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ARTICLE

A Systematic Review of Forensic Approaches to Disasters: Gaps and Challenges

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Abstract
Disaster forensic approaches aim to identify the causes of disasters to support disaster risk management. However, few studies have conducted a systematic literature review of scientific articles that labeled themselves as a forensic approach to disasters. This article provides a qualitative analysis of these forensic studies, focusing on five main issues: (1) the methodologies applied; (2) the forensic approaches used in the disaster risk management phases; (3) the hazards addressed; (4) if the methodologies involve social participation, and using what types of participation; and (5) if there are references to urban planning in the scientific studies analyzed. Our results showed a predominance of the Forensic Investigations of Disasters (FORIN) and Post-Event Review Capability (PERC) methodologies used in isolation or combination. There is a need for methodologies that engage people in participatory FORIN, fostering the co-production of knowledge and action research approaches.

Keywords Dynamic pressures · Forensic investigation · Participatory research · Risk drivers · Root causes

1 Introduction

Looking at processes of disaster risk creation in urban areas, Davis (1978, 1987) identified some of the dynamic pressures that contributed to disasters, such as urbanization, deforestation, and inequitable land ownership. His reflections contributed to the Pressure and Release Framework (PAR) (Blaikie et al. 1994; Wisner et al. 2004; Wisner et al. 2012).

The PAR framework analyzes the root causes of vulnerability and the dynamic pressures contributing to disaster risk. The root causes refer to social and economic structures, such as the characteristics of power, wealth, and distribution of resources and ideologies. Dynamic pressures are processes and activities that translate the effects of the root causes, both temporally and spatially, into unsafe conditions. The dynamic pressures or risk drivers include lack or inefficiency of planning and land use, inadequate disaster risk governance, exploitation of natural resources, environmental degradation, deforestation, and so on (Wisner et al. 2012; Oliver-Smith et al. 2016; Fraser et al. 2020). The PAR framework has been criticized for reducing the role of hazards in disaster risk creation. For instance, Davis (2015), in his Disaster Crunch Model, stated that the root causes and dynamic pressures have also contributed to the progression of human and natural hazards.

Another approach that considers disaster as a process is the Forensic Investigations of Disasters (FORIN), an initiative created as part of the Integrated Research on Disaster Risk (IRDR), a decade-long research program co-sponsored by the International Council for Science, the International Social Science Council, and the United

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Nations Office for Disaster Risk Reduction (UNDRR). FORIN is a "medium and a mechanism for developing better comparative understandings of the root causes and underlying process that lead to disaster risk in diverse socio-economic, cultural, national, regional and local settings" (Burton 2010, p. 5). FORIN has two models, FORIN I (IRDR 2011), which defines its aims and core elements, and FORIN II (Oliver-Smith et al. 2016), which centers on research questions and methods (Fraser et al. 2016). Since the publication of FORIN I and II, some studies have used, adapted, and combined FORIN with other research methods (Nakasu et al. 2018; Nakasu et al. 2020) or created new frameworks from critical analysis of FORIN, such as those elaborated by the Preparing for Extreme and Rare Events in Coastal Regions (PEARL) project (Fraser et al. 2016; Fraser et al. 2020; McDermott et al. 2022).

Using forensic methodologies in disasters has been a path to understanding them. However, only some studies focus on reviewing the literature on these forensic methodologies in disaster studies. In 2014, Fraser et al. (2016, p. 4) conducted a desk review of methodological tools of 40 studies, including those "that had formally adopted the rubric of FORIN, studies that had applied methods incorporated by the FORIN approach but had not formally self-identified with FORIN and a review of the DKKV [German Committee for Disaster Reduction] methodology, a cognate approach." Almost 10 years after this literature review, a new study can be essential to identify research gaps and innovations in disaster forensic science. This study conducted a literature review of scientific articles labeled as forensic research in disasters.

As explained by Mendoza (2019), there are forensic approaches that focus on engineering, emergency management, or incident investigation, but also those centered on ad hoc methods, such as FORIN, Post-Event Review Capability (PERC), Detecting Disaster Root Causes (DDRC), and near real-time Forensic Disaster Analyses (FDA). This article considers these four ad hoc approaches discussed by Mendoza (2019). Our systematic literature review (SLR) focused on five main issues: (1) the methodologies applied; (2) the association of approaches used and disaster risk management (DRM) phases; (3) the types of hazards addressed in these studies; (4) if the methodologies involve social participation; and (5) if there are mentions to urban planning in the studies.

The following section briefly introduces forensic approaches to disasters and types of social participation. Section 3 describes the methodology to conduct the SLR. Section 4 sheds light on the main findings, while the next section discusses the main gaps and challenges in the scientific literature. Finally, we highlight the main conclusions and suggestions for future research.

2 Theoretical Background

This section briefly explains the four ad hoc forensic approaches to disasters discussed by Mendoza (2019).

2.1 Forensic Investigations of Disasters (FORIN)

FORIN investigates the disaster risk root causes so that the underlying causes can be analyzed and addressed through policies and practices (Fraser et al. 2016; Oliver-Smith et al. 2016; Mendoza 2019). The FORIN methodology does not seek or attribute legal responsibility, as the "forensic" term suggests, but rather to understand what factors and how they contributed to the production and occurrence of a disaster (IRDR 2011; Fraser et al. 2016; Oliver-Smith et al. 2016; Mendoza and Schwarze 2019). Furthermore, FORIN has specific objectives of research and education.

FORIN II proposes 37 research questions divided into four main categories: (1) triggering event(s); (2) exposure of social and environmental elements; (3) social and economic structure of exposed communities—vulnerability and resilience; and (4) institutional and governance elements. FORIN guides readers to respond to these questions through causal analysis, identifying root causes and dynamic processes that allow us to understand why unsafe conditions exist (Fraser et al. 2016; Oliver-Smith et al. 2016, 2017). These relationships are explained mainly by four risk drivers: (1) population growth and distribution; (2) urban and rural land use patterns and processes; (3) environmental degradation and ecosystem services depletion; and (4) poverty and income distribution.

FORIN proposes to use one or a combination of four basic methods, namely:

(1) Retrospective Longitudinal Analysis (RLA): It focuses on the temporal development of the processes that have produced disasters in the past. It examines particular patterns of disaster damage and loss, social and environmental processes, and conditions that drive disaster risk;
(2) FORIN Disaster Scenario Building (FDSB): It recommends the selection of a known hazard that preludes a possible inevitable future disaster;
(3) Comparative Case Analysis: An event-based analysis that seeks to identify underlying causes of disasters by comparing disaster impacts or contexts in different social contexts. It focuses on current conditions of exposure/vulnerability or disaster occurrence across a limited range of cases showing common elements or aspects;

(4) Meta-Analysis: It proposes an event- or system-based review of the available literature to identify and assess consistent and contrasting findings across various studies.

2.2 Post-Event Review Capability (PERC)

The PERC is a systematic framework for analyzing how a specific event (or hazard) became a disaster. Created by the Zurich Insurance Group, the methodology considers the phases of the DRM cycle (prospective and corrective risk reduction, preparedness, response, and recovery), with an assessment of the three main components of resilience (Venkateswaran et al. 2015), the systems, institutions, and agents. The PERC model also presents the five capital framework that comprises a set of measurable indicators:

(1) Physical—the things produced by economic activity from "other" capital, such as infrastructure, equipment, improvements in crops, and livestock;
(2) Financial—the level, variability, and diversity of income sources and the access to other financial resources that contribute to wealth;
(3) Human—the education, skills, and health of the people in the system;
(4) Social—social relationships and networks, bonds that aid cooperative action, links to exchange and access ideas and resources; and,
(5) Natural—the natural resource base, including land productivity and actions to sustain it, as well as water and other resources that support livelihoods and well-being.

PERC also has an institutional landscape map to identify the actors involved in the DRM system—at different administrative scales—showing critical decision-making and communication channels and detecting challenges or system failures (Venkateswaran et al. 2015, 2020; Mendoza 2019). The 2020 methodological guide presents different applications of the tool, between June 2013 and August 2020, in other regions and countries. Based on the analysis of seven methodological applications, Keating et al. (2016) stated that PERC addresses the need to learn about successes and failures in DRM, and it reveals the factors underlying disaster risk accumulation.

2.3 Detecting Disaster Root Causes (DDRC) Framework and Tool

The DDRC was requested by the German Committee for Disaster Reduction (DKKV) and funded by the Federal Foreign Office to propose analytic tools that identify disaster root causes and define areas for DRM interventions (DKKV 2012). Mendoza (2019) reported that the DDRC structure has points in common with the FORIN and PERC methodologies. First, DDRC considers causal analyses between disaster impacts and root causes. Second, it argues that limited risk management capacities or management failures can exacerbate or extend crises (DKKV 2012).

The DDRC methodology proposes a matrix approach comprising two main axes. The horizontal X-Axis describes the two main subjects of investigation. The first is the pre-disaster condition of a society or community exposed to natural hazards (vulnerability and disaster risk). The Y-Axis shows the progression of each analysis level from observed impacts and insecurities (drivers) to underlying patterns and structures (root causes) (DKKV (German Committee for Disaster Reduction) 2012). In addition, the framework uses the current reality tree (CRT) tool, which helps identify root causes and causal interdependencies, to help practitioners find the links between symptomatic factors (Doggett 2005; Nakasu et al. 2018).

2.4 Near Real-Time Forensic Disaster Analyses (FDA)

The Center for Disaster Management and Risk Reduction Technology (CEDIM) has developed and updated, since 2011, the near real-time Forensic Disaster Analysis (FDA). The FDA complements the FORIN methodology, providing reports and analysis just a few hours or days after the disaster occurrence (CEDIM 2013). In FDA activity, researchers estimate the direct and indirect impacts, trace their temporal evolution, and identify the decisive factors for the overall effect (CEDIM 2020). The methodology includes analytical tools from different disciplines (for example, engineering and remote sensing). It also combines data from other sources, including crowdsourcing (Prizzia 2016), to set a baseline on current information and procedures while disaster response is still in operation (Girard et al. 2014).

Wenzel et al. (2013) emphasized some fundamental points of the FDA methodology, such as (1) time—as much information emerges within the first days of a disaster; (2) interaction with many actors is most intense and open during these days; (3) potential user's interest—such as emergency, cooperation agencies, insurance, and industry; (4) initial research hypotheses elaborated within the first days after the emergency, which may be tested later; and (5) understanding of disasters in their respective socioeconomic contexts.

These four ad hoc forensic methodologies have different objectives, approaches, and characteristics (Table 1) that can be useful for disaster studies. Some of these methodologies consider root causes, and others do not.

These four approaches have similarities and differences. For example, their objectives converge to analyzing disaster risk reduction (DRR) and DRM phases. The methods involve desk review, fieldwork, semistructured and informal interviews, and expert interviews. There are specific

Table 1 Main aspects of ad hoc forensic disaster methodologies

Name /year	Objectives	Types of hazards	Characteristics
FORIN (IRDR) 2011/2016	Identifying underlying (root) causes in such a way that they can be evaluated and addressed by policy and practice; other specific objectives such as broadening the scope of DRR measures, contributing to an understanding of the ways to incorporate DRR into development planning decision making and economic and social growth	Natural, socio-natural (recognizing the influence of human activity on natural hazards), and technological hazard events	Structured around a causal chain, incrementing in-depth analysis: descriptive analysis (immediate descriptive causal relations) of risk drivers or dynamic processes and root causes
PERC (Zurich Insurance Group and ISET-Int.) 2015	Uncovering root causes, successes, and failures in managing disaster risk before the event, disaster response, and post-disaster recovery; identifying critical gaps and actionable opportunities for mitigating disaster risk	Disasters due to "natural" and "non-natural" hazards	Focusing on the DRM cycle (risk reduction, preparedness, response, and recovery)
DDRC framework and tool (DKKV) 2012	Identifying disaster root causes and defining areas for DRM interventions to address them. The study examines the various context conditions and trends that heavily influence vulnerability, exposure, risk, and DRM	Disasters due to natural hazards	Analyzing causal linkages between disaster impacts and underlying root causes. Integrating the DRM cycle into the analysis approach
Forensic Disaster Analysis in near real-time (CEDIM) 2012	Improving our understanding of how natural hazards do (or do not) become disasters, providing information and results within the first few hours and days	Disasters due to natural hazards: geophysical, meteorological, and hydrological hazards	Focusing on near real-time disaster analyses by interdisciplinary teams; complementing FORIN. Focusing on the complex interactions between the natural hazard, the technical installations, facilities, infrastructures, societal structures, institutions, and capacities

Source Elaborated by the authors, based on Mendoza (2019) and Mendoza and Schwarze (2019).

research questions proposed in their guidelines. There are also differences in these forensic methodologies: they combine various methods and disciplines. They also have some gaps, such as the need to consider aspects related to governance (Fraser et al. 2016; Fraser et al. 2020) and participatory research approaches (Alcántara-Ayala et al. 2015; Oliver-Smith et al. 2016; Mendoza and Schwarze 2019). When analyzing and developing such participatory initiatives, it is essential to question the types of participation and methods implemented.

2.5 Social Participation

Participation can be understood as a distribution of power that allows citizens to be included in political and economic processes shaping their present living conditions and future. It is not limited to economic or political circles, but also involves social and environmental issues through a gradual integration of citizens, individually or collectively (Jiménez and Mujica 2003). It is a strategy by which citizens come together to determine how information is shared, goals and policies are defined, or resources are allocated (Arnstein 1969).

Social participation is essential in formulating and implementing public policies, as it generates greater legitimacy for the process and strengthens disaster risk governance (Ensor et al. 2018; Albagli and Iwama 2022). The academic literature has widely recognized the importance of including local communities in participatory initiatives to assess and manage disaster risk (Atanga 2020; Bubb and Le Dé 2022). However, in most cases, the allegedly participatory processes are top-down, with closed and non-adaptive governments generating centralized and hierarchical policies (Castro-Díaz et al. 2022).

Dyball et al. (2009) characterized six types of participation based on various forms and levels of involvement and the power relations of those involved in participatory initiatives. These six typologies range from passive participation (coercion) to active involvement (co-action) (Fig. 1).

Such types of participation were considered in our SLR. The following section explains how we designed and conducted the review.

3 Material and Methods

This study conducted a SLR to evaluate and interpret available studies and their research questions, field area, or phenomena of interest (Kitchenham and Charters 2007). The research steps that guided the SLR were established in a predetermined protocol and discussed among the authors involved in this study. The authors also defined the research questions and the information to be extracted in articles, such as title, authors, year of publication, journal, and abstract for a later generation of a supplementary file, following the steps proposed by Marchezini et al. (2018).

3.1 Search Strategy

The research steps cover general guidelines relevant to systematic reviews, such as (1) definition of the research question; (2) specific questions; (3) selection criteria

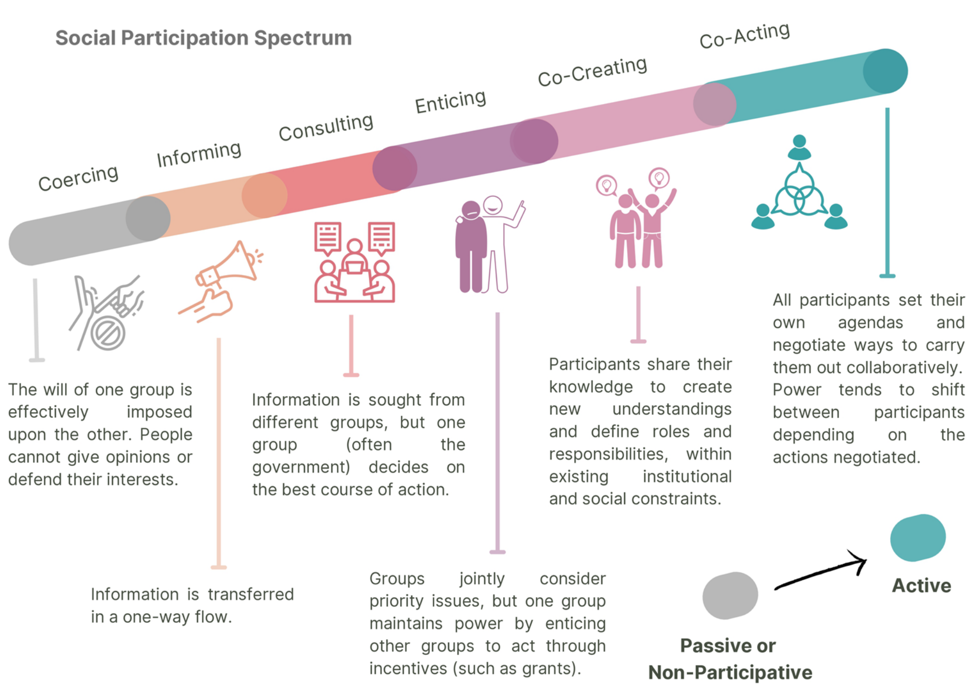

Fig. 1 Types of participation and power relationships. *Source* Elaborated by the authors based on Dyball et al. (2009). The icons are from the Noun Project and Canva (https://thenounproject.com/;)

(inclusion and exclusion); (4) screening and quality assessment; (5) data extraction; (6) synthesis and analysis; and (7) description/report.

Data gathering selected primary studies from three databases: Web of Science, Science Direct, and Scopus that was the one with the more significant number of indexed journals (Chadegani et al. 2013; Powell and Peterson 2017). The data extraction in these three databases occurred on 15April 2022 (by 11:59 p.m. Brasília time zone).

Since this study conducted an SLR of methodologies used in forensic research approaches, the strings "Forensic" and "Disaster" were applied to titles, abstracts, and keywords in the three databases without specifying periods. We did not include "root causes" in our string because: (1) there are forensic approaches that do not focus on root causes; and (2) we want to identify scientific articles that label themselves as forensic approaches to disasters.

Our preliminary results using these two keywords in the three databases returned 2,046 articles in all subject areas, mainly on medicine. Since we focused on four disaster forensic approaches (Mendoza 2019), we chose three subject areas—environmental sciences, geosciences, and multidisciplinary areas.

Our search found 156 documents in the three databases consulted, but 25% (n = 39) were excluded because they were duplicated articles. After eliminating the duplicated articles (39), 117 articles were uploaded to the Parsifal tool online and subjected to a screening process that considered the following selection criteria for inclusion in SLR: (1) studies that used methodologies of forensic investigations in disasters; and (2) published studies that are fully available on these three scientific databases. The exclusion criteria involve studies that were: (1) not related to disaster forensic methodologies; (2) unavailable online; (3) not written in English; (4) without abstract; (5) with a previous version of a complete study on the same research; (6) taken as an editorial, position paper, opinion article, tutorial, and poster or panel; (7) duplicated; and (8) not peer-reviewed. After the screening, 63% (n = 98) of the articles were removed because they did not meet the established inclusion criteria.

Thus, 12% of the studies (n = 19) were accepted for evaluation. These 19 articles were read in full by the authors of this article and analyzed according to the five research questions: (1) What is the methodology used in the article? (2) What is the DRM phase (for example, pre- or post-disaster)? (3) What are the types of hazards studied? (4) Did the methodology involve social participation? and (5) Did the study mention urban planning? After analyzing and extracting relevant information, we classified the articles in ad hoc (11) and non-ad hoc (8) forensic approaches to disaster based on the four methods proposed by Mendoza (2019): FORIN, PERC, DDRC, and FDA. The methodological steps are shown in Fig. 2.

Some research limitations include: (1) the study only considered scientific articles that label themselves as forensic approaches; (2) the study limited the keywords "forensic" and "disaster" to abstracts and titles; (3) the investigation was only in the areas of environmental sciences, geosciences, and multidisciplinary studies, as it is known that other areas of knowledge also resort to forensic methodologies in disasters; (4) gray literature was not included in the review, as performed by Fraser et al. (2016); (5) the study included only scientific articles published in English; (6) the study did not analyze the disaster impacts, as performed by Nakasu and colleagues (Nakasu et al. 2018; Nakasu et al. 2020).

4 Results

This section characterizes and discusses the scientific articles considering the five research questions proposed in the methods section. After analyzing and extracting relevant information, we classified the articles into ad hoc (11) and non-ad hoc (8) forensic approaches to disaster based on the four methods proposed by Mendoza (2019): FORIN, PERC, DDRC, and FDA (Table 2). The following subsections will discuss articles using ad hoc forensic approaches to disasters.

4.1 Types of ad hoc Forensic Methodologies to Disasters

Most studies (n = 9) were related to the FORIN methodology, followed by the association between FORIN and PERC (n = 3), PERC (n = 1), and near real-time Forensic Disaster Analyzes (n = 1). No published articles applied the DDRC framework and tool (DKKV 2012).

The studies adopted different research techniques, such as post-event scenario modeling (Menoni et al. 2016), statistical data, and interviews (semistructured or not) combined with other sources of peer-reviewed and gray literature to support different FORIN approaches (Nakasu et al. 2017; Mendoza and Schwarze 2019; French et al. 2020; Dominguez et al. 2021); and creation of databases for forensic methodologies in disasters (Yuan and Liu 2018; Payo et al. 2022). A summary of the selected studies is presented in Fig. 3 and Table 2.

4.2 Disaster Risk Management Phases

The selected articles cover diverse DRM phases. Some articles (n = 3) did not make this issue clear. Other studies support different stages of DRM, such as those conducted by Payo et al. (2022) and Yuan and Liu (2018), which are related to the acquisition of data and generation of databases

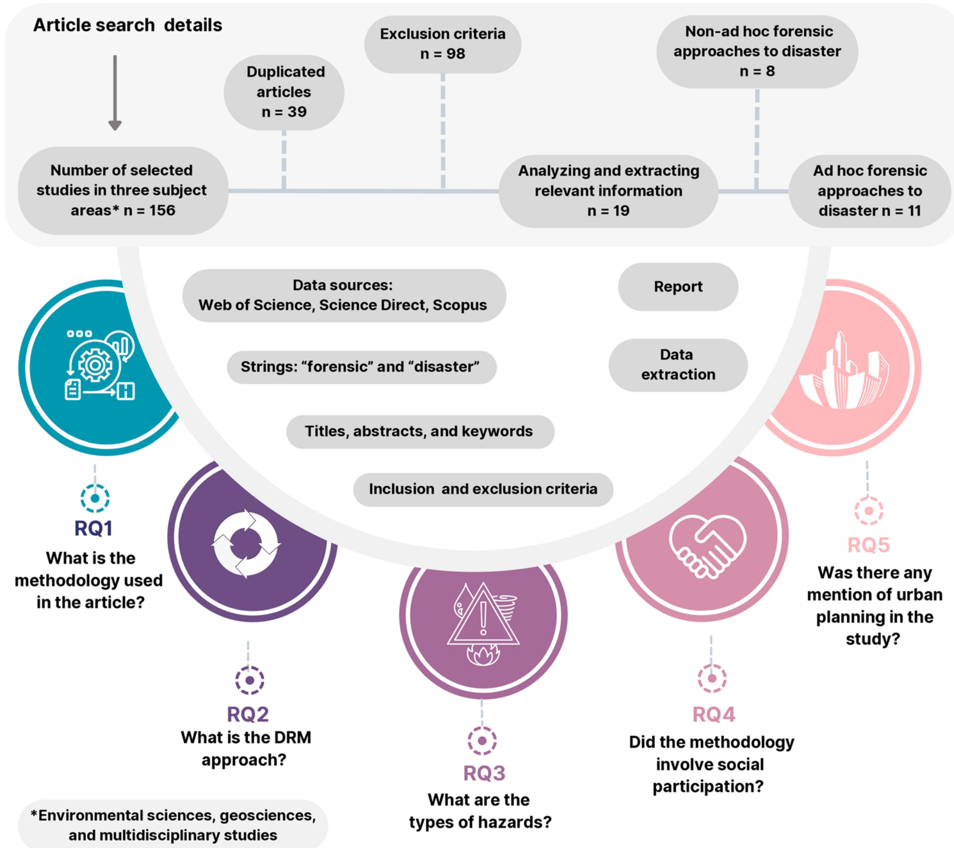

Fig. 2 Methodology summarization: Research questions for further data extraction and search details. *Source* Elaborated by the authors. The icons are from the Noun Project and Canva (https://thenounproject.com/;)

for forensic investigations in disasters, including spatial information and document search gathered in a specific repository.

Articles using FORIN, such as Nakasu et al. (2017), Alcántara-Ayala and Oliver-Smith (2019), and French et al. (2020), were associated with disaster preparedness or response. Some articles used the PERC methodology (Keating et al. 2016). Others adopted methods in a complementary way and covered phases linked to risk reduction and preparedness, response, and recovery (Mendoza and Schwarze 2019; Dominguez et al. 2021). This situation may be associated with the PERC methodology built around the DRM cycle.

Finally, there were studies on flood disaster scenarios that stressed the need for data and information about exposed sectors, types of damage, spatial scales of analysis, the timescale of analysis, and other variables that explain impacts, such as vulnerability, types of assets, and so on (Menoni et al. 2016). Menoni et al. (2016) reported that effective flood risk mitigation requires better knowledge of the impacts of flood events. The authors stated that using an integrated model could help program the financial resources needed for flood risk reduction in the future, in addition to adapting and optimizing flood mitigation strategies based on the forensic investigation of each disaster.

4.3 Types of Hazards

About half of the studies analyzed were related to multi-hazards, that is, different hazards that can occur in a particular area or specific contexts in which they can occur in cascade or cumulatively over time (UNDRR n.d.), such as the 2011 Great East Japan earthquake and tsunami analyzed by Nakasu et al. (2017).

There were also studies on hydrometeorological hazards, that is, of atmospheric, hydrological, or oceanographic origin (UNDRR n.d.). Most studies analyzed were related to floods (Keating et al. 2016; Menoni et al. 2016; Mendoza and Schwarze 2019). Only one study focused on geological hazards (Dominguez et al. 2021), that is, those that originate from internal processes of the earth (UNDRR n.d.). Dominguez et al. (2021) proposed a post-event impact assessment framework to analyze the damage, cascading impacts, and interruptions to critical infrastructure caused by the eruption of the Cordón Caulle volcano (Chile) in 2011–2012.

4.4 Types of Social Participation

The analysis of social participation was based on the six highlighted categories: (1) coercion; (2) informing; (3)

Table 2 Summary of selected articles

Title/citation	Methodology/country	DRM approach	Hazards	Type of participation
Near-Real-Time Analysis of Publicly Communicated Disaster Response Information (Girard et al. 2014)	Near real-time FDA**	Response	Multi-hazards	None
Flood Damage: A Model for Consistent, Complete and Multipurpose Scenarios (Menoni et al. 2016)	FORIN*/Italy	Mitigation, Preparedness	Hydrometeorological	None
From Event Analysis to Global Lessons: Disaster Forensics for Building Resilience (Keating et al. 2016)	PERC**	DRM cycle	Hydrometeorological	Informing
Forensic Investigation of the 2011 Great East Japan Earthquake and Tsunami Disaster—A Case of Rikuzentakata (Nakasu et al. 2017)	FORIN/Japan	Preparedness	Multi-hazards	Consulting
Crowdsourcing for Forensic Disaster Investigations: Hurricane Harvey Case Study (Yuan and Liu 2018)	Database to FORIN/USA	N/C	Multi-hazards	None
Early Warning Systems: Lost in Translation or Late by Definition? A FORIN Approach (Alcántara-Ayala and Oliver-Smith 2019)	FORIN**	Preparedness	Multi-hazards	None
Time in a Bottle: Challenges to Disaster Studies in Latin America and the Caribbean (Alcántara-Ayala 2019)	FORIN*,**	N/C	None	None
Sequential Disaster Forensics: A Case Study on Direct and Socio-Economic Impacts (Mendoza and Schwarze 2019)	FORIN-PERC/Germany	DRM cycle	Hydrometeorological	Consulting
Root Causes of Recurrent Catastrophe: The Political Ecology of El Nino-Related Disasters in Peru (French et al. 2020)	PERC-FORIN/Peru	Preparedness	Multi-hazards	Consulting
Integrative Post-Event Impact Assessment Framework for Volcanic Eruptions: A Disaster Forensic Investigation of the 2011–2012 Eruption of the Cordón Caulle Volcano (Chile) (Dominguez et al. 2021)	FORIN-PERC/Chile/Argentina	DRM Cycle	Geological	Consulting
Developing an Open Database to Support Forensic Investigation of Disasters in South East Asia: FORINSEA v1.0 (Payo et al. 2022)	Database to FORIN/Vietnam/the Philippines	N/C	Multi-hazards	None
The Application of Geographic Information System (GIS) in Forensics Geoscience (McKinley 2017)	GIS in forensic geoscience/Australia/Ireland	Response	Geological	None
ICL Latin-American Network: On the Road to Landslide Reduction Capacity Building (Alcántara-Ayala and Oliver-Smith 2014)	Special session at the International Consortium on Landslides (ICL) FORIN/Mexico	Mitigation	Geological	Informing

Table 2 (continued)

Title/citation	Methodology/country	DRM approach	Hazards	Type of participation
A Tool to Assess Livelihood Preparedness for Disasters: A Study of Kaikoura Earthquake in New Zealand (Kwazu and Chang-Richards 2022)	Survey/modeling/New Zealand	Preparedness	Geological	Consulting
A Reverse Dynamical Investigation of the Catastrophic Wood-Snow Avalanche of 18 January 2017 at Rigopiano, Gran Sasso National Park, Italy (Frigo et al. 2021)	Modeling/Italy	Response	Multi-hazards	None
Forensic Hydro-meteorological Analysis of an Extreme Flash Flood: The 2016-05-29 Event in Braunsbach, SW Germany (Bronstert et al. 2018)	Forensic hydrological analysis/Germany	Recovery	Hydrometeorological	None
Experimental Investigation of Debris-Induced Loading in Tsunami-Like Flood Events (Stolle et al. 2017)	Forensic engineering/Japan	N/C	Multi-hazards	None
Flood Characterization Based on Forensic Analysis of Bridge Collapse Using UAV Reconnaissance and CFD Simulations (Loli et al. 2022)	UAV surveying/numerical modeling/Greece	Mitigation	Hydrometeorological	None
Case Study: Reconstructing the 2015 Dulcepamba River Flood Disaster (Newmiller et al. 2020)	Hydrologic and hydraulic modeling/Ecuador	Recovery	Hydrometeorological	Consulting

Source Elaborated by the authors

N/C not clear, *FDA* Forensic Disaster Analysis, *DRM* Disaster Risk Management

*Study related to methodology, but not necessarily applied to it

**It does not necessarily present an area of study

consulting; (4) enticing; (5) co-creating, and (6) co-acting (see Fig. 1). The highest level of social participation found was consulting (n = 4 studies) (see Table 2) when information is sought from different groups, but one group (such as the government) decides on the best course of action involved in the "participatory" activity (Dyball et al. 2009).

The proposed methods used for consulting were in-depth interviews, semistructured or unstructured interviews, and questionnaires. There were studies where the role of "stakeholders" in research was unclear.

4.5 Association to Urban Planning

The results also showed that five articles mentioned "planning" and "land use." Nakasu et al. (2017) stated that there are social, economic, and political processes behind demographic and land use changes, and these are the true causes of the high loss of life in the Great East Japan Earthquake and Tsunami. Menoni et al. (2016) observed a conflict in a land use plan where industrial development areas stood out in regions subject to hydrogeological risks, leaving to the developers the decision to build or not and how to build.

The lack of zoning measures and a permissive government stance as reasons for the development of numerous urban settlements in the country was also reported by French et al. (2020) when analyzing El Niño-related disasters in Peru. Some studies examined the root causes and mentioned the dynamic pressures or risk drivers, such as population growth, urbanization, marginalization, and rural and urban land use patterns (Alcántara-Ayala and Oliver-Smith 2019). Alcántara-Ayala (2019) also added factors such as different urbanization processes, unplanned territorial management, and different dimensions of vulnerability, emphasizing that there must be a more rigorous consideration of these factors along with DRR and DRM.

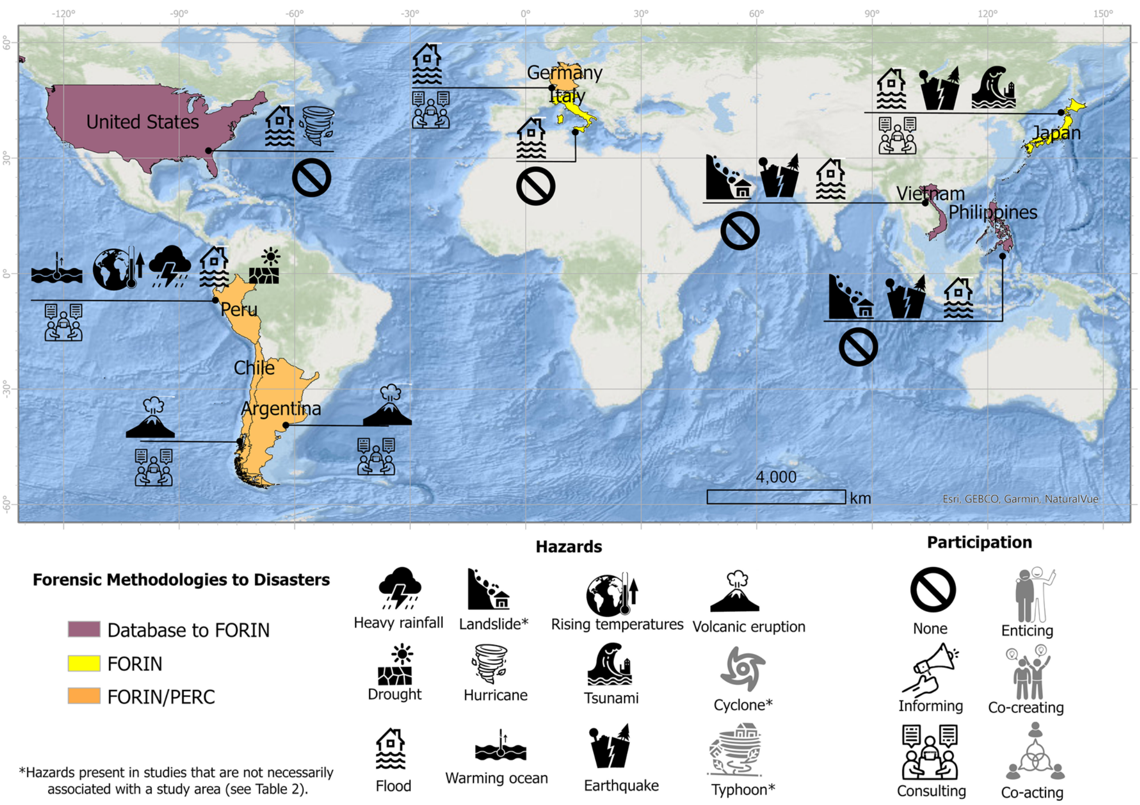

Fig. 3 Spatial distribution of disaster forensic studies according to methodologies, hazards, and types of social participation. *Hazards present in studies that are not necessarily associated with a study area (see Table 2). *Source* Elaborated by the authors. The icons are from the Noun Project and Canva (https://thenounproject.com/; https://www.canva.com/)

5 Discussion

This section discusses the findings according to the five guiding questions (Fig. 2).

5.1 Phases of Disaster Risk Management

The FORIN I guide proposes adopting disaster phases in its methodology (IRDR 2011). The FORIN I guide also stresses the need for studies emphasizing the middle way between geophysical events or "trigger" events and disaster response to understand the decision-making processes involved in the organizational and institutional arrangements before disasters (IRDR 2011). The FORIN II guide, on the other hand, does not have this framework with disaster phases (Fraser et al. 2016). The PERC methodological guide is focused on the so-called "disaster cycle" and its phases. This cycle description may be why PERC is sometimes used together with FORIN since it does not present this separation of DRM phases in the last version.

Of the 40 studies analyzed in the SLR conducted by Fraser et al. (2016), seven were focused on antecedent conditions (2004–2014), 17 on response and emergencies (2000–2014), and 13 on long-term recovery (2001–2014). In our systematic review, the studies analyzed were related to pre-disaster phases, antecedent conditions, and post-disasters, such as the response phase.

Although commonly used, there has been a critique of the continuous cyclic nature of disaster management (Sawalha 2020; Rana et al. 2021), and the disaster cycle has been gaining new perspectives, such as those proposed by Bosher et al. (2021). According to these authors, three points can be highlighted in relation to the disaster cycle. First, the persistent conceptualization of the "disaster cycle" has effectively contributed to a view that underestimates the beneficial impacts of pre-disaster risk reduction activities. Second, these phases tend to classify a disaster as a punctual event or a technocratic problem that can be managed even though it is not linear or cyclical but multidimensional and evolutionary. Third, the cycle phases are not independent but substantially overlapping and interconnected. Some articles analyzed in our SLR proposed an integrated and holistic interpretation of flood events, showing the need for knowledge of the root causes of disasters through past events to support prevention, mitigation, and DRR (Menoni et al. 2016; Mendoza and Schwarze 2019; Dominguez et al. 2021).

5.2 Methodologies

Despite being considered the core element of forensic investigations and having a broad and adaptable approach to the study of the root causes of disasters (Fraser et al. 2016), FORIN applications have not gone deep into the technical aspects of root cause analysis, such as identification and quantitative measurement of vulnerability (Mendoza 2019; Dominguez et al. 2021).

There is a consensus that knowing the risks requires investment in data and information. Where data are available, forensic investigations can be helpful to support policymakers and communities in considering possible future avenues for risk reduction. In this sense, it should be noted that many international reports and databases underestimate small-scale disasters (Fraser et al. 2016; Fraser et al. 2020), such as localized floods. The studies analyzed here represent significant advances in establishing the necessary information for applications of forensic methodologies. For instance, Girard et al. (2014) proposed a method to perform near-real-time forensic analysis of publicly communicated disaster response information. As the methodology is used in the first five days after the event, it can support studies that use official and unofficial perishable data, especially where data sources are scarce (Amaral et al. 2023). Although there are other challenges, such as temporal bias in data coding, the data collection method used to create the data set can be potentially transferable to other regions (Payo et al. 2022). Moreover, the use of different data sources, such as crowdsourcing, can be viable in support of forensic investigations (Yuan and Liu 2018), and it can also contribute to the improvement of local and regional urban governance using tools such as PGIS (Participatory Geographic Information Systems) (Carvalho et al. 2021). Methodologies can also be combined to improve data collection and analysis. For example, Dominguez et al. (2021) proposed a conceptual framework for post-event impact assessment using FORIN, PERC, and multi-risk analysis methodologies in the context of volcanic eruptions. Nakasu et al. (2017) used the FORIN approach and a human vulnerability index to identify the factors that accentuated the loss of human lives in the 2011 Great East Japan Earthquake and Tsunami disaster. The combination between PERC and FORIN is helpful to researchers since PERC has a structured script for the final report that can help in conducting the investigation.

5.3 Types of Hazards

The applications of forensic methodologies proved to be very heterogeneous regarding hazards. Although the PERC methodology is widely used in flood disasters, its guidebook reports that other tests have been carried out to consider other disasters. Moreover, it is necessary to develop research considering technological disasters related to dams, power plants, critical infrastructure, and so on.

The studies analyzed focused on large-scale disasters. Here, we also draw attention to the recommendation of Fraser et al. (2016) to consider medium and small-scale disasters since several hundred small and medium-sized disasters over a long period can cause consequences for societies equal to or greater than larger disasters (Alcántara-Ayala 2019). Forensic methodologies can be combined with other methods to collect data on small-scale disasters, such as guidelines provided by DesInventar.

5.4 The Need for Participatory Methodologies

The FORIN II guide calls for participatory action research and refers to education and extension initiatives (Oliver-Smith et al. 2016). It is essential to highlight the potential for teaching-learning and reflection-action processes since the study must consider the reality of daily life in its different dimensions and interactions (Trajber et al. 2019).

Along with different forms of social participation, reflecting on the various forms of knowledge is essential. Future studies may consider other forms of knowledge in forensic analyses, including co-production through innovative methods. Our SLR identified a gap in participatory FORIN. Previous SLR on forensic disaster approaches (Fraser et al. 2016) has not mentioned participatory initiatives.

5.5 Urban Planning

Spatial planning attempts to plan processes of social, economic, and environmental change for specific purposes, usually using maps, documents, or diagrams, by indicating where sociospatial activities should occur (Huxley and Inch 2020).

Forensic investigations can be helpful for spatial planning. Mendoza (2019) explored forensic investigations for disaster damage data analysis to support spatial planning processes in flood-prone areas. She stated that more research is needed to involve different actors in planning at different spatial levels. There will be barriers when assessing community engagement in participatory decision making for urban development and disaster risk, such as a need for knowledge about how to engage in participatory decision making and the lack of awareness of the benefits of community involvement (Geekiyanage et al. 2020). Well-defined methods, such as participatory and collaborative mapping, can bring and stimulate different forms of knowledge, build community perceptions about their territories, and support urban planning through preventive, corrective, and prospective DRM.

6 Conclusion

This research provided an SLR of ad hoc forensic approach methodologies to disasters.

Of the 156 scientific articles selected, only 11 adopted an ad hoc forensic approach related to FORIN, PERC, DRRC, or FDA. The IRDR program needs to create special calls to gather scientists and practitioners dedicated to or interested in forensic approaches to disasters. This type of initiative would be interesting to identify and connect forensic approaches, studies, and tools using different terminologies. A transdisciplinary effort will be interesting to address other components of disaster risk, the root causes of vulnerability, the dynamic pressures, and the governance aspects—including those with expertise in participatory methods.

In our SLR, most studies focused on applying the FORIN and PERC methodologies or combining the two methods. The studies addressed complex contexts for different types of hazards and multi-hazards, emphasizing physical and demographic, social, economic, and political aspects in their analyses. However, there is a need for greater social involvement in all stages of scientific research, leading to active social participation. For integrated and transdisciplinary research, it is necessary to establish paths and spaces for dialogue for a co-production of knowledge, where there is the creation of new understandings or even the creation of new collaborative agendas. Such a path is a way of working towards a more holistic understanding of disasters' underlying causes and risks.

Forensic approaches to disasters can be combined with methods that promote the capacity building of those exposed to hazards. Participatory mapping and other citizen science initiatives have a great potential to include local people in participatory forensic approaches to disasters. FORIN II has recommended developing educational and extension methods to be conducted by universities, but it still needs to explain how to do it. Is FORIN III going to address this issue? Future studies can address this gap, expanding the use of forensic approaches for advocacy purposes of nongovernmental and civil society organizations.

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