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EDITED BY

Melissa Haeffner,
Portland State University, United States

REVIEWED BY

Abu Reza Md. Towfiqul Islam,
Begum Rokeya University, Bangladesh
Marlies Barendrecht,
VU Amsterdam, Netherlands

***CORRESPONDENCE**

Prince Dacosta Aboagye
✉ dacosta.aboagye.prince.c9@
f.mail.nagoya-u.ac.jp

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Dominant barriers and social injustices in flood early warning systems governance: insights from topic modeling and content analysis

Prince Dacosta Aboagye* and Shinichiro Nakamura

Department of Civil and Environmental Engineering, Nagoya University, Nagoya, Japan

Introduction: Effective flood early warning systems (FEWS) are crucial to mitigating flood impacts. Yet, their governance is often hindered by numerous systemic barriers. These systemic barriers reinforce social inequities, which in turn exacerbate flood risk management and hinder the achievement of disaster justice. Existing studies provide limited insights into the dominant barriers that most significantly hinder effective governance of FEWS. Moreover, research examining the underlying social injustices embedded in these barriers remains scarce, despite the intensifying impacts of floods on existing social inequities, with the most severe consequences affecting vulnerable populations.

Methods: In this study, we employed a Latent Dirichlet Analysis (LDA) topic modeling to identify the dominant barriers to FEWS governance, followed by a qualitative content analysis to examine the underlying social injustice dimensions within these barriers.

Results and discussion: The topic modeling identified five interpretable dominant barriers per FEWS component from the corpus. The analysis revealed that capability injustice is the most prevalent primary social injustice underpinning the identified key barriers, followed by distributional injustice. Capability injustice, the unequal opportunities to utilize or access opportunities to enhance capabilities to operate or benefit from the system, remains an overarching dimension of injustice that is intensified by other forms of injustice. The study emphasizes the need for social justice to be considered in FEWS policy and governance. Going forward, addressing FEWS governance barriers requires attention to the underlying social injustices that perpetuate them, in order to avoid the risk of reinforcing existing inequalities within the system.

KEYWORDS

early warning, flood, governance, qualitative content analyses, social injustice, topic modeling

1 Introduction

Floods are the most common natural disasters worldwide. Climate change is currently exacerbating the frequency and severity of flood events, while unplanned urbanization and developments within flood-prone areas increase the risk among diverse populations (Mohammadi et al., 2024; Rogers et al., 2025). In 2020, a catastrophic flood in South Asia resulted in the deaths of more than 6,500 individuals and inflicted economic damages totaling \$105 billion (United Nations (UN), 2025). Recent severe flood events in the United States, Nepal, Afghanistan, and Pakistan underscore the reality of the threat, which is projected to

intensify under continued climate change. The threat posed by the devastating flood events is especially concerning as they intensify systemic inequities and social injustices, with disproportionate effects on vulnerable populations and individuals living in low-income countries (Rentschler et al., 2022).

As flood risk intensifies alongside deepening inequities, addressing social injustice in flood risk management (FRM) has become highly critical. While scholarly attention to the social justice dimensions of FRM is still emerging, many argue for mainstreaming social justice into FRM, emphasizing that flood disasters fundamentally shape social systems and that FRM should be understood as a social contract between the state and society (Hamdanieh et al., 2024; Thaler et al., 2018). The discourse hinges on the scholarly emphasis that flood disasters cause social disruptions and affect community resilience, thereby worsening social vulnerabilities and inequalities. In effect, flood risk is inherently unfair, and existing FRM approaches are likely to reinforce existing inequalities (Forrest et al., 2020).

Over the years, significant scholarly attention has been given to the spatio-temporal injustice of flood risk (Forrest et al., 2020; Tang et al., 2021; Rentschler et al., 2022), with limited emphasis on the underlying injustices in existing FRM approaches across various social systems and geographical contexts. Of critical significance is the relative neglect of social injustice underpinnings in scholarly discourse of FRM approaches, such as flood early warning systems (FEWS), whose efficacy is grounded in advancing social inclusion and adopting a people-centred approach.

FEWS, defined as an interrelated system of four elements, including *risk knowledge, monitoring and forecasting, warning dissemination and communication, and preparedness and response capabilities*, underlines the integration of the human and social dimensions in its operations, particularly as society rapidly evolves (Cao et al., 2024). In practice, a social approach to FEWS implementation aims to draw lessons from the concept of “social amplification” of risk, which suggests that individuals and groups perceive and interpret hazards not only through direct or potential harm but also through the lens of social processes, such as values, attitudes, social influences, and cultural identity (Kasperson et al., 1988; Renn et al., 1992). While a significant number of countries have invested in FEWS, its governance faces numerous barriers, resulting in less advanced implementation in some areas (Mohanty et al., 2019; Perera et al., 2020). These barriers in FEWS governance not only highlight failure across the system’s components but also expose the underlying social injustices that demand critical consideration. For instance, the exclusion of critical social groups from flood emergency preparedness initiatives in Pakistan (Shah et al., 2023) clearly highlights social injustice in FEWS governance (Vilá et al., 2023).

FEWS, like any other FRM approach, is considered a contract between society and the state, demanding a holistic analysis of the underlying social injustices that hinder the system’s governance, particularly as the world faces a rapid social change. Social injustices in FEWS governance intensify barriers, limit inclusivity, and undermine rights in the system’s operations. This, in turn, increases the vulnerability of populations whose exposure to flood risks is heightened by disability, race, gender, or poverty. However, a comprehensive empirical investigation of the underlying social injustices in FEWS governance remains underexplored in the current literature. This gap makes it difficult to inform relevant FEWS policymaking to address social injustice amid scarce resources, particularly in developing regions.

The discussion above highlights the need for a comprehensive empirical analysis of the dominant barriers to FEWS governance and a deeper understanding of the underlying social injustices embedded in them. Although identifying dominant barriers and their underlying social injustices are significant research themes in FEWS studies, meaningful insights based on empirical evidence remain lacking. This study identifies the dominant barriers to FEWS governance using an integrated systematic review and Latent Dirichlet Analysis (LDA) topic modeling approach, and critically analyzes the underlying social justice dimensions grounded on the social justice theory. The combination of the LDA and social justice theory enables a more systematic and robust examination of dominant barriers and their associated social injustice narratives in FEWS governance, while providing comparative insights that are difficult to achieve through conventional traditional qualitative reviews. The empirical analysis, therefore, uncovers how dominant barriers to and social injustices in FEWS governance manifest across the system’s components, providing the first systematic, global evidence of injustices in FEWS governance.

2 Conceptual framework

2.1 Governance of flood early warning systems

The increasing risks of flooding worldwide, driven by climate change, land-use changes, and population growth, are causing significant loss of life and damage to property and critical public infrastructure (UNEP, 2020; Ponting et al., 2021). With the rising population in flood-prone areas (Tellman et al., 2021), governments are urged to implement urgent mechanisms to mitigate flood risks. Investment in FRM has been conceptualized into two broad measures – structural and non-structural. The structural measure mainly focuses on physical construction and technological applications. The non-structural measures include designing and implementing policies, plans, legal frameworks, capacity-building initiatives, and public awareness and warnings (UNISDR, 2018). A critical non-structural measure for FRM is the investment and establishment of FEWS.

According to previous empirical studies, FEWS operations provide long-term sustainable socio-economic benefits at minimal costs (Rai et al., 2020; Kuller et al., 2021; Islam et al., 2024). Many countries across the globe have installed and operated FEWS to address riverine, coastal, and flash floods. Despite arguments suggesting that the socio-economic benefits of FEWS can be enhanced through proper structures and funding, the proven successes in saving lives, reducing damage, and strengthening community resilience remain undeniable. Empirical studies report the socio-economic benefits and reliability of FEWS, mostly in many flood-prone regions and local watersheds. For example, Cools et al. (2016) point to the benefits of FEWS in saving lives during flood disasters and generally adapting to climate change within selected countries in Europe and Africa. In the Karnali River Basin of Nepal, Rai et al. (2020) found that FEWS saves flood-exposed households an average of USD 1,083 in asset and health-related costs. Similar evidence is reported in the Brahmaputra River Basin in Bangladesh, where FEWS operations enable households to preserve asset expenditures worth approximately USD 2,525.59 (Islam et al., 2024).

The primary objective of operating FEWS is to monitor, forecast, and predict hazards, as well as to assess and communicate flood disaster risk, enabling social actors to prepare and take timely action to mitigate flood disaster risks before hazardous events occur (UNDRR and WMO, 2023). Thus, FEWS has been defined as an interconnected and interlinked system comprising four components: risk knowledge, monitoring and forecasting, warning dissemination, and response capabilities. The foundation of FEWS is the implementation of the *risk knowledge* component, where data is collected systematically, risk assessments are conducted, and hazard maps are developed to inform monitoring and forecasting, as well as policy and planning for preparedness, response, and recovery (UNDRR and WMO, 2023). The *monitoring and forecasting* component involves observing, analyzing, and predicting flood hazards, while the *warning dissemination* component prioritizes the communication of risk information and disseminating warnings across various governance scales. *Response capabilities* ensure that social groups and actors are prepared to respond to warnings and take relevant actions to protect themselves, their communities, and their assets (UNDRR and WMO, 2023). The functioning of each component and the extent of their interconnectivity often influence the overall effectiveness of the system. This means that assessments of the system should critically examine how each component functions effectively, rather than analysing the system as a single entity.

FEWS governance has often been discussed in the context of flood risk governance, encompassing the processes, institutional arrangements, policies, and frameworks that define how the system operates across its components to manage flood risk (Brown et al., 2019; Chereni et al., 2020). Studies suggest that there is no one-size-fits-all framework for FEWS governance (Ishiwatari, 2019). However, the dynamics are often hinged on diverse governance principles and regimes. Participatory approaches have been noted as an effective principle for FEWS and flood risk governance. Ro and Garfin (2024) argue that flood mitigation initiatives require engagement and collective efforts of various actors and institutions, hence emphasizing the need for participatory FEWS governance. The growing body of literature on participatory FEWS governance reflects an evolving emphasis on the involvement of a wide range of state and non-state actors and the inclusion of often-overlooked stakeholders in previous risk mitigation activities (Matczak and Hegger, 2020). However, despite the participatory turn, questions remain regarding institutional capacity and the extent and effectiveness of multi-actor, multi-level, and cross-sectoral collaborations across different stages of FEWS operations (Raška et al., 2020; Avoyan and Meijerink, 2021; Marchezini et al., 2022). These structural and collaborative gaps, along with underlying social factors, such as human behavior, social systems, and cultural identities, repeatedly result in barriers to effective FEWS governance.

Several studies have highlighted governance barriers in FEWS across various contexts and scopes, comprising cognitive limitations, mistrust, socio-cultural influences, insufficient technology and infrastructure, inadequate finance, institutional weaknesses, the exclusion of critical social groups, a lack of political will, and limited resources (Islam et al., 2025; Shah et al., 2023). These barriers not only highlight failure across the system's components but also reveal the underlying social injustices that demand critical attention. Yet, the fragmented nature of the literature on FEWS governance barriers makes it challenging to develop a comprehensive understanding of these barriers and their underlying social injustices. By synthesizing the state-of-the-art literature, we critically identify barriers to FEWS governance and

employ computational text analysis to uncover dominant barriers across contexts, as well as the underlying social injustices embedded within them.

2.2 Social justice—conceptual foundations and key dimensions

The theory of social justice has gained increasing attention in the 20th century for promoting fairness, equality, and dignity within society, influenced mainly by philosophers such as John Rawls, Nancy Fraser, and Amartya Sen. John Rawls' "*Theory of Justice*" is well-known for introducing principles such as the veil of ignorance and the original position targeted at generating fair policies by asserting on social and economic inequalities if it provides benefits to the least advantaged. This theory critically emphasized the distributive justice (Flynn and Ruffinengo, 1975). Consequently, Nancy Fraser broadened the scope beyond distributive justice and highlighted the need for recognition, stressing that social justice must also involve cultural recognition, participation, and political independence and voice (Fraser, 2008). Amartya Sen, however, argues through the capabilities approach, asserting that social justice should consider individual opportunities to develop capabilities and achieve well-being. This highlights the need to address institutional and structural injustices that inhibit everyone from having access to basic capabilities and opportunities to flourish (Saito, 2003).

In effect, social justice seeks to rectify inequities and unfairness in treatment, resource allocation, opportunities, and burdens, particularly in relation to historical events that disproportionately affect disadvantaged populations. Over the years, social justice has been discussed within three main dimensions: *distributive justice* (Flynn and Ruffinengo, 1975), *procedural justice* (Blader and Tyler, 2003), and *recognition justice* (Fraser, 2008). However, contemporary scholarship suggests that social justice should be treated as an evolving, multifaceted phenomenon, allowing for the introduction of new dimensions. This assertion has driven the emergence of new social justice dimensions beyond (re) distribution, recognition, and procedural (Bonatti et al., 2023). This also means that a standardized social justice framework may not exist and is likely to evolve in response to the underlying injustices observed in specific fields. Nevertheless, the concept of social justice has been adapted to various fields, including education (Rentzi, 2024), public health (Garcia, 2021), urban planning (Alizadeh and Sharifi, 2023), and environmental policy (Demirel et al., 2021; Zheng et al., 2025). For instance, distributive justice has been defined in the context of environmental policy and planning as a principle that ensures the fair distribution of risks and benefits arising from environmental pollution caused by economic activities (Di Fonzo et al., 2022). In another breadth, distributive justice has also been conceptualized more broadly as fairness in the allocation of resources, information, and access to the capacity and capability necessary for disaster risk reduction (Emrich et al., 2022). While debates continue on how social justice should be measured and operationalized in various contexts, the available literature suggests that distributive justice in risk reduction and environmental policy involve the equitable distribution of both risk and benefits (outcomes), with priorities given to the needs of targeted actors (Jafino et al., 2021; Di Fonzo et al., 2022; Emrich et al., 2022). Similarly, procedural justice, a concept commonly discussed in criminal justice studies (Chan et al., 2023; Politis et al., 2025), has been adapted to the fields of environmental policy as the principle of fairness in the policymaking, planning, and implementation processes

of efforts and initiatives aimed at addressing environmental challenges. Here, emphasis is placed on who can participate in the decision-making processes, how they participate, how decisions were finalized, and whose information or knowledge was considered and adopted (Wenta et al., 2019; Juhola et al., 2022). Building on Nancy Fraser's previous work, recognition justice has been applied in environmental policy to refer to the principle of recognizing and acknowledging diverse perspectives, social actors, cultures, identities, rights, and voices in addressing environmental challenges (Juhola et al., 2022; Van Uffelen, 2022; Yang and Lo, 2025). The premise of recognition justice in environmental policy discussions is that contexts, social structures, and the need to uphold basic human rights are essential and can inform solutions to environmental challenges. In climate adaptation, for instance, it is posited that pre-existing societal structures and contexts can influence how climate change impacts are experienced by vulnerable groups and the nature of adaptation needs across different social groups (Shi et al., 2016; Juhola et al., 2022). Consequently, social injustice arises when there is a failure to achieve fairness and equality in (1) the distribution of resources, risk, and outcomes, (2) processes in addressing environmental challenges, and (3) recognizing and acknowledging social structures and contexts of vulnerable populations amid rapid social change.

2.3 Why social injustice matters in FEWS governance

In recent years, social injustice has emerged as a critical concern in FRM within the broader environmental policy scholarship. This has become imperative due to the need to prioritize the justice dimensions of FRM, as there is a likelihood that certain social actors may benefit from FRM efforts while others may lose, and thus, social injustice considerations are likely to produce different outcomes in policy and implementation (Cooper and McKenna, 2008; Thaler et al., 2018). Many studies on this trajectory often focus on FRM and its implications for the injustice faced by vulnerable groups. As noted by de Herve (2022), these injustices emanating from FRM have been examined across various scales, dimensions of justice, strategies, and approaches. Additionally, other scholars have specifically identified gaps in FRM and examined how these gaps may lead to inequities stemming from underlying social injustices. Vilá et al. (2022) identified several federal and state-level barriers to facilitating the U.S. Federal Emergency Management Agency (FEMA)'s hazard mitigation support programs and explored how these barriers may influence social injustices in FRM. Among others, the majority of reports observed premium increases among properties that initially benefited from subsidies, as a way to stop FEMA's National Flood Insurance Program (NFIP) from incurring financial losses. These reforms have been ascribed as a challenge that may exacerbate social injustices in FRM, particularly for low-income communities and socially vulnerable groups in the U.S. (Shively, 2017). Similar patterns of inequity in flood response programs have been identified across developed regions, including Canada and European countries (Tesselaar et al., 2020; Thompson, 2024).

Despite widespread insights into social injustice considerations in FRM, studies on FEWS governance consistently fail to recognize these inequities beyond the system's challenges. Perera et al. (2020) identified key challenges in FEWS governance that deserve urgent attention from a social justice perspective. However, these issues, including participatory gaps in warning dissemination, insufficient consideration

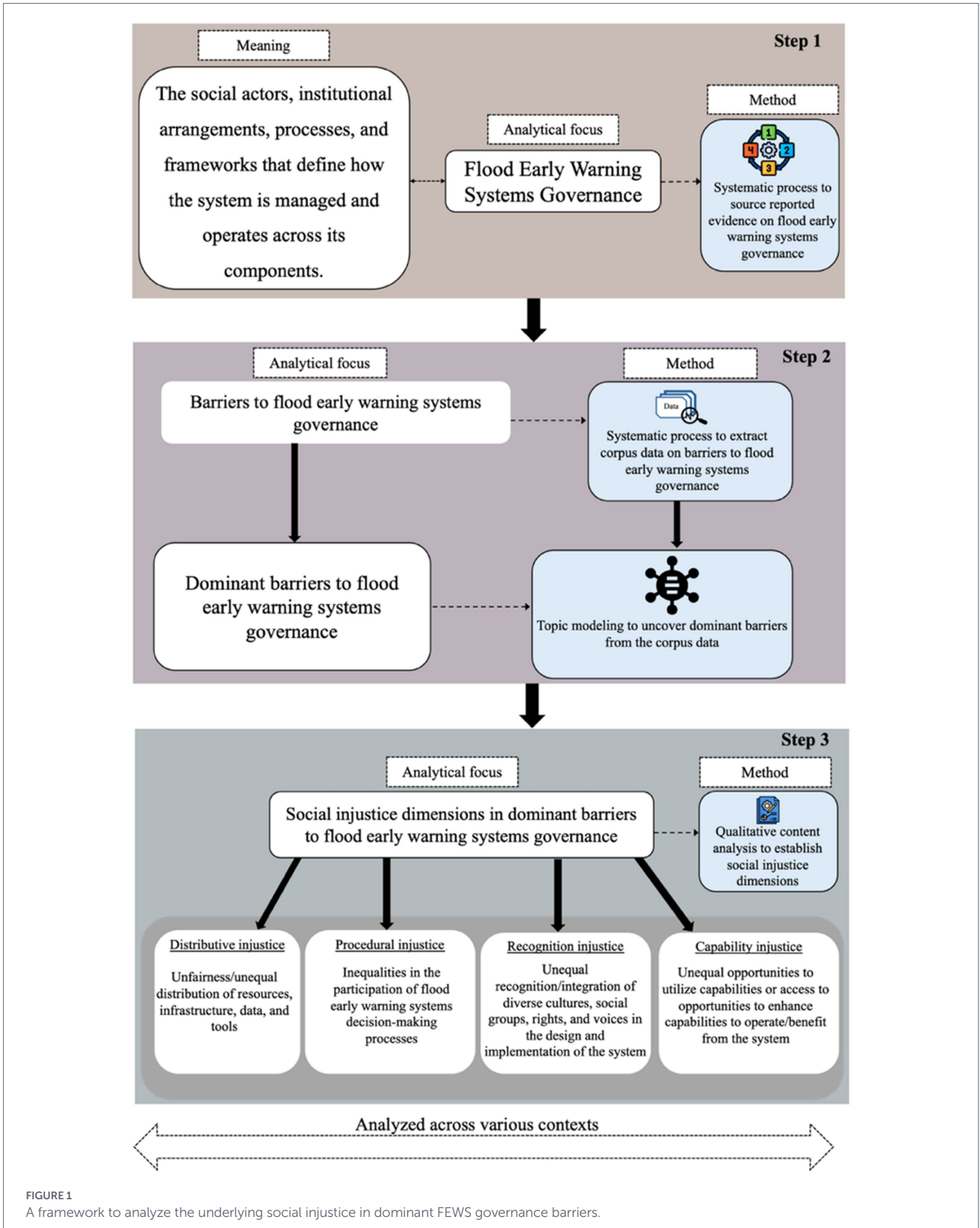
of gender and social inclusion across FEWS components, and limited institutional collaboration and cooperation, have been treated as merely structural and systemic barriers without considering their underlying social injustices. Again, past investments in FRM have primarily focused on structural measures, including infrastructure development (such as building dams, levees, and floodgates) and maintenance. There has been limited consideration for reducing inequities in the governance of FRM approaches, such as FEWS (Perera et al., 2019).

As FRM transitions from response to resilience, it has become imperative to understand the social aspects, including the social injustice undertones, in FEWS governance. Nigussie et al. (2025) assert that adopting a social justice approach, such as leveraging Amartya Sen's "Capability Justice," can enhance community trust, the effectiveness of FEWS governance, and improve community resilience. Additionally, critically examining FEWS governance as an approach to FRM will help address the overgeneralization of social justice issues in flood mitigation efforts, as observed in de Herve (2022) flood risk justice framework. It is also worth noting that FEWS constitute a distinct component within the broader framework of FRM, featuring inter-related structural and non-structural measures. Hence, governance barriers across the different components of the system may vary by governance scale and geographical context. Therefore, analyzing such barriers and their associated social injustices is crucial in contributing to the design of sustainable solutions to address existing inequities in FEWS governance. Ultimately, the effectiveness of FEWS heavily depends on a critical understanding of the governance structures that shape it, the inherent challenges within these structures, and the social injustice dimensions underlying these challenges (Hasan and Islam, 2024; Nigussie et al., 2025).

3 Analytical framework: social injustice in the context of FEWS governance

The analytical framework is grounded in the social justice theory and its dimensions, a conceptual framework of FEWS governance, and an understanding of existing gaps in FEWS governance (Figure 1).

Distributive injustice in the context of FEWS governance is interpreted as unfairness and an unequal distribution of resources, models, data and information, and infrastructure necessary for institutions at all levels and vulnerable groups to operate efficiently and access the benefits of FEWS. Procedural injustice focuses on inequalities in the participation of FEWS decision-making processes. Here, prominence is on how decisions about FEWS design and implementation are made, who can participate in the decision-making process, and whose knowledge or information is considered. Recognition injustice, therefore, implies unequal recognition and acknowledgement of diverse cultures, social groups, rights, and voices. Specifically, the analytical framework defines recognition injustice as whether the social differences, vulnerabilities, and knowledge of marginalized groups are recognized and integrated into FEWS design and implementation. Notably, a clear distinction exists between procedural and recognition injustice in the context of FEWS governance. That is, while procedural injustice results in unfairness in the processes used to make FEWS decisions, recognition injustice denies the recognition and inclusion of people's identities, cultures, and dignity in FEWS design and implementation. However, there is a possibility that an



injustice may create or reinforce another one (de Herve, 2022). For example, the failure to include certain marginalized groups in the processes leading to the design and implementation of FEWS (procedural injustice) may exacerbate recognition injustice, where the social vulnerabilities, cultures, knowledge, rights, and voices of these

groups may not be recognized and integrated into the FEWS design and implementation.

In this paper, we include the capability injustice, which is deeply rooted in Amartya Sen's "Capability Approach." In particular, capability injustice in FEWS governance is interpreted as unfairness in

opportunities to utilize capabilities or access to opportunities that enhance the capabilities of institutions, communities, and individuals to either implement and/or benefit from FEWS operations (Figure 1). Regarding individuals and communities, capability injustice refers to inequalities in people's real opportunities or access to opportunities to enhance and exercise their capabilities, thereby limiting their ability to benefit from FEWS operations. This is related to the "capability approach," where a person or community's well-being is measured by their ability and freedom to function and achieve desired outcomes, rather than just the provision of resources (Gasper, 2017). In this analysis, two main forms of capability injustice are emphasized under identified barriers: first, situations where individuals or communities possess the capabilities but face unequal opportunities or restrictions on their use. For example, in cases where people have increased awareness of flood risks but cannot access evacuation centers, despite the provision of these centers. The second form of capability injustice involves the deprivation of opportunities to build capabilities. Here, the focus is on injustices in accessing opportunities (such as education, information, or institutional support) to build awareness of FEWS operations.

Capability injustice also manifests at the institutional level, as espoused by Gutwald et al. (2014) as "collective capabilities." This can be observed in instances where FEWS institutions lack autonomy, inter-agency collaboration, coordination, or the enabling conditions necessary to deliver on their mandates. Such gaps result in the inability to translate available resources, skills, or knowledge into meaningful outcomes or deprive them of opportunities to enhance their capabilities in implementing FEWS. Critically, capability injustice may be reinforced by other dimensions of social injustice. For instance, the unequal distribution of resources to prepare for flood events (distributive injustice) may result in people's inability to respond to flood disasters (capability injustice). Again, the unequal recognition of diverse actors in the FEWS operations (recognition injustice) or inequalities in the participation of FEWS decision-making processes (procedural injustice) may hinder vulnerable actors, such as communities, from utilizing their abilities or accessing opportunities to enhance their abilities to respond and recover from flood events. Generally, the analytical framework follows the premise that FEWS governance can be studied across various scales (Raška et al., 2020; Avoyan and Meijerink, 2021; Marchezini et al., 2022) and social injustice is an evolving concept that allows for the conceptualization of new dimensions based on identified inequalities in the field (Bonatti et al., 2023). This study will emphasize the governance barriers of each component and highlight the underlying social injustices that these barriers reveal. Importantly, the study's aim is not to measure the magnitude of social injustice or provide a quantitative assessment, but rather to examine the different dimensions of underlying injustices associated with the dominant FEWS governance barriers. In doing so, the research uncovers latent social injustices embedded in the primary structures of FEWS governance, providing a starting point for discussing how these, in turn, shape the general effectiveness of the system.

4 Materials and methods

4.1 Data sourcing

The Preferred Reporting Items for Systematic Literature Reviews and Meta-Analyses (PRISMA) protocol (Stovold et al.,

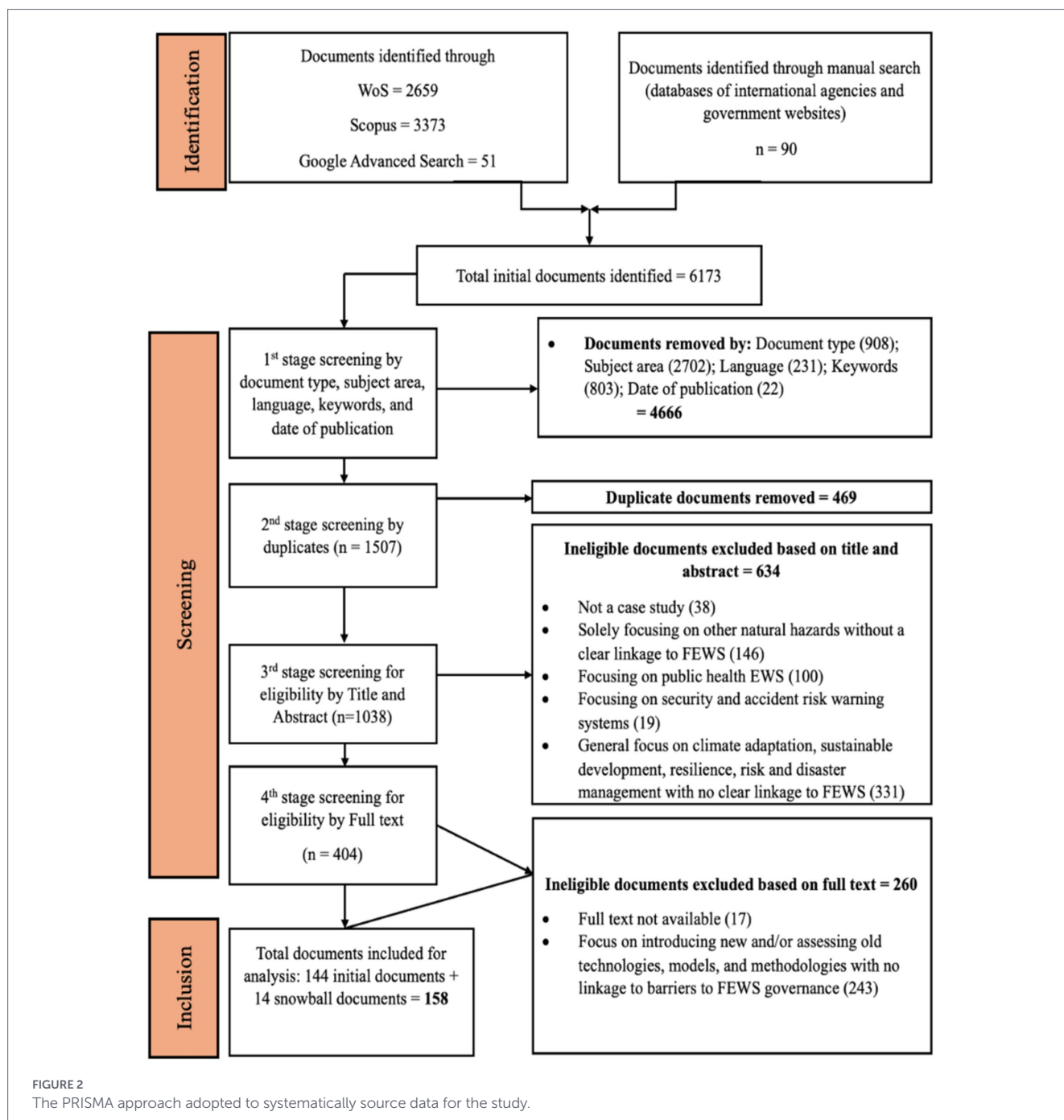
2014) was adopted to systematically source data for this study. The process of data sourcing is illustrated in Figure 2. To ensure that the retrieved data represent a broader range of perspectives and contexts relevant to addressing the research questions, we included documents from both peer-reviewed and gray literature. First, a literature search was conducted in Scopus, Web of Science, and Google Advanced Search databases with keywords that define the main concepts of the study:

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Query = ((("Social Acto*" OR "stakehold*" OR "communit*" OR "local*") AND ("govern*" OR "institutional arrange*" OR "policy" OR "management struct*" OR "Approach*" OR "Framework*" OR "Instrumen*" OR "legisl*") AND ("flood early warning system*" OR "emergency warning*" OR "EWS"* OR "FEWS"* OR "Alert*" OR "flood risk manage*" OR "flood resilien*") AND ("implementation" OR "operation" OR "management")))).
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Second, gray literature on FEWS governance or barriers to FEWS governance was sourced from government websites and databases of key global organizations and international agencies, including the World Bank, Practical Action, Japan International Cooperation Agency (JICA), People in Need, International Federation of Red Cross and Red Crescent Societies (IFRC), Prevention Web, Global Facility for Disaster Reduction and Recovery (GFDRR), and World Meteorological Organization (WMO). A snowballing technique was further employed to identify additional relevant documents for inclusion. After removing duplicates from the databases, we included documents published only in English, clearly focused on FEWS governance, and explicitly highlighted barriers to effective FEWS governance.

The study specifically targeted documents published since 2005, aligning with the release of the Hyogo Framework for Action (2005–2015) (UNDRR, 2007), the first disaster risk reduction framework that emphasized the importance of early warning systems as a tool for disaster prevention and reduction. Documents without full texts, letters to the editor, commentaries, and systematic literature reviews were excluded from the analysis. We also included documents focusing on multi-hazard early warning system governance, particularly from countries with integrated systems in which flooding is among the targeted hazards. The initial search returned 6,173 documents from the databases and 14 documents through the snowballing approach.

A total of 158 documents met the inclusion criteria and were subsequently included in the study. In developing the coding protocol (Supplementary Table 1), the WMO Multi-hazard Early Warning Systems checklist (WMO, 2017) was used to categorize and define FEWS components. Additionally, the protocol development was guided by the research questions, emphasizing the extraction of reported evidence on barriers in FEWS governance across the system's components. The coding protocol also defined variables for extracting data on author (s), publication year, and the case study area (i.e., country of focus). A Microsoft Excel extraction matrix was used to systematically capture relevant corpus data from the final set of documents. The data on FEWS governance barriers were extracted for each distinct component to develop a corpus for the topic modeling. To ensure data extraction validity, the initial coding was conducted by a single author. Regular discussions between the two authors clarified challenges in coding processes and supported the iterative refinement of coding decisions. Additionally, the final extracted data were compared



with the coding protocol to ensure consistency between the data and the set protocol.

4.2 Topic modeling using the latent Dirichlet allocation (LDA)

In this study, the topic modeling approach was used to understand the dominant barriers from textual corpus data on barriers to FEWS governance. Topic modeling is a powerful text-mining technique that can uncover latent themes or topics, such as dominant barriers, within a large collection of textual data, including extracted evidence on barriers to FEWS governance (Cheng et al., 2018). We employed the Latent Dirichlet allocation (LDA) model, the most commonly adopted algorithm in topic modeling (Jung and Kim, 2023), for the analysis.

4.2.1 The LDA

The LDA is a type of topic modeling approach that identifies hidden thematic structures or topics and their probability distributions (based on raw counts) across numerous unstructured text documents. In LDA, a document (individual text entry within a corpus of large text data) is assumed to be composed of a mix of several topics (bag of words), and each topic comprises certain words that tend to appear together. In the present analysis, the model identified which topics are present within the corpus of extracted texts on FEWS governance barriers. The LDA further estimates the relative dominance of topics within the entire dataset of FEWS governance barriers.

The order of words in a document is not particularly important in LDA modeling. In other words, the model considers which words

appear and how frequently, not where they appear in the text. As a result, individual words within a document can be assigned to different topics, resulting in a single document generating multiple topics on a word-by-word basis (Tomojiri et al., 2022). In this study, a document represents the extracted structured narratives of evidence on FEWS governance barriers entries per case across the system's components, not fully published articles or gray literature. In the context of this study, LDA can assign words related to institutional coordination, resource limitations, and community engagement to different topics, with their contributions and interpretations depending on the thematic context of each topic. This approach enables the identification of multiple, diverse governance barriers across components and the further assessment of their dominance. Hence, the approach is relatively flexible and more suitable for this study, unlike other unsupervised clustering methods, such as K-means, which assign a single word or document to only one cluster or another, assuming the existence of a single dominant topic in a document (Ikotun et al., 2023).

Figure 3 illustrates the iterative process in LDA topic modeling. Each circle in Figure 3 denotes a random variable, while α and β serve as hyperparameters governing the Dirichlet distribution θ_d and φ_k , respectively. The LDA uses Dirichlet distributions to model the distribution of topics in each document (θ_d is the topic distribution of document d) and the distribution of words within each topic (φ_k is the word distribution of topic k). N_d represents the number of words in document d , while $z_{d,i}$, which is drawn from θ_d , is the set of topic collection for document d . Each $z_{d,i}$, therefore, denotes the topic assigned to the i -th word in document d . Similarly, $w_{d,i}$ which is informed by θ_d and $z_{d,i}$ is the word collection in document d , while each $w_{d,i}$ corresponds to a specific word token in that document. As can be observed in Figure 3, each generated topic consists of a cluster of words and an associated probability distribution of those words. Here, a cluster of high probability words is used to interpret the semantic meaning of the topic. In this case, the cluster of words and their corresponding probabilities were used to interpret the nature of the FEWS governance barrier represented by each topic. Again, each document (the extracted large text data on FEWS governance barriers) may contain multiple topics. The probability distribution of these topics across

documents was then used to analyze the dominant topics or barriers across FEWS components.

4.3 Analyzing topic variation across FEWS components using the LDA

To analyze the distribution of topics across FEWS components, we adapted the following formulas, as suggested by Xiong et al. (2019) Tomojiri et al. (2022), and Sun and Yin (2017).

4.3.1 Distribution of topics across FEWS components

We defined θ^f as the topic distribution of the various FEWS components, and θ_k^f as the proportion of the k^{th} topic in a specific component f .

$$\theta_k^f = \frac{\sum_{d \in f} \theta_{dk}}{n^f}$$

Where $d \in f$ denotes the published documents in a specific component, θ_{dk} denotes the proportion of the k^{th} topic in each document d , and n^f represents the total number of documents in a specified component f .

4.4 Preprocessing of the LDA

A standard LDA analysis requires preprocessing the raw text corpus to improve the accuracy, relevance, and interpretability of the generated topics (Zimmermann et al., 2024). As the textual data was manually collected in a Microsoft Excel file with multiple narrative columns describing reported barriers, the initial step was to merge these columns into a single full-text field for each document across all FEWS components.

Because each FEWS component represents a conceptually distinct stage of the system with its own vocabulary and semantic structure, the topic modeling and topic number selection were conducted at the component level. This was done to avoid imposing a single topic granularity

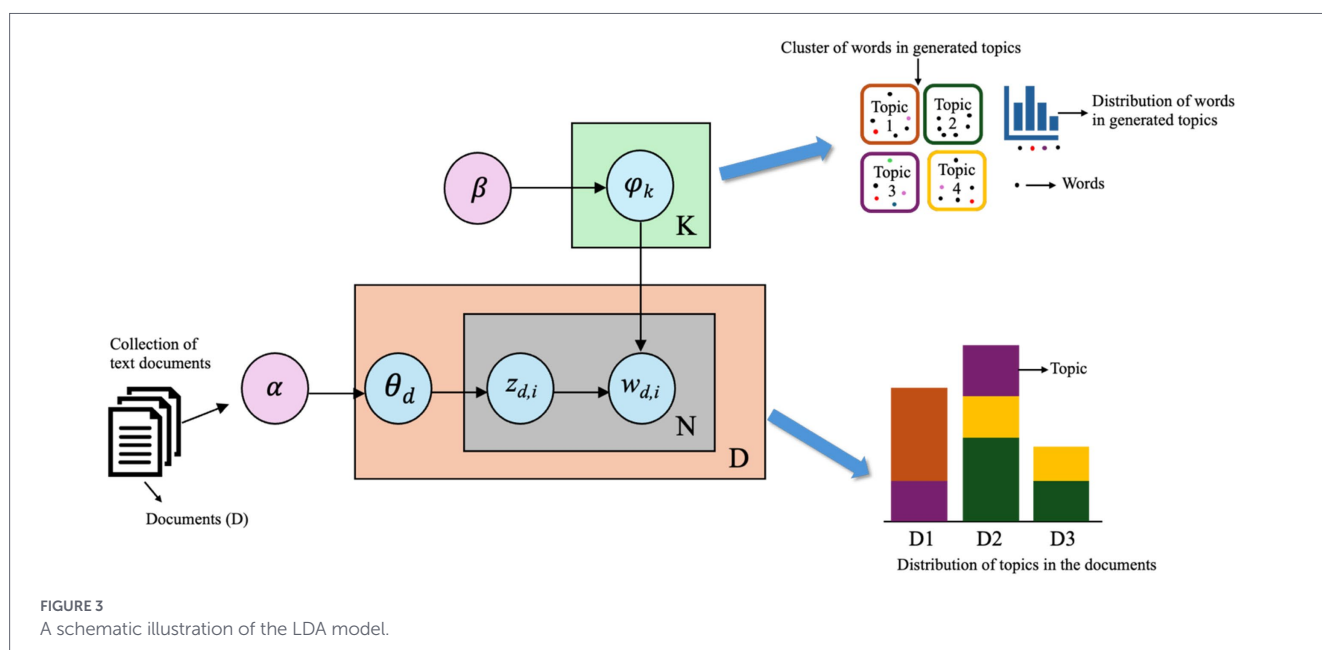


FIGURE 3 A schematic illustration of the LDA model.

on semantically heterogeneous texts and improve the interpretability of component-specific barriers. For each FEWS component, texts were first compiled into component-specific corpora. Standard preprocessing, including lowercasing, removal of non-alphabetic characters, tokenization, and lemmatization, was then applied separately to each corpus prior to topic modeling. Stopwords were removed using standard English stopwords (e.g., “a,” “is,” “the,” “by”) across all narratives in each FEWS component, except “*warning dissemination*.” Regarding warning dissemination, an additional set of custom stopwords was applied to remove frequently occurring but uninformative words (e.g., “*warning*,” “*flood*,” “*alert*,” “*risk*”) to improve topic coherence and interpretability. Again, multi-word terms with semantic meaning that appeared frequently were merged into single tokens (e.g., *early + warning* to *early_warning*) to preserve contextual information in the warning dissemination component. We then applied vectorization before performing LDA across all the FEWS components. LDA hyperparameters α and β were kept at their default values to allow for neutral topic modeling. Notably, the LDA was conducted on the full text of each article as a single document, after preprocessing. No pre-selection or manual segmentation of text fragments was conducted before the LDA analysis.

Given that the text corpus in this study is relatively small compared to those used in big-data studies, we tested the model with 5, 7, and 10 topics and ultimately selected 5 topics per component. The 5-topic solution achieved the highest C_v coherence among the tested models ($k = 5, 7, 10$) across all components, with scores decreasing as the number of topics increased (Supplementary Table 2). Importantly, inspection of the topic structures showed that the five-topic model produced distinct dominant barriers and semantically consistent, interpretable topics across all components.

4.5 Analyzing underlying social injustice dimensions in dominant barriers

In this study, we used a qualitative content analysis approach to analyze the underlying social injustice dimensions in the identified dominant barriers. Qualitative content analysis is one of the common qualitative methods used to systematically analyse non-numeric data for the purpose of identifying themes, patterns, and making meanings of concepts and context. This analytical approach has been adopted in various research fields, including urban planning, urban studies, public health, and disaster risk management (Seddighi et al., 2021; Van Zyl et al., 2021; Sheydayi and Dadashpoor, 2023). We employed a deductive approach to qualitative content analysis to critically analyse the underlying social injustice dimensions in the identified dominant barriers. The deductive analysis was appropriate for this study because it provided a structured and systematic approach to analyse the dominant barriers in relation to pre-existing, defined social injustice dimensions (distributive, recognition, procedural, and capability), as presented in the analytical framework of this study.

5 Results and discussion

5.1 Overview of the published documents used to generate the corpus

The PRISMA approach was used to source 158 peer-reviewed articles (59%, $n = 93$) and gray literature (41%, $n = 65$) for the study.

Figure 4 provides an overview of the literature used to generate the corpus, highlighting the types and geographical distribution of the sources. Among the 65 gray literature, 23 (35%) are government reports, while 22 (34%) are reports of international agencies (Figure 4A). Others include book chapters (8 documents), NGO/CSO project reports (5 reports), theses and dissertations (5 documents), and conference materials (2 materials) (Figure 4A). The documents used to generate the corpus represented 199 case studies of reported evidence on barriers to FEWS governance from 84 countries.

The geographical distribution of case studies shows a concentration in South and Southeast Asia and parts of Europe. The highest number of case studies originated from Nepal and the United Kingdom ($n = 13$), followed closely by Indonesia ($n = 11$) and Bangladesh ($n = 9$) (Figure 4B). The uneven geographical distribution of accessible literature on FEWS governance may affect the capacity to identify and comprehensively understand dominant barriers and social injustice narratives, especially in underrepresented contexts, including small island states, parts of Latin America, and Sub-sahara Africa. This creates policy-relevant gaps that may limit the formulation of context-appropriate interventions to address barriers and social injustice narratives in these regions. Nevertheless, the case study bias may reflect increased discussions and the urgent need to address flood issues in regions such as South and Southeast Asia, which are considered the most vulnerable to floods (Rentschler et al., 2022). Similar discussions have intensified across parts of Europe in recent years, driven by the increasing frequency and severity of floods across the region (Tradowsky et al., 2023; Kimutai et al., 2024). The full dataset is attached as Supplementary material.

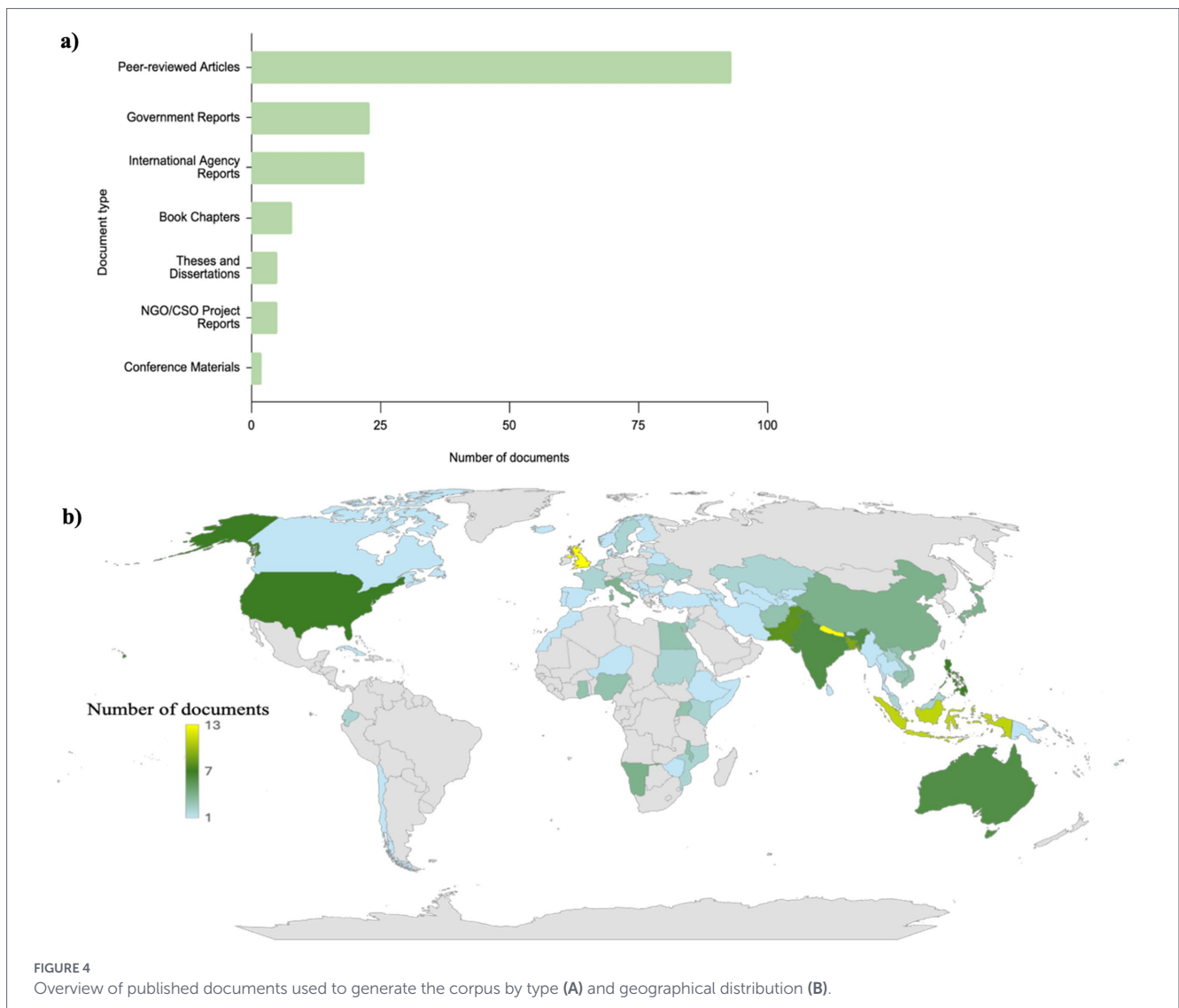
5.2 Identification of dominant barriers across FEWS components

The identified dominant barriers represent the topics generated from the LDA modeling. The study obtained five dominant barriers in FEWS governance across all FEWS components. A pairwise correlation test and cosine similarity analysis were conducted in Python as a post-processing robustness test on the LDA outputs. These robustness checks were essential to verify the independence of the derived topics, as standard LDA is based on the assumption that topics are always unique from one another, although it cannot model their correlations (Song et al., 2008). The results of the pairwise correlation test revealed a negative correlation among all topics within each component (Figure 5).

This finding indicates that the generated topics are distinct from one another and do not thematically overlap, further confirming the robustness of the LDA modeling and the reliability of the identified dominant barriers. On the other hand, the cosine similarity test yields moderate positive similarity scores among all topics within each component (Figure 6). This means that, although the topics are unrelated and largely distinct (as shown by the negative pairwise correlations), they share common vocabulary (AlShammari, 2023).

For instance, barriers in FEWS governance are likely to share words such as “lack,” “limited,” “flood,” “risk,” and other component-specific terms. The barrier labels and arrangement of the dominant barriers followed the order of topics derived by the LDA, such that topic 1 in risk knowledge is the dominant barrier in the component (RK_1).

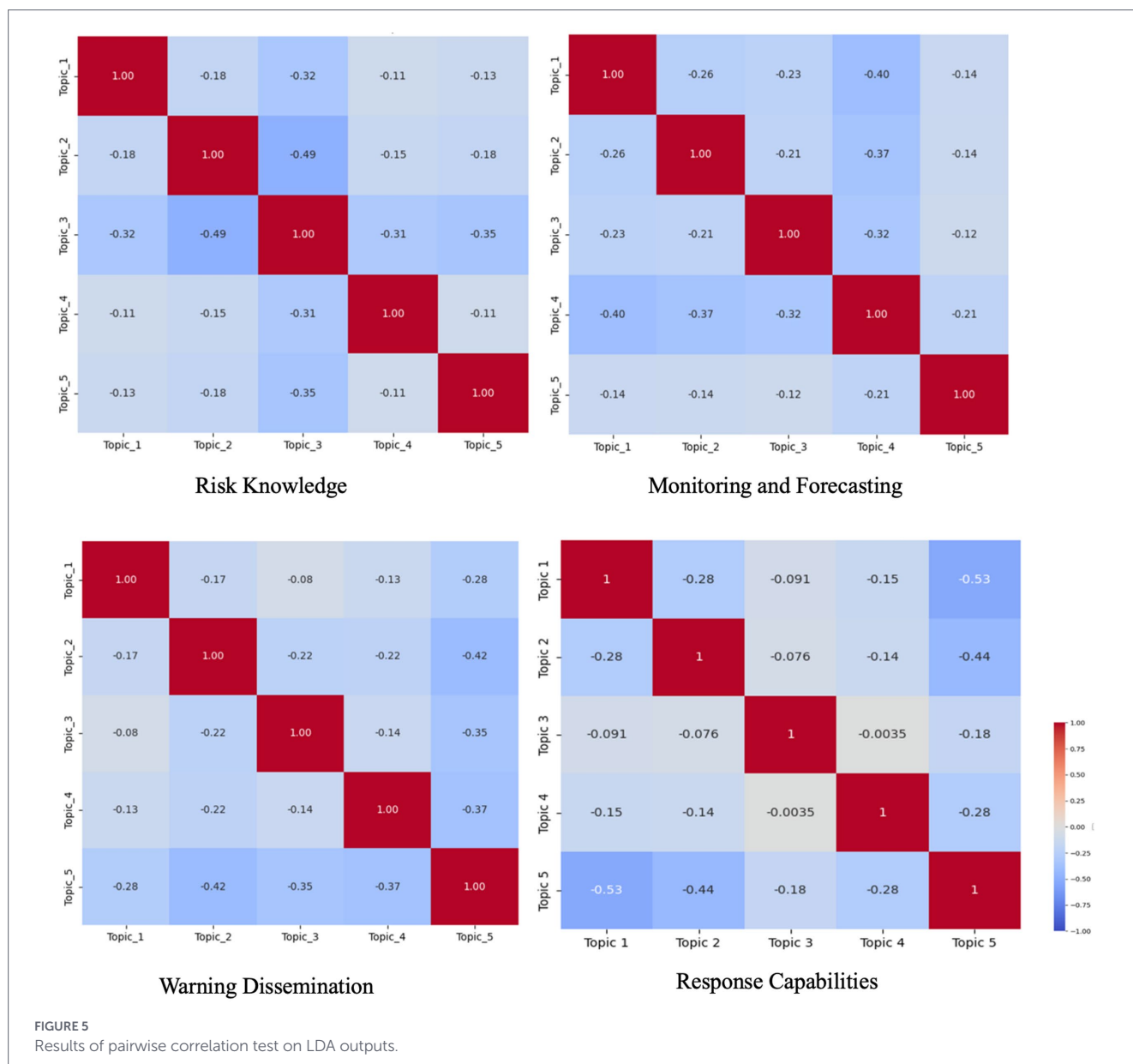
Table 1 presents the list of dominant barriers identified by the LDA, along with their top words related to FEWS governance



barriers. Although the LDA modeling algorithm can generate topics and group together words that characterize them (Sharifi et al., 2025), it does not automatically assign meaningful and human-readable names for those topics. Thus, we followed the processes adopted by Jung and Kim (2023) in naming topics on sustainability and marketing research and Sun and Yin (2017) in naming themes and trends in transportation research. First, we named these topics by analyzing the most frequent words that appear as the strongest indicators of the topic. Second, we identified common themes that connect these top words and contextualized them with previous literature, including insights from the documents used to generate the corpus. Common terms, such as “flood,” “warning,” “alerts,” and “risk,” were excluded from the naming process, as they were removed during preprocessing. However, references to these terms appeared in the topics only when they attained high weights and demonstrated strong contextual relevance to naming the barrier. The terms “lack,” “limited,” “gaps,” and “challenges” were employed to accurately frame and interpret the topics as barriers within the context of this study (Table 1).

5.3 Underlying social injustice dimensions within dominant barriers

Social injustice in FEWS governance renders the operation of the system unfair (Forrest et al., 2020). The importance of analyzing the underlying social injustice in barriers to FEWS governance cannot be underestimated. This section presents the underlying social injustice dimensions associated with the identified dominant barriers across the FEWS components (Table 2). The analysis in this section is conducted in relation to the conceptualization of distributive, procedural, recognition, and capability injustices, as discussed and illustrated in Section 3 and Figure 1 of this study, respectively. Additionally, following the assertion that injustices create or reinforce other injustices (de Herve, 2022), we examine how the four social injustice dimensions relate to each other and the corresponding dominant barriers. In this study, a social injustice dimension central to or directly underlying a dominant barrier is termed the “primary social injustice narrative” of that barrier. In contrast, dimensions that explicitly emerge from or are directly reinforced by the primary



social injustice narrative are regarded as “secondary social injustice narratives.”

5.3.1 Capability injustice in barriers to FEWS governance

As shown in Table 2, most of the dominant barriers’ primary social injustice narrative falls under the capability injustice dimension. The findings indicate that the capability injustice dimension accounts for more than half (60%) of the primary social injustice narrative in risk knowledge, as well as in monitoring and forecasting. In other words, capability injustice is the most prevalent form of social injustice underlying dominant barriers to both risk knowledge and to monitoring and forecasting governance. This suggests that unequal opportunities for institutions and communities to utilize their capabilities or access opportunities to enhance their abilities to operate or benefit from FEWS directly shape or are central to barriers to risk knowledge and monitoring and forecasting governance. Risk awareness and hazard maps play a crucial role in enhancing public perception and

willingness to prepare for and respond to flood events (Pedoth et al., 2025). Limited public awareness of local flood risk and hazard maps (RK_1) can undermine local communities’ risk knowledge, hindering their ability to understand their risk levels and prepare adequately to respond to flood events (capability injustice). On the other hand, this barrier can inhibit institutions’ ability to efficiently implement FEWS at the local level (collective capability injustice), as many people lack awareness of their risks and of existing hazard maps. This situation results in the exclusion of such communities from meaningful participation in FEWS governance and decision-making processes (procedural injustice), rendering them passive recipients of FEWS benefits. If this occurs, it increases the possibility of undervaluing and failing to recognize the needs, vulnerabilities, legitimacy, and voices of local communities (recognition injustice) (Thaler and Seebauer, 2025). The relationship between the injustices indicates that all social injustice dimensions reinforce or create a capability injustice, a secondary injustice narrative. Consequently, capability injustice can be understood as an overarching form of injustice that is intensified by other forms of injustice.



5.3.2 Distributive injustice in barriers to FEWS governance

In addition to capability injustice, distributive injustice accounts for a significant share of the primary social injustice narratives, underpinning 8 (40%) of the 20 dominant barriers identified across the FEWS components. Notably, the analysis reveals that distributive injustice, as a primary social injustice narrative, reinforces or creates capability injustice across all eight dominant barriers observed (Table 2). This situation occurs when the unequal distribution of resources, infrastructure, data, and tools (*distributive injustice*) reinforces unequal opportunities for actors to access opportunities or to utilize their abilities to benefit from FEWS (capability injustice). For example, the limited availability of hydro-meteorological stations and data for flood forecasting (MF_4) restricts relevant institutions' access to real-time information needed to issue warnings. This, in turn, limits communities' ability to receive accurate and timely warnings and to adequately prepare to respond to expected flood events. Instances of the interlinkages between distributive and capability injustice in

FEWS governance have been reported significantly in the literature. In Namibia, José Moisés et al. (2023) reports indicate that the unequal distribution of monitoring stations, particularly in smaller tributaries and watercourses (*distributive injustice*), poses hurdles to the efficient dissemination of warnings by institutions and preparedness by local communities (*capability injustice*), thereby increasing damage and loss. Distributive injustice also tends to create or reinforce procedural and recognition injustice in many instances of response capabilities (Table 2). The lack of stakeholder cooperation frameworks in response activities (RC_3) creates instances where diverse actors, their needs, and expertise are not recognized and given the opportunity to participate in decision-making processes. Addressing this barrier and its underlying injustices may require regulatory frameworks to guide and enforce stakeholder involvement and coordination (Mehryar and Surminski, 2020). However, RC_4 indicates that such legal frameworks are limited for flood risk preparedness and response, further emphasizing instances of recognition and procedural injustices despite the importance of participatory FEWS in disaster risk reduction (Aboagye et al., 2026).

TABLE 1 Dominant barriers and their top words across FEWS components.

Barrier label	Barrier name	Top 10 words
Risk Knowledge (C_v Coherence = 0.4647)		
RK_1	Limited public awareness of flood risk and hazard maps at the local level.	Hazard, risk, lack, maps, awareness, local, assessment, low, information, public
RK_2	Lack of community-level hazard and vulnerability maps to inform risk knowledge at the national level.	Flood, maps, national, hazard, risk, level, information, vulnerability, communities, systematic
RK_3	Lack of national and local-level data and information for flood risk assessment.	Risk, flood, lack, data, knowledge, assessment, information, local, national, hazard
RK_4	Limited national and local capacity for community risk assessment and communication.	Risk, local, national, limited, assessment, communities, levels, capacity, communication, sharing
RK_5	Challenges in institutional capacity for collecting flood risk data and developing a knowledge database on local hazards and vulnerabilities.	Hazard, data, risk, vulnerability, database, disaster, knowledge, institution, collection, local
Monitoring and forecasting (C_v coherence = 0.4367)		
MF_1	Insufficient capacity to gather relevant data for flood monitoring and forecasting.	Flood, limited, data, forecasting, lack, capacity, monitoring, weather, inadequate, areas
MF_2	Data gaps and model limitations across different meteorological agencies, hindering existing flood forecasting systems.	Forecasting, data, flood, systems, agencies, areas, meteorology, different, models, limited
MF_3	Lack of technical capacity in operating hydro-meteorological stations for monitoring and forecasting at national and local levels.	Forecasting, hydro, stations, lack, national, local, monitoring, capacity, meteor, technical
MF_4	Limited monitoring stations and data availability across local and national institutions for flood forecasting.	Forecasting, monitoring, flood, limited, stations, lack, national, institutions, data, local
MF_5	Lack of internal capacity and external cooperation for maintaining monitoring stations and radars.	Lack, monitoring, forecasting, stations, country, cooperation, terms, maintenance, countries, radars
Warning dissemination (C_v Coherence = 0.4741)		
WD_1	Lack of multi-scale institutional capacity to deliver timely and reliable warning messages.	Early_warning, message, people, national, time, always, institution, local, effort, effective
WD_2	Lack of communication channels and responsibility mechanisms for receiving feedback on issued alerts.	Warning, communication, networks, issued, alert, responsibility, without, feedback, mechanism, challenge
WD_3	Lack of trust among local, regional, and national meteorological services and authorities arising from systemic challenges in operating and coordinating multi-level FEWS.	Local, authority, service, meteor, national, trust, challenge, regional, system, issue
WD_4	Inadequate institutional capacity to issue clear warning messages with broad coverage to local communities.	Warning, message, inadequate, institution, issue, local, people, clear, alert, coverage
WD_5	Challenges in warning dissemination due to language barriers and limited access to local and vulnerable communities.	Warning, medium, language, local, community, area, access, challenge, message, vulnerable
Response capabilities (C_v coherence = 0.4455)		
RC_1	Lack of institutional capabilities in flood preparedness and response activities at the local level.	Response, lack, preparedness, flood, level, capability, local, institution, activity, resource
RC_2	Lack of flood risk disaster preparedness and response plans at the local level.	Disaster, response, plan, lack, flood, area, preparedness, local, evacuation, risk
RC_3	Lack of frameworks in ensuring stakeholder cooperation in flood response activities.	Stakeholder, warning, challenge, early, people, flood, lack, framework, cooperation, activity
RC_4	Limited legal frameworks for ensuring institutional responsibility to stakeholder coordination for preparedness and response.	Responsibility, flood, response, limited, institution, actor, preparedness, law, organisation, coordination
RC_5	Lack of local community evacuation centres and limited resources for flood response.	Response, flood, lack, community, local, evacuation, people, limited, resource, capacity

TABLE 2 Underlying social injustice dimensions of barriers across FEWS components.

Barrier label	Barrier	Underlying social injustice dimension (s)			
		Distributive	Procedural	Recognition	Capability
Risk knowledge					
RK_1	Limited public awareness of flood risk and hazard maps at the local level.	-	*	*	√
RK_2	Lack of community-level hazard and vulnerability maps to inform risk knowledge at the national level.	√	-	-	*
RK_3	Lack of national and local-level data and information for flood risk assessment.	√	-	-	*
RK_4	Limited national and local capacity for community risk assessment and communication.	*	*	-	√
RK_5	Challenges in institutional capacity for collecting flood risk data and developing a knowledge database on local hazards and vulnerabilities.	*	-	*	√
Monitoring and forecasting					
MF_1	Insufficient capacity to gather relevant data for flood monitoring and forecasting.	*	-	-	√
MF_2	Data gaps and model limitations across different meteorological agencies, hindering existing flood forecasting systems.	√	-	-	*
MF_3	Lack of technical capacity in operating hydro-meteorological stations for monitoring and forecasting at national and local levels.	-	-	-	√
MF_4	Limited monitoring stations and data availability across local and national institutions for flood forecasting.	√	-	-	*
MF_5	Lack of internal capacity and external cooperation for maintaining monitoring stations and radars.	*	√	-	√
Warning dissemination					
WD_1	Lack of multi-scale institutional capacity to deliver timely and reliable warning messages.	*	-	-	√
WD_2	Lack of communication channels and responsibility mechanisms for receiving feedback on issued alerts.	*	√	*	*
WD_3	Lack of trust among local, regional, and national meteorological services and authorities arising from systemic challenges in operating and coordinating multi-level FEWS.	-	√	*	*
WD_4	Inadequate institutional capacity to issue clear warning messages with broad coverage to local communities.	*	*	*	√
WD_5	Challenges in warning dissemination due to language barriers and limited access to local and vulnerable communities.	*	*	√	*
Response capabilities					
RC_1	Lack of institutional capabilities in flood preparedness and response activities at the local level.	-	-	-	√
RC_2	Lack of flood risk disaster preparedness and response plans at the local level.	√	*	*	*
RC_3	Lack of frameworks in ensuring stakeholder cooperation in flood response activities.	√	*	*	*
RC_4	Limited legal frameworks for ensuring institutional responsibility to stakeholder coordination for preparedness and response.	√	*	*	*
RC_5	Lack of local community evacuation centres and limited resources for flood response.	√	-	*	*
No. of primary social injustice narratives		8	3	1	9
No. of secondary social injustice narratives		9	7	9	11

√Primary social injustice narrative.

*Secondary social injustice narrative.

-Not applicable.

5.3.3 Procedural injustice in barriers to FEWS governance

Participatory injustice in FEWS governance manifests through the exclusion of key actors from participation in FEWS governance processes, largely due to weak stakeholder coordination across multiple levels of governance and sectors, and the absence of legally mandated frameworks to ensure cross-stakeholder coordination for preparedness and response. The lack of coordinated and institutional mandates to ensure stakeholder coordination also increases the possibility of unequal recognition and acknowledgement of diverse social groups, their unique vulnerabilities, rights, and identities, which ultimately undermines their ability to prepare, respond, and recover from flood events (*recognition injustice*) (Okunola, 2024; Mugari et al., 2025). While the provision of feedback enhances the planning and implementation of risk mitigation strategies, this study observed that a key barrier to warning dissemination, creating procedural injustice, is the lack of channels for institutions to receive feedback on warnings issued. Here, the procedural injustice limits the extent to which end users of early warnings participate in the process of enhancing the accuracy of risk communication, fostering positive relationships between warning issuers and end users, and promoting impact-based risk communication. As shown in Table 2, this injustice creates additional injustices. In Uzbekistan, we observed that the lack of feedback mechanisms limits the ability of institutions to recognize critical actors and their needs (*recognition*), verify the impact of warnings and provide vulnerable communities the opportunity to utilize their capabilities (*capability*), as well as provide needed resources for addressing disruptions (*distributive*) (UNDRR, 2024). Addressing such injustices may require appropriate portals and platforms and the capacity-building of diverse actors to provide reliable feedback (Aboagye and Sharifi, 2026). Effective feedback can also enhance trust among stakeholders at various governance scales and address barrier 3 in the dissemination of warnings.

5.3.4 Recognition injustice in barriers to FEWS governance

The results show that most of the dominant barriers are not primarily underpinned by recognition injustice, compared with procedural, capability, and distributive injustices. Nevertheless, evidence on the reinforcing nature of capability and distributive injustices on recognition injustice cannot be overemphasized. As can be observed in Table 2, RC_5, which primarily presents a distributive injustice narrative, is reinforced by recognition injustice in FEWS governance. This situation may happen when the diverse flood response and evacuation needs of marginalized communities are not accounted for in FEWS decision-making processes (*recognition*). Such unequal recognition may lead to the failure in the provision of necessary flood response resources and infrastructure to meet the diverse needs of marginalized local communities. In warning dissemination, WD_5 is mainly observed as a recognition injustice, where failure to recognise and include different languages in warning communication has created a barrier for institutions to disseminate warnings efficiently and for vulnerable communities to access them. A typical example of this injustice is reported in Nepal, where flood warnings issued by national units are communicated in Nepali, while most affected villages speak either Maithili, Tharu, or Sonaha languages (Shrestha et al., 2021; Pham et al., 2024). In Bangladesh, evidence shows that warnings are sometimes disseminated in the national language, which many people in remote areas cannot understand due to regional dialect differences (Hasan and Islam, 2024). In effect, the recognition injustice underlying

WD_5 will increase the vulnerability of communities by limiting their ability to interpret and act on warnings due to the language barriers, participate in ongoing flood response activities, and access resources to protect themselves from future flood events.

The findings in Table 2 indicate multiple associations between the primary and secondary social injustice dimensions across FEWS components, further underscoring the need to consider social injustice in the system's governance as a broader phenomenon that creates or reinforces each other (de Herve, 2022).

5.4 Share of dominant barriers and underlying primary social injustices across FEWS components

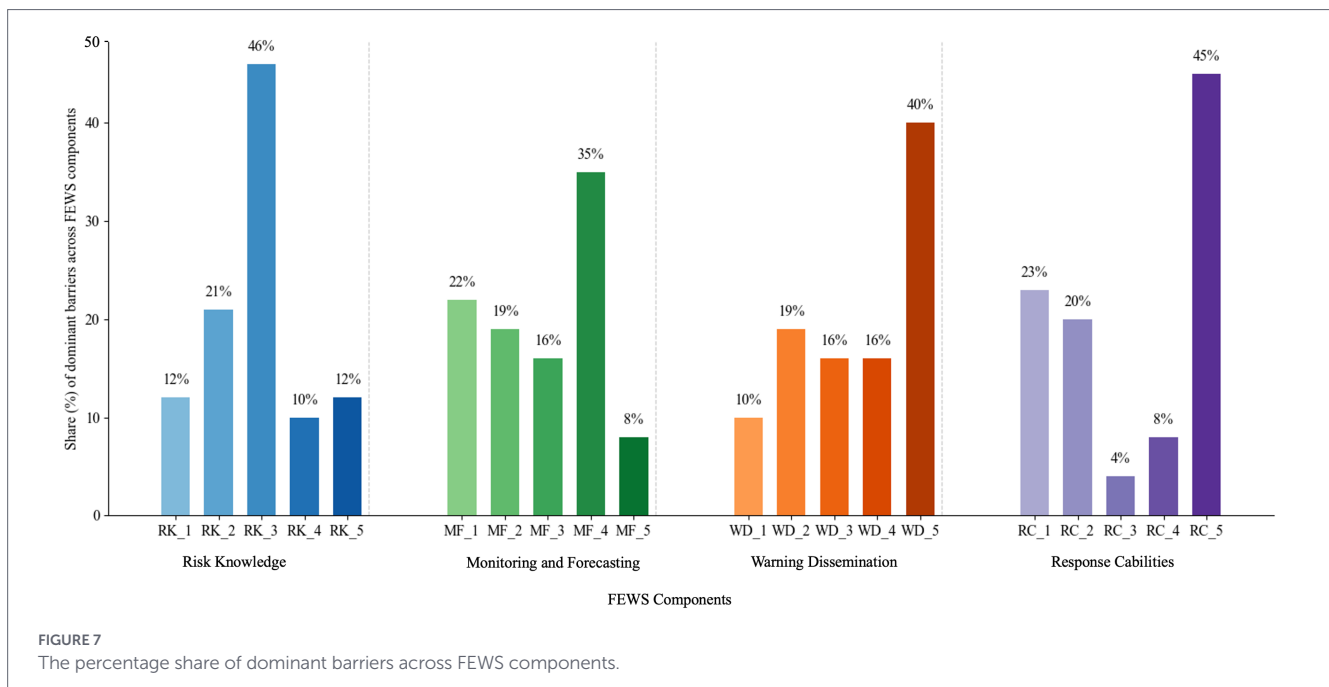
In this section, we present results on the percentage share of each dominant barrier across each FEWS component, as illustrated in Figure 7. Here, the study utilized the posterior document-topic distribution θ_d and the component categorization of barriers from each document d .

Figure 7 clearly shows that RK_3, which has a *distributive injustice* undertone, accounts for the largest percentage share of barriers to risk knowledge governance. The RK_3 has been identified globally, particularly in developed countries such as Sweden and Japan (Norén et al., 2016; Cao et al., 2024), as well as in developing countries such as Kenya and Uganda (Arinabo, 2023; Juma et al., 2023). Available reports indicate that insecurity and local conflicts may lead to a scarcity of data and information for flood risk assessment, as seen in Afghanistan (Noori and Sherzad, 2020).

Monitoring and forecasting flood risks are crucial in effective FEWS governance. The findings of this study reveal that MF_4 "limited monitoring stations and data availability across local and national institutions for flood forecasting" constitutes the most dominant challenge in monitoring and forecasting governance, accounting for 35% of all major barriers within this component. MF_4 exposes distributive injustice in monitoring and forecasting, and reinforces capability injustices, limiting the ability of institutions to effectively monitor floods. Interestingly, issues related to the capacity to gather data (MF_1), operate (MF_3), and maintain these stations (MF_5) are among the most significant barriers in monitoring and forecasting. These barriers directly highlight capability injustice in flood forecasting and monitoring, as seen in Table 2.

Evidently, these barriers can consistently hinder the implementation of monitoring and forecasting and the overall effectiveness of FEWS. This is because the system is supported by hydro-meteorological stations that are sometimes equipped with telemetry systems to transmit real-time data to a central database for monitoring and modeling (Koutsovili et al., 2023). Inaccurate predictions emanating from data gaps, model limitations, and a lack of technical capacity in monitoring and forecasting can erode trust in warnings among multi-level meteorological agencies and authorities (Serra-Llobet et al., 2013; Acharya and Prakash, 2019), as observed in WD_3. Such a barrier (WD_3) distorts onward institutional cooperation and coordination for warning dissemination (*procedural injustice*).

Response to flood risk is mainly considered a local-level responsibility. Local authorities are responsible for taking critical, life-saving actions, such as preparing and coordinating evacuation activities, and providing emergency relief to support recovery efforts (Begum, 2023). The results of this study reveal that these efforts at the local level may be hindered by various barriers that are consistently reinforced by underlying social injustices. While RC_3 and RC_4 in response capabilities governance and their underlying social injustices are not



exclusive to any particular governance unit, they arguably exert a greater influence on response capabilities at the local level. Ultimately, the analysis indicates that the “lack of local community evacuation centres and limited resources for flood response” (RC_5), which is underpinned by *distributive injustice*, remains the most frequently reported barrier in flood response capabilities globally, accounting for 45% of all dominant barriers (Figure 7).

6 Conclusion and implications

The present study contributes to ongoing discussions on equity issues in FEWS by empirically analyzing dominant barriers in the system's governance and their underlying social injustice dimensions. This study is the first of its kind to use topic modeling to identify dominant governance barriers and employ qualitative content analysis to critically analyse patterns of social injustice within the identified key barriers across the four components of FEWS. The study also examined the distribution of these barriers and their underlying social injustices across the FEWS components.

Five interpretable dominant barriers were identified for each FEWS component. These barriers were derived from topics generated by the LDA model, which was tested with 5, 7, and 10 topics before determining that a 5-topic solution yielded the most meaningful results. A pairwise correlation test of the topics revealed their distinctiveness, despite their high semantic similarity. The proportional contributions of the identified dominant barriers and their underlying social injustice dimensions vary across FEWS components. These dynamics offer critical insights for FEWS policy and governance by highlighting the barriers that contribute significantly to failures in FEWS governance and which should be prioritized for intervention amid the urgent need for effective FRM. It also reveals their underlying social injustices, which may reinforce existing systemic inequities in FEWS operations.

Capability injustice emerges as the leading dimension directly shaping barriers to FEWS governance. This critical dimension reflects systemic inequalities that limit the ability of institutions and communities to develop and utilize the capacities necessary to engage with or benefit from FEWS governance. Distributive injustice also accounted for 40% of the primary social injustice narrative underlying the dominant barriers across the components. Moreover, the findings indicate multiple associations between social injustice dimensions in barriers across FEWS components. These social injustices are interlinked and interrelated, such that recognition injustice (the failure to recognize, respect, and regard social group differences) may lead to distributional injustice (the unfair allocation of FEWS benefits and outcomes) and that there is the need for social injustice to be considered in FEWS policy and governance as a broader phenomenon that creates or reinforces one another (de Herve, 2022). Additionally, capability injustice emerges as a broad, overarching injustice shaped and reinforced by multiple forms of injustice. For instance, a failure to address the unequal distribution of resources to vulnerable communities for flood preparedness (distributive injustice) may limit their ability to respond when floods occur (capability injustice). The same applies when these communities are excluded from FEWS decision-making or when their differentiated needs and social diversity are overlooked in FEWS implementation. This study emphasizes that it will be imperative for decision-makers to prioritize efforts to address barriers with the highest share among all dominant barriers identified. Beyond this, there should be proactive measures to address the remaining barriers across components, as they are interconnected and a failure in one might impede the efficient implementation of the others and, to a larger extent, disrupt the entire system (ICIMOD, 2019). These findings translate into concrete implications for FEWS design and governance, investment priorities, and institutional reform. First, for the monitoring and forecasting component, donor and public investments should explicitly target the empirically identified and worsening constraint of the insufficient numbers of monitoring stations and data availability. There is a need to improve access to data and monitoring stations to

support warnings in vulnerable communities and to ensure adequate flood preparedness and response.

Second, there should also be institutional reforms that address social injustices in access to and the ability to utilize risk knowledge for flood response. Institutions must be supported through capacity building, funding, and infrastructure development to gather and access relevant risk data and translate these data for evidence-based decision-making. Third, institutional reforms that prioritize coordination and cooperation among institutions and stakeholders for warning dissemination and response are critical. Improved collaboration can reduce distributional and capability injustices by ensuring that warnings reach vulnerable populations in usable forms and that response capacities are equitably supported. In practice, these reforms enhance institutional capacity, strengthen trust, and help mitigate the impacts of flood risks, which are disproportionately borne by marginalised communities. The study has a few limitations that are worth noting. The criteria used to source documents for the corpus may introduce selection bias, and the barriers will reflect only evidence from documents that meet the inclusion criteria. This study's approach to document selection yielded a relatively small text corpus compared to studies that employ large datasets. As a result, the five dominant barriers identified may not fully capture the breadth of dominant barriers in FEWS governance. Future studies incorporating larger datasets, such as social media content, may reveal additional interpretable dominant barriers. More importantly, the study extends beyond documenting critical barriers to FEWS governance by highlighting the various dimensions and dynamics of social injustice within the system. It is hoped that these insights will inform the design of standard frameworks that capture the multifaceted nature of social injustice in FEWS governance amid a rapidly evolving society.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author.

Author contributions

PA: Writing – original draft, Software, Visualization, Formal analysis, Data curation, Conceptualization, Project administration, Methodology, Writing – review & editing, Validation, Investigation. SN: Investigation, Conceptualization, Funding acquisition, Resources, Writing – review & editing, Project administration, Supervision, Data curation, Visualization, Validation.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/frwa.2026.1759855/full#supplementary-material>

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