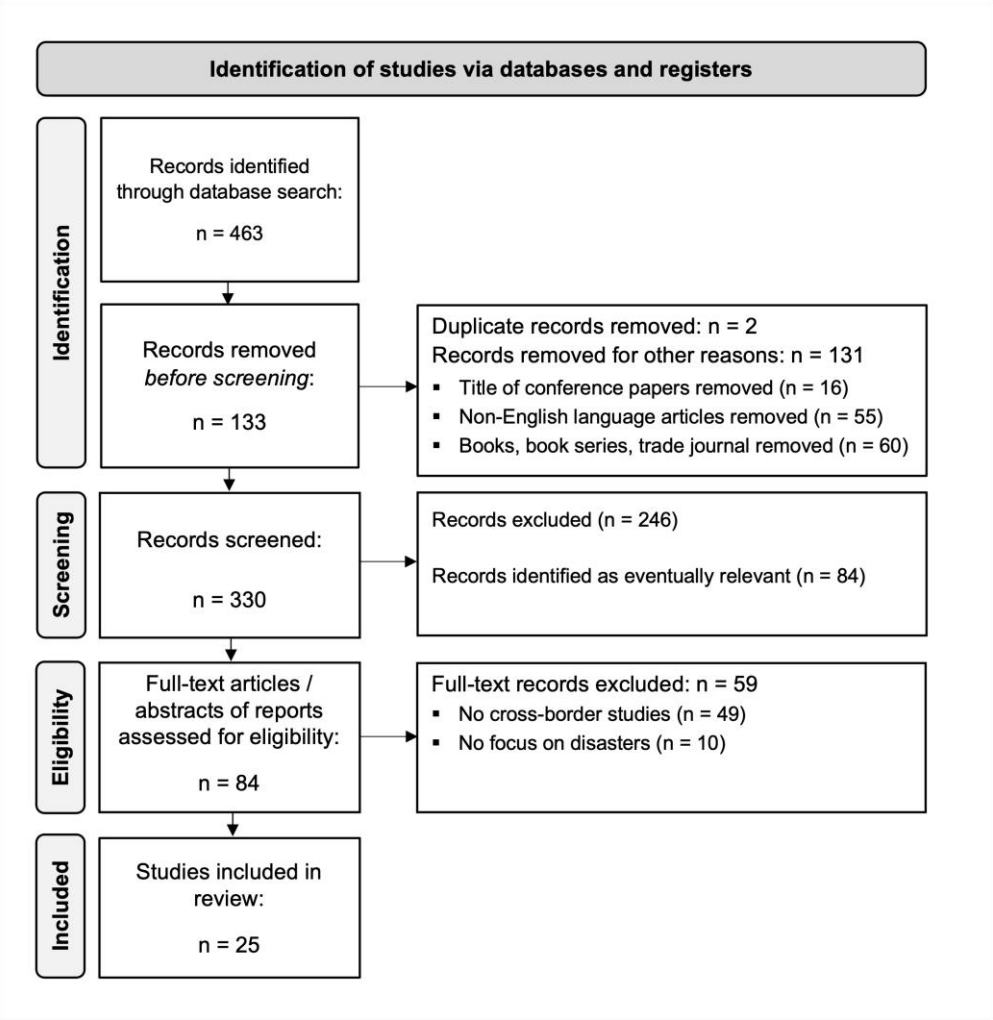

Figure 1: Systematic literature review procedure according to the PRISMA Flow Diagram

4 Multi level analysis of data fragmentation in cross-border disaster management

4.1 Quantitative analysis of reviewed articles

Considering the volume of published scientific articles over time, the frequency of publications per year has increased significantly. According to the number of publications, as presented in Figure 2, a notable number of articles was published in 2022 (32 articles). In 2018 (17 articles) and 2019 (18 articles), fewer articles were published, but overall, the distribution shows an increasing scientific relevance of the research field.

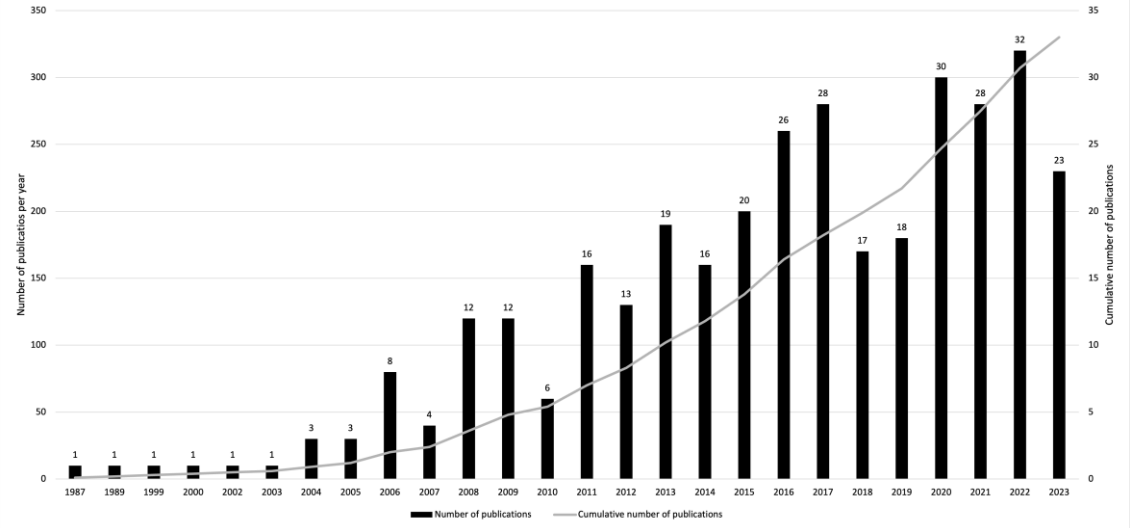

Figure 2: Number of publications per year since 2005

Using VOSviewer, an analysis of keyword co-occurrences was conducted. Figure 3 shows circles of varying sizes representing the number of co-occurrences of keywords. Keywords are clustered in five groups, marked with one color each. The circles are linked together, where the number of co-occurrences of the keywords determines the strength of each link: The more extensive the lines connecting the circles, the more significant the common occurrence of keywords.

The clustering reveals the diversity of perspectives on data integration and fragmentation for disaster management at borders. The purple cluster highlights challenges inherent to data production through sensors and geographical technologies. The yellow cluster evidences socio-technical stakes in data integration for disaster management. The green cluster reveals the importance of interoperable information systems across the border. Data integration, therefore, remains a challenge in various phases of managing cross-border disasters, highlighting the need for data integration in each phase of the disaster management cycle. The clusters also reveal that data integration is socio-technical. This advocates a comprehensive stance on its inherent challenges.

The results obtained are reflected in the set of 25 selected articles included in the following qualitative literature review. Whereas three articles address disaster prevention and preparedness, eight articles relate to disaster response. Most articles are concerned with disaster management in

more general, thereby addressing all phases of disaster management, which emphasizes the topic's relevance at all stages of the disaster management cycle.

Considering the thematically relevant set of articles in further detail, 13 Conference proceedings and 12 Journal articles are included. Among the Journals, the Journal of Disaster Prevention and Mitigation, the Journal of Contingencies and Crisis Management, the Journal of Decision Systems, and the International Journal of Disaster Risk Reduction are listed. Overall, a widespread distribution within various Journals and Conference proceedings is observed, highlighting the international pertinence of the subject across multiple sectors.

When reviewing the research methods of the respective articles, it is noticeable that most articles primarily employ a qualitative research approach. Among these are several reports of research projects, established frameworks and ontologies, and results of conducted interviews. The latter method, in particular, has the potential to acquire domain-specific and context-related knowledge of disaster experts and, thus, insights into real-world challenges and solution approaches.

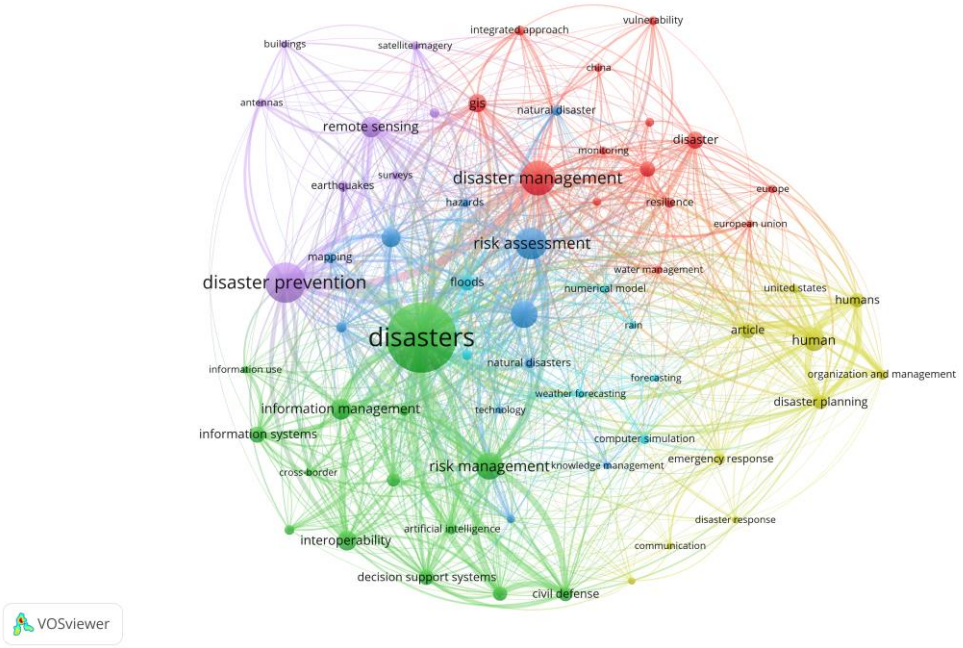

Figure 3: Mapping of keyword occurrences

4.2 Qualitative content analysis of reviewed articles

The following section includes a comprehensive qualitative analysis of difficulties and challenges in data handling in cross-border disaster management. For a comprehensive examination, a classification scheme is derived. This scheme was inspired by existing research on information integration. However, through our investigation of the literature, we identified several categories that we present in the following table. In sum, the challenges are divided into seven different categories and analyzed respectively. Based on this, solution approaches will be elaborated to achieve efficient data integration.

4.2.1 Challenges of data integration in cross-border disaster management

Table 2 shows that the management of fragmented data is accompanied by several challenges, encompassing technical and legal barriers, but also language and culture-related factors, which will briefly be discussed in the following section.

Data management challenges. In a cross-border context, data acquisition and availability pose a significant challenge. In particular, the various sides of the border can implement distinct methodologies and structures, such as varying parameters of measurement scales or resolution [36, 34]. Ertac et al. [30] study data harmonization for a flood early warning system and report differing conceptual schemes in terms of different ways to classify land cover of flood risk warning levels within the respective countries. Thus, a lack of standardization within cross-border organizations hinders data exchange between agencies [23]. Data storage can also represent a challenge, including heterogeneous, duplicate, or inconsistent recording and storage of data [37, 30, 31, 32]. Another key challenge is data interoperability, both at a syntactic [29, 30, 33, 36] and semantic level [37, 29, 38, 31, 33]. At the syntactical level, different countries and organizations use varying data formats (e.g., JPEG, PNG, PPT) [36], models, and communication protocols that represent the foundations for efficient data exchange and collaboration [29, 30, 33, 36]. At a metadata level, different metadata profiles exist due to a lack of formalization and standardization [30]. Heterogeneous data representation practically means inconsistent color codes, different graphical symbols or sets [29, 33], but also differing vocabularies and terminologies referred to as a lack of semantical data interoperability [37, 29, 38, 31, 33]. Differing vocabularies and terminologies may cause interpretation issues and diverging interpretations of words depending on the context [38]. These differences stem from difficulties in combining data from heterogeneous sources into integrated, consistent, and unambiguous information products [30].

Technical challenges. The challenges inherent to data management are accompanied by a lack of technological infrastructures and systems allowing for cross-border data sharing and storage [23, 39, 41, 24, 31, 42]. In line with a lack of standardization, various information and communication technology service and product providers exist between agencies, all with diverse requirements and characteristics [39]. These different systems can cause technical incompatibility by design [29, 42].

Informational challenges. Abdeen et al. [23] highlight informational challenges arising in multiagency collaboration. The authors report a lack of relevant information shared between partners across the border [23]. In addition, several studies report information overload as a challenge to data integration [23, 24, 31, 42, 41]. For instance, the rising amount of social media data collected, analyzed, and used in disaster response can lead to information overload, preventing disaster managers from effectively using and integrating the information [41]. Hence, the volume of information available to decision-makers may be too large, causing inefficiencies in information processing and the inability to search, find, and use the information needed [24, 31].

Communicational challenges. At an international level, cross-border resilience involves a lack of communication between organizations [23]. Månsson [43] discuss information integration in disaster risk management systems from various stakeholders. They shed light on communication issues due to a lack of incentives towards organizations to engage in communication procedures, particularly varying incentives between public and private stakeholders. Another driver of a lack

of communication is diversity in language and cultural particularities, which will be discussed in the following [29].

Table 2: Overview of challenges regarding data integration

Category	Challenge	Source
Data management challenges	Lack of common methodologies and structures	[29, 30, 31, 32, 33, 34, 35]
	Data interoperability (Lack of data harmonization)	[30, 32]
	Syntactical interoperability (data formats, models and communication protocols)	[29, 30, 33, 36]
	Semantic heterogeneity (differing vocabularies, terminologies, and data representations)	[29, 31, 33, 37, 38]
	Lack of standardization	[30, 31, 32, 37]
	Heterogeneous, duplicate and inconsistent recording and storage of data	[32, 38, 39, 40]
Technical challenges	Lack of technological infrastructure	[23, 24, 31, 39, 41, 42]
	Lack of collaboration platform for data sharing	[23]
	Various information and communication technology service and product providers	[39]
Informational challenges	Incomplete information	[23, 32]
	Information overload	[23, 24, 31, 42, 41]
	Information processing delay	[24,39,43]
Communi-cational challenges	Lack of communication among agencies	[23]
	Lack of incentives to engage in communication / information exchange	[43]
Legal and regulatory challenges	Political tensions between jurisdictions	[23]
	Institutionalization and political power between actors	[23]
	Data privacy issues	[37, 42, 43]
	Legal issues (different regulation, complex legal landscape)	[29, 33, 35, 41]
Organizational challenges	Lack of formal, systematic, inter-organizational coordination procedures	[23, 41, 44, 45, 46, 47]
	Lack of understanding of available resources, contribution from each organization, roles, tasks and responsibilities	[23, 35, 42, 44]
	Diversity of organizational structures	[29, 31, 33]
	Different stakeholder objectives	[39]
Language and cultural challenges	Behavioral and risk perception issues	[23]
	Diversity in language	[29, 31, 33, 35, 37, 38]
	Lack of trust	[24, 31]
	Lack of common culture between organizations	[29, 33, 39, 41, 48]

Legal and regulatory challenges. Referring to the aforementioned data storage, Babitski et al. [37] illuminates the argument from a legal perspective, arguing that maintaining all data within a single globalized database is often not desirable due to data privacy. Moreover, the confidentiality of data and safeguarding of sensitive information is necessary since the exposure of vulnerabilities can harm organizations and undermine the people's trust in the organization [43, 42]. Furthermore, different legal regulations in different regions lead to a complex legal landscape where cross-border agencies operate in [29, 33].

Organizational challenges. The challenges of a lack of standardized data management procedures and common structures, methodologies, and policies are also reflected at the organizational level. Effective coordination between organizations is a prerequisite to achieving disaster resilience [41]. During a disaster, time dependencies between activities may occur, indicating the

interdependence of activities of different organizations. For this reason, coordinating these activities is indispensable for disaster response [45, 44]. Before disasters, organizations need to co-construct joint procedures and test them in exercises. Both before and during disasters, information is a crucial ingredient for coordination between organizations. Information and data integration requires shared understanding between organizations about what and when to share, as well as the willingness to share [49]. According to Abdeen et al. [23], organizational challenges manifest in inter- and intra-organizational structures and procedures. Particularly, the lack of clarity and understanding regarding roles, tasks, and responsibilities in data sharing is commonplace within organizations [23]. Between organizations, there is an incomplete understanding of available resources and contributions from each organization, resulting in insufficient formal, systematic, and joint coordination and collaboration procedures [23, 39, 24, 31, 33].

Language and cultural challenges. Another often-discussed challenge is the language barriers that exist between different countries. Both Schütte et al. [33] and Casado et al. [29] investigate interoperability systems in the emergency management sector, focusing on Europe. With 28 member states and more than 24 official languages, a lack of a common language poses significant challenges to data handling on both IT and human levels. Cultural differences also magnify this since each organization may have its own culture, and thus, hinder the understanding of information since the concepts, structures, and reference framework may vary [33]. Klein et al. [48] highlight cultural differences across countries, which encompass beyond others uncertainty avoidance, long-term versus short-term orientation, individualism versus communitarianism, achievement versus ascription, or task-based versus relationship-based trust building. To nuance this view, the authors refer to a "cross-border identity" that exists in cross-border regions and is understood as an even more deeply rooted culture than the respective culture of the country [48]. Other behavioral factors, especially intrinsic forces such as motivation for inter-organizational collaboration, inter-personal trust, prestige, competition for resources, or cognitive constraints to proceed with the received volumes of information can hinder efficient cross-border collaboration Månsson [43] and Neville et al. [24].

4.2.2 Solution approaches

To overcome the addressed challenges in cross-border disaster management, a range of solution approaches is proposed within the reviewed articles. Building on the classification scheme of the previous section, the solution approaches are categorized accordingly and will be summarized in the following section (see Table 3).

Data management solutions. Solution approaches to managing data-related challenges in cross-border disaster management can be summarized and termed as data harmonization and data interoperability solutions [30, 24]. These solutions include approaches to standardize data [38] and approaches to ensure the interoperability of different systems, including semantic and syntactic data interoperability [23, 37, 29, 33, 32]. One avenue to achieve data standardization consists of using a common XML-based messaging standard, for instance, the Emergency Data Exchange Language (EDXL) suite of standards that facilitates emergency information sharing between government entities and other emergency organizations [38]. Ertac et al. [30] address data harmonization and interoperability in a spatial data infrastructure for a flood early warning system. In particular, the project discusses semantic data heterogeneity by solving issues related to varying spatial reference systems and consistency across the borders. Additionally, data

capturing, maintenance, and visualization are covered [30]. Thereby, transforming data from heterogeneous sources into common formats is a crucial step for data harmonization to process requests [30, 29, 34, 40]. Babitski et al. [37] develop an ontology stack covering the basic disaster management concepts. The ontology includes broad categorizations of damages caused by a disaster and available resources to organizations for response. Casado et al. [29] propose a two-fold solution depicting a common modular ontology shared among all shareholders, considering different countries and cultural, semantic, and linguistic issues. In addition, the solution includes implementing a transparent service-oriented architecture (SOA), providing a mechanism so that different emergency management systems can share data and operate collectively during the management of crisis scenarios [29].

Table 3: Overview of solution approaches regarding data integration

Category	Solution	Source
Data management solutions	Development of a common, modular ontology	[29, 33, 37, 38]
	Implementation of transparent service-oriented architecture	[29]
	Development of taxonomies based on international standards	[31, 42]
	Interoperable databases and data harmonization	[24, 30, 32, 38]
Technical solutions	Development of technical platforms for collaboration and data sharing	[23, 40, 50]
	Integrated software solutions	[29, 33, 36]
Informational solutions	Promotion of a data sharing culture across entities	[23]
	Establishing information quality systems	[31]
Communicational solutions	Ontology-based messaging service	[38]
	Establishing cross-border communication channels	[33, 46, 50]
Legal and regulatory solutions	Legislative policies and procedures for multi-agency collaboration	[23, 50, 51]
Organizational solutions	Provide frequent training for staff	[23, 31, 41, 50]
	Reference process model for common understanding of coordination	[44]
	Increased networking between stakeholders at various levels	[41, 43]
Language and cultural solutions	Promoting community awareness and willingness	[23, 41]
	Including liaison officers to assist translation	[50]
	Availability of translated documents for emergency managers	[50]

Technical solutions. To enable cross-border data sharing and collaboration, a technological platform can help [23]. These technological platforms require integrated software solutions as comprehensive systems to receive and process these requests while meeting functional (e.g., specific data formats and communication protocols) and non-functional (e.g., security and policy) requirements [29]. Franke et al. [45] implements a model for coordinating activities with temporal dependencies in an extension to the Google Wave collaboration infrastructure. It builds on the Open Wave Federation Protocol to support interoperability among heterogeneous organizations. Additionally, on the user level, communication solutions to exchange and share information via web-based solutions or conferencing tools are required to facilitate communication and collaboration between stakeholders [36, 33].

Informational and communicational solutions. Establishing and ensuring information quality is essential for organizations since poor information quality can be lethal to the affected [31]. To ensure a mutual understanding among disaster managers, Elmhadhbi et al. [38] focuses on solving communication issues by proposing an ontology-based messaging service. The proposed

architecture provides information tractability and consolidation for semantic translation, which enables the exchange of emergency response information among the involved stakeholders. International communication channels are established, including procedures for altering exposed neighbor regions and ensuring communication throughout an incident [50]. To overcome challenges regarding information overload, Neville et al. [31] emphasize the achievement of a balance between providing accurate information and on-demand requests for additional information needed in specific situations.

Legal and regulatory solutions. A regulatory framework for disaster-related activities is needed to foster cross-border disaster management, including long-term cross-boundary policies and strategies [51, 23, 50]. These agreements must include tasks' definitions and responsibilities, agreements on data sharing, and administrative arrangements for moving resources such as equipment and personnel over borders [50]. To ensure a common understanding by several agencies, these agreements must be bilateral and multilateral [50]. In addition, existing local or regional disaster management strategies must be merged and adapted to integrated arrangements [51, 50].

Organizational solutions. A frequently discussed challenge is coordination between organizations, including a common understanding of roles, tasks, and resources. Therefore, sustaining collaboration requires the development of partnerships among agencies in the long run [23]. This includes a shared understanding of roles in disaster management within and between organizations since common knowledge facilitates coordination among different inter-organizational stakeholders [44]. Nevertheless, disaster activities are often highly dependent, and thus, a model for coordinating activities with temporal dependencies is needed and proposed by Franke et al. [45]. Another crucial step in harmonizing coordination activities is interagency training and exercising to test practices and protocols to share information and resources [50, 23, 31, 41]. The cognitive capabilities of decision-makers are essential for responding to emergencies in rapidly changing situations. Thus, navigating in uncertain situations requires a range of skills that must be trained in advance [50].

Language and cultural solutions. For building disaster resilience, the understanding of community behavior is an essential determinant [48]. Klein et al. [48] develop a simulation framework based on a multi-agent system to study the characteristics of cross-border resilience and to support the simulation of individual, collective, and organizational behavior. The presence or absence of a border and cultural biases, communication problems, and regulatory issues are considered [48]. Furthermore, enhanced situational awareness and willingness among the community is required [23, 41]. Particularly in the case of community warning, public education and acceptance are needed for enhanced disaster preparedness and incident response for the general public [39]. Leveraging digital volunteers in disaster response and recovery presents a valuable solution approach for enhanced situational awareness, according to Kaminska [41]. Besides, inter-organizational trust is a determining factor, which must be ensured in the long run to foster collaboration Månsson [43] and Kaminska [41]. Increased trust could be reached by networking between public and private stakeholders at various levels and from training and the management of sensitive information [43, 39]. Stewart-Evans et al. [50] propose including liaison officers trained to assist cross-border communication. In the case of non-consistent languages, they serve as translators for the border regions. Nevertheless, the preparedness and response materials must be available in different languages to be accessible to multiple stakeholders [50].

5 Discussion and conclusion

5.1 Principal findings

Based on iteratively defined keywords, the Elsevier Scopus database has been selected and searched to identify relevant contributions addressing data fragmentation and data integration in cross-border disaster management. In Figure 2, the resulting number of publications per year has been presented, highlighting the subject as an increasing field of research. The conducted literature review process yielded 25 relevant publications, which were further assessed, particularly according to addressed challenges regarding the fragmentation of data and solution approaches in data integration for disaster management. Considering different phases of the disaster management cycle, most reviewed studies take a holistic perspective of disaster management, highlighting the need for developing sophisticated data integration models in each disaster management phase [52].

The main findings of the comprehensive qualitative analysis on difficulties and challenges in cross-border disaster management reveal a complex landscape with multidimensional barriers. The analysis classifies challenges into seven distinct categories, shedding light on various levels of the manifestation of data fragmentation and associated solution approaches to integrate data to achieve disaster resilience.

Various challenges concern the data generated before, during, and after disasters [52]. This includes data acquisition and storage difficulties since the extant systems are disparate and provide limited integration or hardly enable collaboration on data [53]. In particular, data interoperability issues in terms of semantic and syntactic data heterogeneity are frequently reported. The challenges inherent to collaboration on data do not only stem from data management or infrastructure management. They also depend on processes and organizational practices. This stresses the need for socio-technical approaches to data fragmentation and integration. This includes the standardization of data formats, models, and protocols, but also the harmonization of vocabularies, terminologies, processes, and representations. However, data and information sharing between multiagency stakeholders using different IT systems cannot be granted without a unified technological infrastructure [54]. This implies that issues regarding technological incompatibility from diverse information and communication technology providers with distinct requirements must be solved by integrated software solutions. A unified infrastructure can enable information exchange, but moreover, there is an additional need for willingness and incentives to engage in information exchange on the organizational level. Therefore, coordination between cross-border agencies is required. Nevertheless, adopting integrated software solutions is not enough. A lack of formal, inter-organizational coordination procedures may lead to failures such as inappropriate allocation of resources [8]. Increased networking between stakeholders at various levels and a shared understanding of coordination are needed to ensure a common understanding of available resources, contributions from each organization, tasks, and responsibilities of each partner. To nuance our view, addressing data fragmentation between cross-border entities comes with challenges. For instance, a unified data solution poses the question of international data governance, which can be undermined by legal and regulatory issues, as well as potential legacies from the border history (such as defiance or conflicts). In addition, challenges on the organizational level are in accordance to Bharosa et al. [8] and are also driven by community and individual-level related issues, including cultural and linguistic differences. However, cultural

and linguistic barriers must be overcome to foster inter-organizational collaboration and to increase trust between the actors in the long run. In addition, legal perspectives emphasize the need to balance globalized data sharing with data privacy considerations.

5.2 Implications

Following the aforementioned challenges regarding data fragmentation in cross-border disaster management, several implications for research and practice arise. Overall, the results obtained from the conducted review allow researchers to accurately ground and guide further research efforts that have been previously omitted. Regarding the multidimensional challenges of data fragmentation and the need for data integration in cross-border disaster management, researchers and practitioners should focus on developing and assessing holistic frameworks that address these multiple obstacles. This includes investigating integral solutions spanning technological, organizational, legal, and cultural aspects to provide comprehensive insights. These should be applied to real-world scenarios to enhance the practical effectiveness of disaster management strategies. To strengthen the foundations for cross-border disaster management, there is a need to investigate long-term cross-boundary policies that address deep (but somewhat less visible) challenges, such as legal, cultural, and organizational ones. One avenue is the design or refinement of policies on data sharing and data privacy to ensure and facilitate a long-term collaboration between multiple agencies to increase the resilience of border regions. International concertation on data strategies (such as the data act in Europe) can trigger cross-border reflection on these policies.

5.3 Limitations and outlook

Due to the continuous increase in the occurrence of natural disasters, effective disaster management is a dynamic and continuously important research area. Therefore, the present fails to include all innovative approaches and may lack coverage of recent developments or emerging challenges in the field. In addition, cross-border dynamics are heavily influenced by the respective countries' cultural, political, and regional factors. This study acknowledges these differences but may not fully capture the nuanced variations between the wide spectrum of cross-border regions in the world. This implies that the challenges and solution approaches presented in this work may differ based on specific cultural contexts and geopolitical locations and should thus be considered in future work.

To conclude, this study provides a comprehensive quantitative and qualitative analysis of data fragmentation related to disaster management at borders. It shows that data fragmentation manifests at different levels within and between organizations. It identifies and categorizes various challenges and related solution approaches regarding data management, technical, information, communication, organizational, and cultural factors. Finally, it argues the need for integrated approaches to increase the resilience of cross-border regions.

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