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Research Article

A Three-Decade Bibliometric Mapping of Scholarly Trends in Industrial Disasters Across High-Risk Sectors

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ABSTRACT

Industrial disasters in high-risk sectors such as the petrochemical industry continue to occur, despite significant advancements in process safety and technological controls over the years. This suggests ongoing operational challenges and a lack of consistent academic understanding across both technical and regulatory dimensions. While earlier bibliometric studies have focused on specific thematic areas such as domino effects and risk analysis, a thorough synthesis of the thematic evolution and collaboration structures in industrial disaster research remains limited. To address this gap, this study provides a systematic bibliometric mapping of research focused on industrial disasters, analyzing the themes, impact, and collaboration trends over the past thirty years. The analysis assessed publication trends, co-authorship networks, citation dynamics, bibliographic coupling and keyword co-occurrence through the evaluation of 357 Scopus-indexed publications from 1995 to 2025. The findings indicate a gradual transition from technical risk assessment to more comprehensive integrative perspectives. While domino effects and process safety remain the primary focus of study, recent publication trends demonstrate a growing interest in safety culture and organizational factors. European nations, especially Italy, the Netherlands, and Belgium, have become significant players in global research collaborations, suggesting a wider European focus on industrial safety management and regulatory structures such as the Seveso Directive. Thematic clustering revealed three main themes: technical risk assessment, human and organizational factors, and the environmental and societal impacts of disasters, highlighting a growing integration of technical and socio-regulatory issues. Through a comprehensive longitudinal and network-based synthesis that addresses various themes, this study highlights significant works, overlooked correlations, and new research domains such as resilience-oriented risk governance, establishing a basis for more integrated industrial safety research, policy formulation and organizational risk management strategies.

Keywords: Industrial disaster, high-risk industries, network analysis, bibliometric analysis

INTRODUCTION

Even while industrial disasters are of limited incidence in high-risk industries such as the chemical, and oil and gas industry, despite decades of regulatory advancement and technological improvement. Within the academic discourse, this situation has left a few important unresolved scholarly questions about the boundaries of state-of-the art risk assessment, preparedness, and emergency management strategies. Incidents of industrial disasters in these sectors are of limited occurrence, but once started, their impacts can be catastrophic and sometimes long-lasting. Considerable attention was brought over the Bhopal gas tragedy of 1984, wherein toxic gas resulted in thousands of deaths and a much more over long term suffering; a recent drilling accident near Brazil of Chevron Company in 2011 involving offshore operation and environmental damage; an explosion at one port of Beirut in 2020 which

killed a great amount of citizens at proximity was provoked by ammonium nitrate left unpacked and untreated in a dangerous container resulting in environmental disasters and major damage. Whereas the examples, including nuclear, offshore, and dangerous packing at port facilities, could be considered over a totally different background as nuclear and offshore safety regulations and protocols might differ greatly, and port safety rules will be completely over another paradigm from these, the cases have one single aspect in common to show that all process-based high-risk industries will be facing one common vulnerability. The problem is more insidious, though. Disasters are generally caused by a complex interplay of technical failures, safety management failures, and organizational or cultural problems, yet studies tend to look at them separately [1], [2]. Engineering may concentrate on technical reliability and physical processes of control, whereas safety management of organizational studies examines safety culture control and organisational/cultural/safety problems that lead to organizational failure without really appreciating the technical factors that exist and cause their interaction to lead to industrial disaster escalation. Understanding the way in which the technical and the organizational factors of fragmentation in industrial plants influence industrial disaster escalation is greatly impeded by this fragmentation. There is tremendous scope for improving disaster management as regards risk assessment and technology, but culture and organizational aspects are two main culprits in high-risk industries, which need to be addressed with seriousness since they are the actual underlying problems with high risks involved. Risks in today's world with high-tech installations are multidimensional, and management should be adept at dealing with multidimensional risks more than any other issue to carry out proper responses against risks.

Despite the growing body of literature on industrial disasters and safety in high-risk industries, existing bibliometric studies have largely focused on specific themes or sectors, or limited time periods, leaving a comprehensive bibliometric analysis that systematically maps the evolution of research across high-risk industries over time insufficiently addressed. Previous bibliometric studies have investigated specific phenomena within the process industry, such as the global distribution of domino effect research [3] and the textual analysis of multi-risk scenarios involving cascading events [4]. Similarly, other reviews have mapped the geographic evolution, prominent authors, and citation trends specifically within the sub-field of process safety and risk analysis [5]. While these studies have provided valuable insights into their respective domains, their scope remains largely confined to specific process safety themes and does not offer a comprehensive synthesis of industrial disaster research across multiple high-risk sectors. As a result, thematic evolution, geographic influence, collaboration structures, and intellectual linkages across the wider field of industrial disaster research have received comparatively limited bibliometric attention. This limitation constrains a broader understanding of how industrial disaster research has evolved across technical, organizational, environmental, and governance-related dimensions, as well as how these domains interact within the wider research landscape. The analyses provide an overview of the 30 years research landscape from 1995 to 2025 regarding geographic distributions, research focus, key contributors, and publication trends. The results will enable in identifying the long-term shifts, recent inflection points, and emerging themes, particularly those that reflect current research directions in this field. Using the Scopus database and visualized through the VOSviewer tool, the analysis explores research trends, geographical distribution, institutional collaboration, and thematic clusters. By identifying leading countries, journals, and research themes, this study aims to provide a structured understanding of the field's evolution, supporting future research and proactive risk management strategies for policymakers, industry practitioners, and scholars.

The severe consequences of industrial disasters in high-risk industries, affecting human life, environmental sustainability, and economic stability, underscore the need for a deeper analytical understanding to inform more effective prevention and safety management strategies [6], [7], [8]. Industries such as chemical manufacturing and petrochemical are particularly vulnerable due to handling toxic, flammable, and reactive substances. The catastrophic consequences of industrial failures, which frequently arise from systemic deficiencies in risk assessment,

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safety protocols, and regulatory compliance, are exemplified by historical incidents. For instance, the Bhopal Gas Tragedy of 1984 was caused by poor maintenance and inadequate safety systems, resulting in the catastrophic release of toxic methyl isocyanate gas. The Chernobyl Nuclear Disaster of 1986 resulted from design flaws and operator errors during a safety test, revealing significant weaknesses in safety culture and regulatory oversight. The Deepwater Horizon oil spill in 2010 resulted from a combination of technical failures and poor decision-making influenced by time and cost constraints [9]. The explosion at Tianjin Port in 2015 resulted from the illegal storage of hazardous chemicals nearby, violating safety regulations [10], [11]. In the case of the Beirut Port explosion in 2020, the incident was caused by the prolonged and improper storage of ammonium nitrate, underscoring significant governance shortcomings [12]. Although technical failures are frequently emphasized, contemporary safety science has increasingly underscored the critical role of organizational culture and management practices in accident prevention, highlighting the necessity of a comprehensive risk management strategy [13], [14], [15]. Understanding these factors is crucial for developing effective risk mitigation strategies that ensure industrial safety and resilience.

Technical failures remain one of the significant factors in industrial disasters, with design flaws and inadequate process safety management (PSM) substantially contributing to catastrophic failures [16], yet existing research has not fully mapped how these technical dimensions are connected to broader organizational and cultural factors across the literature. Some shortcomings in PSM that contribute to these failures include inadequate hazard identification and risk controls, management engagement and employee participation, poor incident response and learning, and insufficient leadership [17]. The likelihood of accidents is particularly high in the chemical and petroleum industries, where inadequate hazard assessment, poor maintenance practices, and non-compliance with safety standards are prevalent [14]. Moreover, industrial disaster risks are further intensified by the absence of redundancy in safety-critical systems and the failure to account for unforeseen operational conditions. Beyond technical issues, organizational culture and safety management practices significantly influence accident prevention. Numerous industrial disasters have been attributed to a poor safety culture, characterized by a lack of proactive hazard identification, poor communication, and negligence in adhering to safety protocols [11], [12]. Additionally, the accumulation of risks is frequently the result of ineffective safety barrier management, which renders organizations insensitive to potential hazards and increases vulnerability to major accidents [18], [19]. Research has shown that organizations that prioritize safety, encourage employee engagement in safety initiatives, and implement structured safety training programs exhibit increased resilience in emergencies and lower accident rates [20].

The impacts of industrial disasters are not limited to the immediate workplace; they frequently result in hazardous releases that cause long-term health effects and environmental degradation that can persist for years [21], [22], [23], [24], and mapping research trends through bibliometric analysis can help identify how these long-term impacts have been addressed over time and where research gaps remain. Although industrial disasters accounted for approximately one-fifth of reported technological accidents, they affected over 1.4 million people between 2000 and 2019. A notable example is the explosion in 2020 at the Port of Beirut, where a large quantity of improperly stored ammonium nitrate detonated, which caused 220 deaths and affected more than 300,000 people. This gruesome event further fuelled existing social unrest and economic decline, escalating the risk of a broader humanitarian crisis. This case is among the many cases that highlight that even though industrial disasters rarely happen, their impacts are often immense, deeply unsettling, and enduring.

Industrial accidents frequently involve the release of toxic chemicals, radioactive materials, or flammable substances, contaminating air, water, and soil. For instance, the Bhopal Gas Tragedy that occurred due to the leakage of Methyl Isocyanate (MIC) resulted in pervasive toxic exposure, resulting in thousands of fatalities and severe long-term health complications among survivors. Exposure to hazardous substances during and after disasters can result in both acute and chronic health conditions, including respiratory diseases, cancers, and long-term mental health disorders [22], [23]. In the case of Bhopal, about 45 tons of the dangerous MIC escaped into the surrounding area.

The final death toll was estimated to be between 15,000 and 20,000, while around half a million survivors experienced multiple health effects. Beyond physical health, affected communities frequently experience psychosocial distress, especially when their health concerns are ignored by authorities, resulting in increased anxiety, depression, and a lower quality of life [22]. The environmental consequences are equally devastating, as industrial accidents frequently cause soil and water contamination, making land unsuitable for agriculture and contaminating vital drinking water supplies [25]. Moreover, ecosystem disruption caused by chemical spills and hazardous emissions can result in biodiversity loss, threatening local flora and fauna and significantly impacting livelihoods that rely on natural resources. The proximity of hazardous facilities to vulnerable communities exacerbates the societal risks associated with industrial activities, thereby increasing their exposure to industrial pollutants and disasters [26]. A combination of environmental monitoring, risk-informed urban planning, and community preparedness is necessary to mitigate these risks. In addition, industries must invest in resilient emergency response frameworks, including real-time monitoring systems and rapid containment strategies, to minimize the broader consequences of industrial accidents [27], [28], [29], [30].

A strong safety management system (SMS) is a critical component of industrial disaster prevention. SMS is defined in various ways across different perspectives. However, it consistently encompasses three fundamental components [31]. The term "safety" refers to mitigating adverse events such as accidents, while "management" emphasizes the organizational mechanisms and control measures implemented to address the underlying causes of such events. The "system" component refers to a structured and systematic framework through which safety objectives are achieved. Briefly, SMS represents an organized set of management principles and processes aimed at identifying, controlling, and minimizing risks to prevent accidents effectively [31]. It has been demonstrated that industries that implement structured risk control frameworks, such as ISO 45001, and process safety management guidelines, experience significantly reduced accident rates [32]. Besides, organizations that successfully adopt OHSAS 18001 demonstrate improved hazard control, regulatory compliance, and safety culture, though challenges such as bureaucracy, insufficient training, and tokenistic adoption remain barriers to sustained improvement [33], [34]. Risk reduction is significantly influenced by the safety culture of an organization, as workplaces that prioritize proactive safety reporting, hazard identification, and continuous improvement exhibit superior safety outcomes [35], [36]. Research on near-miss management systems indicates that workplace safety can be improved by incorporating lessons from minor incidents before they escalate into major disasters [37], [38]. Furthermore, an organization's capacity to mitigate risks and adhere to safety standards is significantly influenced by regulatory enforcement, worker training programs, and management commitment to safety [39], [40]. Case studies have shown that companies that conduct regular safety audits, have defined emergency response protocols, and involve employees in safety decision-making have improved operational safety and stronger disaster resilience [41].

Based on the aforementioned discussions on the causes and consequences of industrial disasters, it is evident that ensuring safety in high-risk industries requires a multifaceted approach that integrates technical safeguards, organizational safety culture, and robust regulatory frameworks, yet existing bibliometric studies have not comprehensively mapped how these dimensions have been explored and connected across the literature. Although earlier bibliometric studies have provided valuable insights into narrow thematic areas, such as domino effects or isolated risk analyses [3-5], a broader synthesis integrating thematic evolution and collaboration structures across the entirety of industrial disaster research remains limited. This specific fragmentation in the prior literature constrains our comprehension of macroscopic research trends, central collaborative networks, and critical gaps at the intersection of engineering and safety governance. By expanding beyond the scope of these specialized prior studies, the present study addresses this overarching gap through a multidimensional mapping approach. Given the increasing complexity of industrial operations and the growing reliance on hazardous materials, a comprehensive bibliometric analysis of research trends in industrial disasters is necessary to identify key areas of focus, influential

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studies, and emerging patterns in safety research. As such, the following objectives for the present bibliometric review are presented:

1. To determine the most influential publications and citation trends related to industrial disasters in high-risk industries with emphasis on sector-specific differences between the chemical and oil and gas industries.
2. To evaluate the geographic contributions and international collaboration patterns among highly published and cited studies through citation analysis.
3. To map the evolution of industrial accidents research by identifying linkage among central articles over time through bibliographic coupling analysis, highlighting shifts in research focus across decades.

To investigate emerging themes and identify potential future research trajectories in industrial accidents using co-occurrence analysis with specific attention to recent trends in the last five years.

METHODS

Search Strategy and Data Collection

The search string demonstrated in Table 1 was used in the "advanced search" option of Scopus to identify relevant literature related to 'industrial disaster', 'major accident', 'petrochemical plant', and 'high-risk industries' based on the title, abstract, and keywords. The Scopus database was selected for its broad multidisciplinary coverage and comprehensive indexing of peer-reviewed journals, making it appropriate for large-scale bibliometric analysis of industrial disaster literature. The Scopus database search was conducted on February 10, 2025, and the retrieved records reflected the database coverage available at the time of analysis and manuscript preparation. Hence, publications after this date were excluded, and the 2025 data should be considered as preliminary, given the incomplete coverage of the ongoing calendar year. The search strategy used Boolean operators to combine generic disaster-related terms (e.g., 'industrial disaster', 'major accident') with sectoral and risk-focused keywords (e.g., petrochemical plant, high-risk industry). This structure was set up to prioritize literature on major industrial hazards and process safety commonly reported in chemical and petrochemical operations. Although the term 'high-risk industries' might cover wider sectors, the operational search boundary of this study was intentionally focused on process-industry literature to ensure thematic consistency and relevance to industrial disaster research. The data source was limited to publications from 1995-2025, to provide a balanced 30-year longitudinal perspective on the evolution of industrial disaster research, with research and review articles as the primary sources. The mid-1990s demonstrate a transitional period in safety science, with increasing use of systematic risk assessment methods, process safety management approaches, and greater international attention to industrial safety and major hazards. The starting period was set to 1995 to ensure sufficient historical coverage and adequate publication volume for appropriate bibliometric analysis. Regulatory developments such as the Seveso II Directive were considered part of the broader shift of modern industrial safety management and not as the only reason in deciding the time boundary. Besides, books and book chapters were excluded to ensure consistency in bibliometric indicators and metadata as peer-reviewed journal articles have standardized citation structures. However, this limitation may have restricted the inclusion of some conceptual or foundational discussions, particularly in the earlier stages of industrial disaster research, when some theoretical developments were published mainly in books or edited volumes.

The initial Scopus search using the final search query (Table 1) resulted in 626 records. The database was then filtered directly in the Scopus system by limiting the publication period to 1995–2025, resulting in 507 records. Additional restrictions were then applied, as outlined in Table 2, limiting the dataset to English-language documents and document types comprising journal articles, reviews, and conference papers. After applying these predefined database filters, the final dataset consisted of 357 publications. No further manual relevance screening was performed, as all filtering procedures were applied using the Scopus database criteria.

Table 1. Search string in Scopus database

Keywords		Justification
Disaster-related terms	"industrial disaster*" OR "industrial accident*" OR "industrial emergency" OR "industrial emergencies" OR "major accident*" OR "major incident*"	To identify literature on industrial disaster or major accident
Industry-related terms	"chemical plant*" OR "chemical industry" OR "chemical industries" OR "petrochemical plant*" OR "petrochemical industry" OR "petrochemical industries" OR "high-risk industry" OR "high risk industries" OR "high-risk industries" OR "high risk industry"	To identify literature on high-risk industries exhibiting major accidents
Final Scopus query	TITLE-ABS-KEY (("industrial disaster*" OR "industrial accident*" OR "industrial emergency" OR "industrial emergencies" OR "major accident*" OR "major incident*") AND ("chemical plant*" OR "chemical industry" OR "chemical industries" OR "petrochemical plant*" OR "petrochemical industry" OR "petrochemical industries" OR "high-risk industr*" OR "high risk industr*"))	To integrate disaster-related and industry-related terms such that retrieved publications directly address industrial disasters in high-risk sectors.

Table 2. Limitation for data mining from the Scopus database

Options	Limits applied
Types of documents	Articles, Review, Conference paper and proceeding
Language	English
Source type	Journals and Conference proceeding

Bibliometric Analysis

Following article selection, the metadata were exported from Scopus in comma-separated values (CSV) format for analysis. The bibliometric analysis was conducted by VOSviewer (version 1.6.20), a specialized software for establishing and visualizing bibliometric networks. The selected dataset was analyzed through multiple approaches:

i. Citation analysis: evaluate the most influential articles in a given field [42]. This analysis relies on the argument that citation is an effective and reliable measure to assess the influence of publications or authors in a particular field [43]. Raw total citation counts extracted from the Scopus database were used as the primary metric for ranking articles and countries according to their cumulative citation frequency. No time-normalized citation indicators were applied. These metrics enabled ranking of publications and aggregation of citation performance at the country level to assess research influence within the field. The country assignment rule is based on the first author's country attribution. Therefore, for multi-country publications, citation counts were assigned based on the first author's country of affiliation.

ii. Bibliographic coupling: explore a research field's current and recent development [44]. The fundamental principle in bibliographic coupling is that when two publications share similar references (citing documents), they share similar themes [45], providing an overview of the current research front [46]. Network visualization was generated using the Association Strength normalization method with the default layout parameters in VOSviewer (attraction = 2; repulsion = 1). Several citation thresholds ranging from 35 to 45 citations were evaluated to optimize network clarity and thematic interpretability. After several trials, a minimum threshold of 39 citations was finalized, resulting in 57 documents being included in the final coupling network. It is crucial to ensure that the minimum citation is neither too high, causing overfiltering, nor too low, causing underfiltering. The former leads to missing crucial documents, and the latter leads to cluster redundancy in the network.

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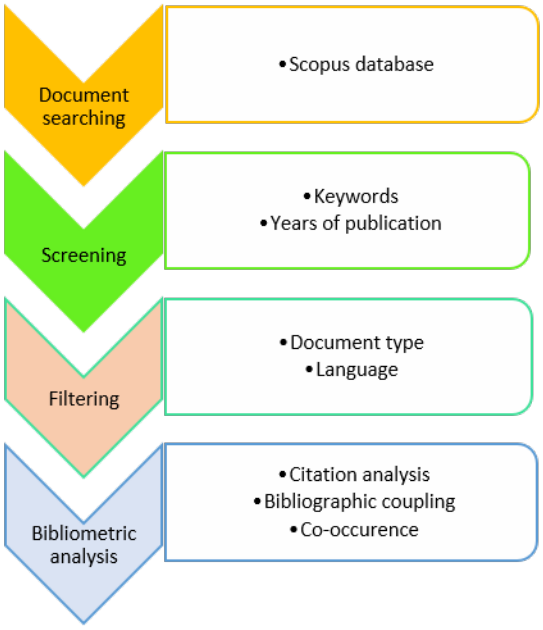

Figure 1. The process flow illustrates the research analysis in this study

iii. Keyword co-occurrence analysis: connects the concept that co-occurs based on words within the document titles, keywords or abstract [47]. In this work, full counting was applied, with a minimum occurrence threshold of 12 to facilitate significant cluster formation and prevent excessive fragmentation of the network. However, full counting may amplify terms that are frequently repeated and those associated with rich keyword fields of the documents, which may affect the cluster prominence. Thus, cluster size and prominence should be interpreted with caution, as these may reflect counting effects rather than purely substantive importance. Co-occurrence analysis assumes keywords that appear together frequently create a thematic relationship. This analysis can be used to predict future research in the field by applying notable "words" from the publication's implications and future directions. The association between the keywords enables researchers in determining the emerging subject to chart future research paths [44].

The primary analytical approach was citation analysis, including geographic distribution and collaboration network. Figure 1 summarizes the workflow of data collection, screening, and bibliometric analysis. The bibliometric methods used in this study are based on the established methodological practices. The methodological contribution lies in the integrated application of these methods on a 30-year dataset covering various high-risk industrial sectors. This study applied bibliographic coupling, citation analysis and keyword co-occurrence mapping into a single analytical framework, forming a longitudinal and network-based synthesis of industrial disaster research that has not been extensively explored in the previous bibliometric reviews.

RESULTS AND DISCUSSION

Publication Trends and Descriptive Analysis

Figure 2 shows the distinct developmental phases of the research on industrial accidents in high-risk industries from 1995 to 2025, reflecting changes in safety science paradigms and regulatory focus. The graph shows the total number of citations across all documents from 1995 to 2025. During the initial period (1995–2005), fewer than 10 manuscripts were published annually, suggesting that the field was still in its early stages of development. The number of articles increased significantly between 2006 and 2015, implying a paradigm shift from human-centered errors

([48], [49], [50]) to systemic Process Safety Management (PSM) ([51], [52]). This trend could be interpreted as a result of increased regulatory and academic interest following major industrial disasters such as BP Texas City incident in 2005 and Deepwater Horizon tragedy in 2010. These incidents have been a recurring topic in subsequent research associated with accident investigation frameworks, process safety management and organizational learning, highlighting their significant influence on industrial safety field [52-54]. In 2018 and 2019, publication activity increased significantly, peaking at 19 articles. The topic area distribution shown in Figure 3, along with the wider range of journal representation in engineering ([55],[56]), safety management ([57], [58]) and organizational studies ([59], [60], [61]), indicate that these publications encompass various research approaches.

Rather than direct measures of research quality or impact, citation trends provide additional insights into the field's scholarly impact. Citation counts between 1995 and 2010 were relatively low, which is typical for a developing field. However, starting in 2011, the number of citations rose steadily, with a significant increase from 2017 to 2024. The peak was recorded in 2022 and 2024, with over 700 citations, demonstrating its growing significance, impact and development of the study. This highlights that work from previous years has received significant recognition, enhancing both scholarly discussions and practical applications. It is important to note that the decrease in citations

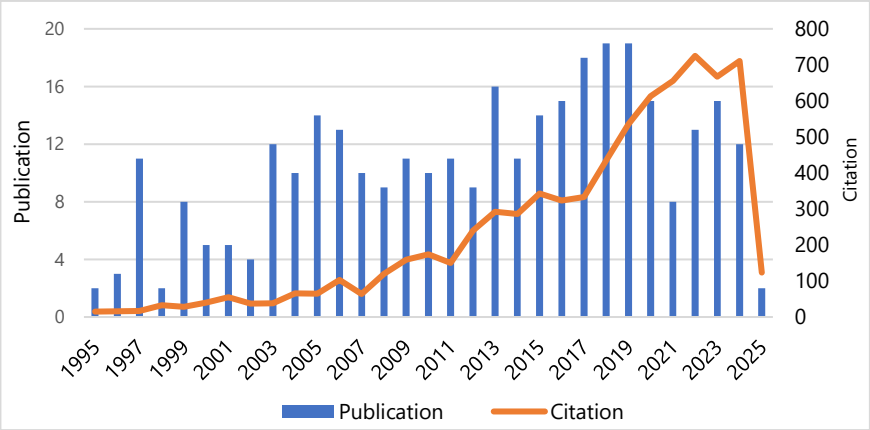

Figure 2. Number of publications and citations between 1995 and 2025
(Scopus database, February 2025)

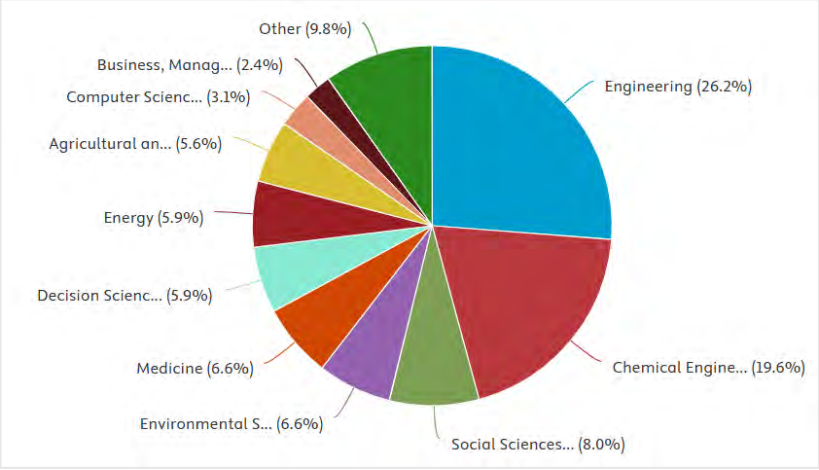

Figure 3. Publication distribution from 2016 to 2021 across various subject areas
(Source: Scopus database)

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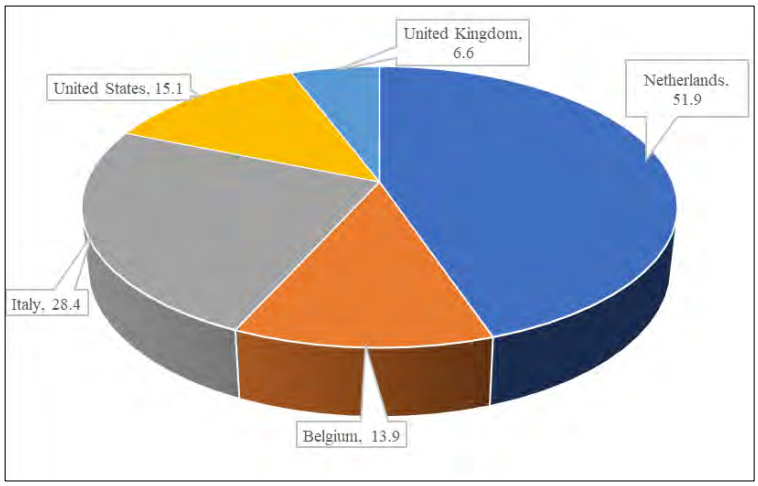
in 2025 should be interpreted with caution, as the current year's articles have not yet accumulated significant references. Moreover, it is noteworthy that interpretations based on citations are significantly influenced by the dynamics of time-dependent accumulation, disciplinary citation norms, and the potential for self-citation.

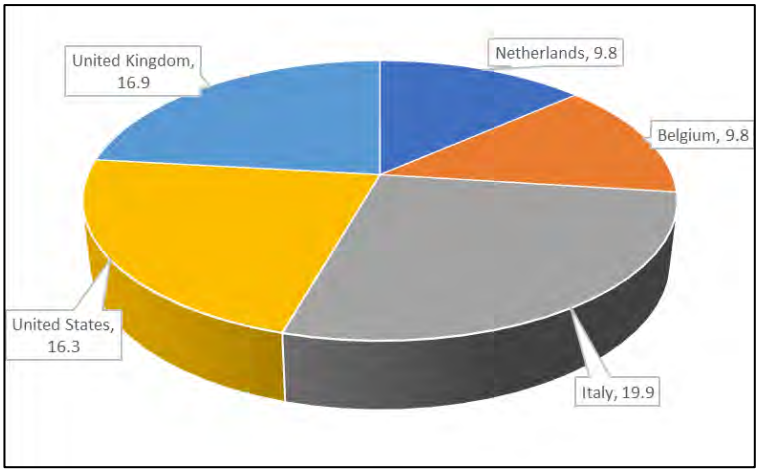
Citation Analysis

Geographic Distributions

The citation analysis was conducted to identify the key contributors, distribution and influence of scientific articles across different regions. As illustrated in Figure 4, Italy leads in the research field, accounting for 19.9% of publications and demonstrating strong collaborative engagement, as indicated by high citation counts (2117) and total link strength (TLS) values (2727) (Table 3). Italy's strong research presence may also reflect broader European investments in industrial safety research and regulatory initiatives. For instance, several European Commission-supported projects and safety frameworks related to Seveso Directive, which was developed after the Seveso chemical disaster (1976) [62-64]. The United Kingdom and the United States, which contributed 16.9% and 16.3%, respectively, also play significant roles in the global collaboration network attributed by their advanced research



a. Publications by Country



b. Citation from the top five countries

Figure 4. Geographical distribution and citations of publications from the top five countries (Scopus, Feb 2025)

Table 3. Top 10 countries with the most publications and citations

Country	Publication	Citation	Total link strength
Italy	65	2117	2727
United Kingdom	55	494	487
United States	53	1129	931
Netherlands	32	1003	3873
Belgium	32	1034	3602
China	29	272	1410
India	21	1222	647
France	16	438	420
Norway	15	533	1364
Malaysia	14	263	1055

(Source: Scopus database, February 2025)

infrastructure, historical industrial developments and strong regulatory frameworks. As contextual background for the publication trends, it is important to acknowledge the significant influence of organizations such as the Chemical Safety and Hazard Investigation Board (CSB) and the Occupational Safety and Health Administration (OSHA) on research initiatives and safety policies. Although these institutions do not emerge as key terms in the bibliometric dataset, their investigation reports and regulatory frameworks serve as significant catalysts for the US-based research identified in this study (which accounts for 16.3% of publications).

The analysis of bibliometric indicators in Table 3 reveals a distinction between research output and scholarly influence. Despite having a moderate number of publications (32 each), the Netherlands (TLS: 3873) and Belgium (TLS: 3602) demonstrate the strongest connectivity in the global network. Their high TLS relative to moderate productivity indicates that their research is highly collaborative and integrated into international safety networks, likely influenced by their involvement in the Seveso regulatory frameworks. In contrast, a significant number of publications accompanied by a lower TLS/Citation ratio, as observed in the United Kingdom, might suggest an emphasis on localized industrial studies. Thus, TLS serves as a critical indicator of a country's intellectual integration and collaborative influence, whereas publication counts mainly reflect individual research capacity.

Collaboration Network of Countries

Using a similar citation analysis, global collaboration networks were analyzed and visualized in Figure 5. Notably, the Netherlands leads with 3873 total link strength and 32 publications, showing strong collaborations with Italy and the United States. Belgium follows with 32 publications and 3602 total link strengths. Italy ranks third, with 65 publications and a total link strength of 2727. China and Norway are in fourth and fifth positions, respectively. Although they have fewer documents, their international cooperation shows many links, as listed in Table 3.

The findings provide valuable context for the growing trend of research focused on disasters, emphasising the role of international collaborations and shared resources in fostering academic interest. The strong collaborative integration within the global research network is empirically evidenced by the high Total Link Strength (TLS) of countries such as the Netherlands (3873), Belgium (3602) and Italy (2727) (as shown in Table 3). The collaboration map also reveals that these countries hold central positions within the network and maintain extensive cross-national linkages, suggesting their role as important hubs for knowledge exchange and research coordination in industrial disaster studies. Furthermore, the strong collaboration among European nations could be associated with rigorous

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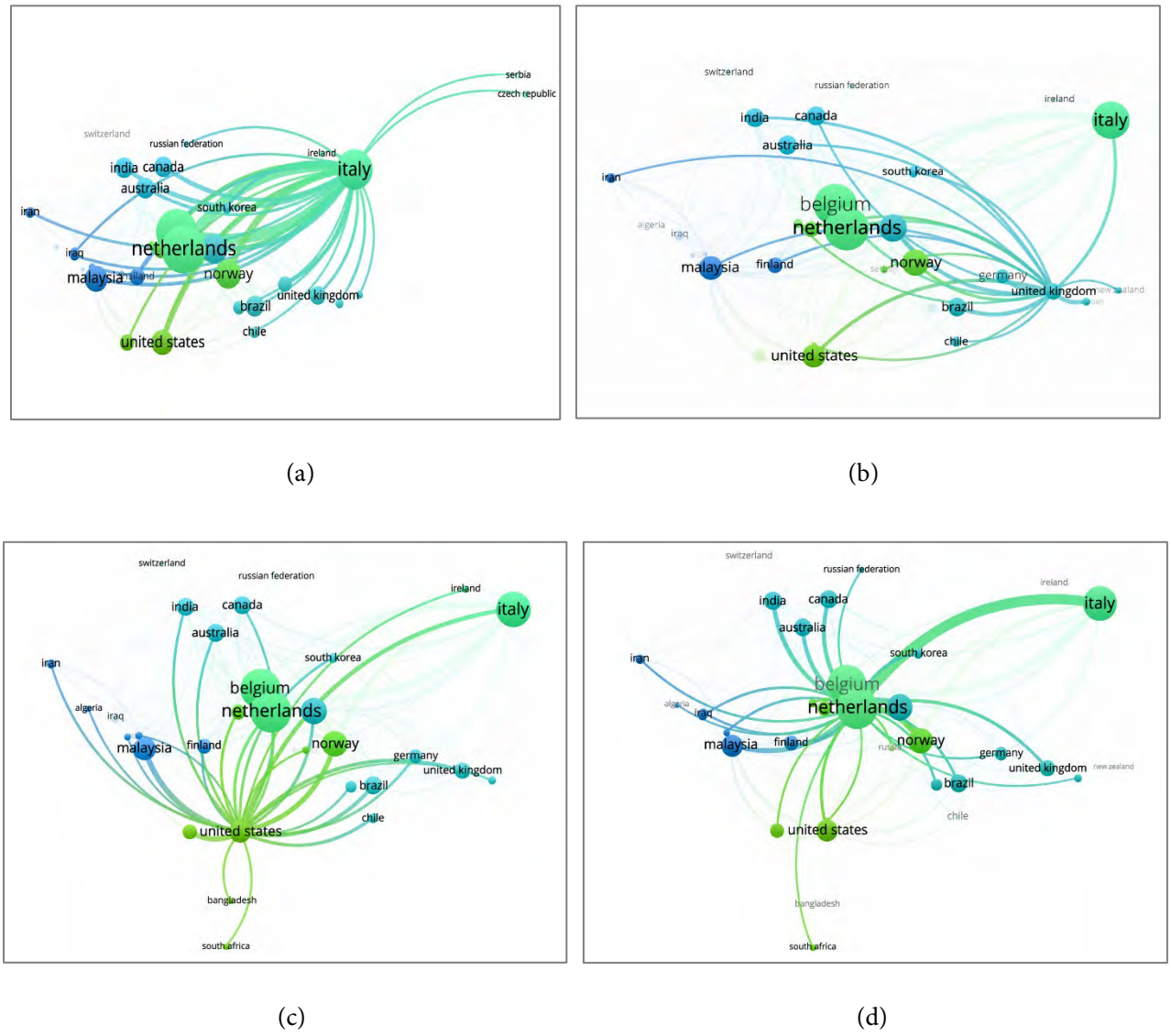

Figure 5. Global collaboration networks, (a) Italy's network, (b) the United Kingdom's network, (c) the United States network and (d) the Netherlands' network
(Sources: Scopus database, VOSviewer version 1.6.20, February 2025)

regulatory frameworks and funding programs established by the EU, which prioritise industrial safety and resilience against disasters. This collaboration network plays a significant role in enhancing knowledge exchange and increasing the visibility and impact of disaster research globally. Consequently, publication volume and citation trends have risen significantly over the past decade.

Bibliographic Coupling

The first step in this analysis is to determine the citation threshold to produce the most appropriate and robust network visualization. From the 357 documents, 57 met the threshold of 39 citations. This threshold was selected through a sensitivity check to ensure the inclusion of the most impactful works while maintaining a manageable, interpretable network density. The threshold must be adequate, not too high, causing over-filtering and excluding recent high-impact publications that are essential to the current research landscape, or too low, causing under-filtering. Table 4 presents the top 10 publications by total link strength (TLS). The top 3 documents based on TLS are Swuste et al. [65](58 TLS), Li et al. [3](40 TLS) and Khan [66] (32 TLS). Notably, these high TLS counts can be

Table 4. Top 10 documents in bibliographic coupling analysis

No	Author	Journal	Scope	Citation	TLS
1.	[65]	Process Safety and Environmental Protection	Internal and external domino effects in the chemical and petrochemical sectors	65	58
2.	[3]	Journal of Loss Prevention in the Process Industries	Domino effects in the chemical industry	72	40
3.	[66]	Journal of Loss Prevention in the Process Industries	Domino effect in chemical process industries, highlighting chain reactions from accidents in one unit to another.	56	32
4.	[69]	Journal of Hazardous Materials	Domino effect in chemical and process industries, highlighting its catastrophic potential	349	27
5.	[70]	Reliability Engineering and System Safety	Vulnerability in chemical facilities to external attacks, particularly through a quantitative probabilistic approach using Bayesian	65	26
6.	[71]	Process Safety and Environmental Protection	Security of chemical and process facilities against external attacks	50	26
7.	[72]	Safety Science	Emergency response planning for major accidents in chemical clusters, enhancing public and worker safety	63	23
8.	[73]	Journal of Loss Prevention in the Process Industries	Development of a software procedure for assessing the domino effect in industrial risk	125	23
9.	[74]	Journal of Loss Prevention in the Process Industries	Process safety education, focusing on teaching methodologies and testing approaches	60	22
10.	[75]	Journal of Hazardous Materials	Prevention of domino accidents in chemical and process plants through inherent safety approaches	132	22

attributed to its fundamental contribution to accident causation theory, particularly its application of the Domino Theory, which is still one of the most impactful frameworks in the safety science literature. However, the continuing impact of these fundamental models is driven by their integration into modern research areas that emphasize dynamic and systemic risk management. This transition is demonstrated in recent studies ([67], [68]) which enhance basic principles with methodological innovations, enabling established frameworks to remain relevant to the current complexities of industrial resilience.

Figure 6 presents a network visualization of bibliographic coupling. There are four visible clusters (red, green, blue, and yellow), while the other clusters can be neglected due to insufficient thematic cluster formation. The clusters are labeled based on inductive interpretation by examining highly connected publications within each cluster and synthesizing shared themes and dominant research streams reflected in the representative articles. Cluster themes were interpreted by examining overlapping citation relationships and shared conceptual foundations among representative publications with high node prominence within the bibliographic coupling map. For instance, the strong bibliographic linkage between studies in red cluster examining the causes and consequences of major accidents in process industries [76] and domino accidental events [69] reflects a shared emphasis on industrial accident propagation and consequence assessment. Similarly, research on emergency response planning for major accidents in chemical industrial areas [67] contributed to the same thematic structure. The convergence of these

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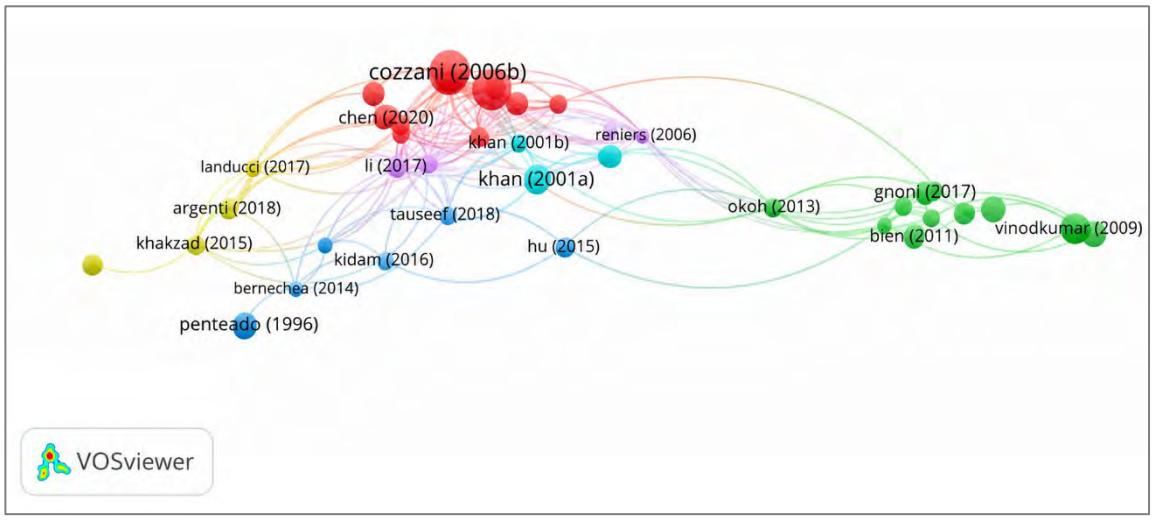

Figure 6. Visualization of networks based on bibliographic coupling
(Source: Researcher findings)

publications within the same network cluster supports the thematic interpretation of the cluster as representing industrial accident management research. The green cluster illustrates the importance of human factors, organizational safety culture and management practices in the context of accident prevention. This cluster serves as a conceptual link connecting technical safety indicators with management practices. Research on leading safety indicators [77] occupies a highly central position, emphasizing their function in connecting the communication effectiveness and managerial commitment to proactive safety outputs. The bibliometric patterns identified within this cluster demonstrate a significant co-occurrence between 'systemic weaknesses' and 'organizational failures' [78], suggesting that maintenance planning and interdepartmental communication are often addressed together in relation to industrial accident causation and organizational risk management. Besides, the Texas City Refinery case study is a significant example demonstrating how deficiencies in safety culture often serve as a common failure point that connects technical failures with human and organizational errors throughout the network.

In addition, the blue cluster comprises of research focusing on methodologies for process safety and risk assessment. It emphasises the development of comprehensive approaches for identifying and mitigating hazards in complex industrial systems. For instance, Kidam et al. [79] propose a framework for reviewing an accident-based inherently safer design (ISD), utilizing insights from actual accidents to identify common design flaws, particularly in reactors, piping systems and storage tanks. Besides, Hu et al. [80] highlight the need to utilize early warning signs obtained from previous accident data to enhance risk forecasting. Their research establishes a correlation between pre-accident factors such as equipment failure and safety violations, and potential impacts, providing essential insights into real-time operating risks. These findings highlight a transition in safety science from reactive to preventive strategies.

The yellow cluster, a smaller yet thematically distinct element of the bibliographic coupling network, comprises four publications. It focuses on external threats and emergency planning, which might affect the vulnerability of the facilities. Despite the lower node density as compared to the dominant technical and organizational clusters, its unified structure suggests a specialized, focused research area. Previous studies exemplify this theme through probabilistic models' application in assessing the likelihood and impact of attacks on industrial facilities [70], [71]. In general, these studies highlight the importance of integrating security elements into conventional process safety frameworks, emphasizing the need for proactive emergency planning and performance-oriented protection strategies in high-risk sectors.

Keyword Analysis and Research Clusters

Co-occurrence analysis illustrates distinct thematic clusters, differentiating between well-established and emerging topics within industrial disaster research. A minimum occurrence threshold of 12 was set for each of the 57 identified keywords to ensure precise visualization. Figure 7 demonstrates that "chemical industry" is the most frequent keyword with 200 occurrences. Meanwhile, another set of top keywords is listed in Table 5. A number of frequently used terms exhibit conceptual similarities (e.g., descriptors associated with processes and industry), indicating terminological variability rather than different research themes. The interrelation of these overlapping terms indicates a strong connection, emphasizing that they provide a fundamental conceptual basis for more specific and refined research topics. The prominence of "chemical industry, risk assessment, and accidents" indicates a significant research focus on the influencing factors and preventive strategies associated with industrial disasters in the chemical industry, one of the highest-risk industries worldwide.

Based on Figure 7, the keyword co-occurrence network generated by VOSviewer identified five clusters. However, only the three dominant clusters were interpreted in detail because they contained the most highly connected and thematically significant keywords within the network. The remaining two clusters were relatively small and less densely connected; therefore, they were omitted from further discussion. To begin with, all the clusters are closely related and well-integrated. Each cluster highlights the prominent research areas in industrial disasters in high-risk industries. Cluster I (red) with 18 keywords is labelled as "Effects of Industrial Disaster". This cluster identifies key aspects such as occupational accidents, hazardous substances fire and explosion, emphasising the risks associated with industrial operations. The co-occurrence relationships among these keywords reflect a dominant research focus on accident severity, hazardous releases and the human and operational impacts associated with industrial incidents. The prominence of this cluster within the network suggests that consequence-oriented research remains a central component of industrial disaster literature [81]-[84].

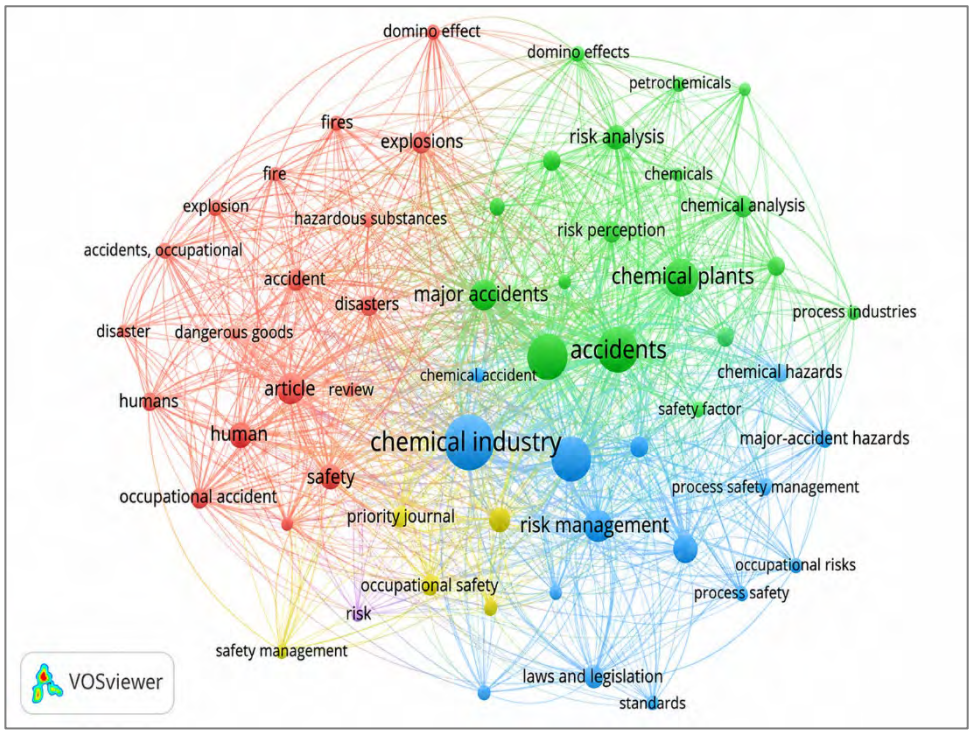

Figure 7. Keyword co-occurrence network
(Sources: Scopus database, VOSviewer version 1.6.20, February 2025)

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Table 5. Top 10 keyword co-occurrence analysis

Rank	Keyword	Occurrences	Total link strength
1	Chemical industry	200	1136
2	Risk assessment	138	886
3	Accidents	141	859
4	Accident prevention	129	737
5	Risk management	70	464
6	Chemical plants	96	440
7	Major accidents	63	415
8	Human	44	340
9	Safety	43	306
10	Hazards	52	304

(Sources: Scopus database, VOSviewer version 1.6.20, February 2025)

Cluster II (green) with 18 keywords is identified as "Risk Analysis and Safety Factors in Chemical Industries". The cluster focused on identifying, assessing, and mitigating risks in chemical industries. The key terms of "risk analysis", "risk perception", "risk assessment", and "safety factor" highlight both scientific and managerial approaches in risk management. It emphasises the importance of systematically identifying, evaluating, and mitigating potential hazards in chemical industries. Risk analysis focuses on assessing hazards to determine the probability and severity of accidents, while risk assessment combines both qualitative and quantitative methods in measuring these risks and formulating effective mitigation strategies [85]. On the other hand, risk perception addresses the human and organizational factors that shape understanding and management of risks, significantly affecting decision-making and regulatory compliance. Inaccurate assessment and risk perception can lead to inadequate safety measures, ultimately increasing the likelihood of industrial disasters [86], [87].

Finally, the blue cluster (III), comprising 15 keywords, is labeled as "Factors Associated with the Accident Occurrence". The keywords of "accident prevention", "risk management", and "process safety" highlight a significant focus on proactive strategies in identifying, assessing, and mitigating hazards before they escalate into catastrophic incidents. Process safety management (PSM) is frequently associated with these concepts, and reflects systematic organizational strategies that integrate operational procedures, technical controls and human factors in ensuring the safety of industrial processes [88], [89]. The inclusion of the terms "major-accident hazards" and "occupational risks" highlights a dual focus on large-scale industrial failures and worker-level safety, reinforcing the need for comprehensive safety systems. Simultaneously, the concepts of "environmental protection", "regulatory compliance", and "standards" highlight the external pressures and sustainability factors that influence safety performance. These terms emphasize the interplay among regulatory frameworks, engineering controls, and organizational culture in reducing the likelihood and impact of industrial accidents, signifying a transition from reactive measures to proactive approaches and system-oriented safety management.

Table 6 gives a clear summary of the co-occurrence analysis from VOSviewer. These thematic clusters support the study's objective of mapping the intellectual structure and identifying research gaps in industrial disaster research. Cluster I explores existing research that focuses on the immediate consequences and outcomes concerning human safety following industrial disasters. Cluster II focuses on the complex and well-established aspect of risk analysis and safety factors in the chemical industry, highlighting the importance of quantitative risk assessment and engineering-driven safety evaluations. In contrast, Cluster III (Factors Associated with Accident Occurrence) encompasses process safety management, regulatory compliance and environmental protection, underscoring the increasing yet still fragmented relationship between technical controls and governance-focused strategies. The

Table 6. Co-occurrence analysis

Cluster	Cluster theme	Number of keywords	Representative keywords	Reference
I (Red)	Effects of Industrial Disaster	18	Occupational accidents, explosions, fires, hazardous substances, human safety	[83], [84], [81], [90], [91]
II (Green)	Risk Analysis and Safety Factors in Chemical Industries	18	Chemical plants, reliability, risk analysis, risk assessment, risk perception, safety engineering, safety factor	[66], [82], [92], [93], [94]
III (Blue)	Factors Associated with The Accident Occurrence	15	Accident prevention, environmental protection, major-accident hazards, occupational risks, process safety, process safety management, regulatory compliance, risk management, standards	[84], [52], [95], [96]

limited integration across these clusters highlights a notable gap in the synthesis of consequence-based studies with proactive risk governance and regulatory implementation. Addressing this gap is essential, emphasizing the need for more integrative and cross-cluster research to improve systemic resilience in high-risk industries.

Implication

The findings of this study provide a solid analytical foundation for implications for research, industry practice, and policy development in high-risk industries. They illustrate the structure, evolution, and uneven development of research areas related to industrial disasters. The thematic cluster analysis reveals three main domains: technical risk assessment, human and organizational factors, and environmental and societal impacts. This highlights that industrial disaster research extends beyond purely engineering perspectives. The sustained prominence of human and organizational clusters, despite technological advances, indicates that industrial accidents may still recur due to systemic and cultural deficiencies that limit the effectiveness of safety practices. Simultaneously, the emergence of underexplored associations between these domains, such as resilience-oriented risk governance, highlights areas where existing research remains fragmented and where comprehensive studies are critical. The publication trend analysis reveals that industrial disaster research is a growing area of interest, maintaining both academic and practical significance. In contrast to previous bibliometric studies that focused on specific thematic areas such as domino effects and process safety analysis, this study advances by integrating publication trends, collaboration dynamics, citation influence, bibliographic coupling and thematic evolution into a comprehensive synthesis of industrial disaster research. While publication counts primarily reflect national research capacity, citation analysis indicates a country's level of intellectual integration and collaborative impact within the global research network. In this context, the analysis of collaboration networks demonstrates that countries with strong international linkages gain advantages from shared expertise and resources, reinforcing their influence in shaping dominant research agendas and safety discourses. Overall, these findings indicate that technological innovations such as automation and artificial intelligence must be accompanied by stronger organizational structures that support human oversight, adaptive decision-making, and continuous learning. The growing focus on environmental and societal impact clusters also reflects an increasing global commitment on sustainable development and proactive risk governance. By synthesizing thematic evolution, collaboration dynamics and geographic influence, this study extend beyond earlier bibliometric analysis to provide a more integrated understanding of how research priorities, institutional capacities and international collaboration jointly influence industrial disaster prevention. These insights facilitate the development of more focused research agendas, policy interventions, and industry strategies that integrate technical, organizational and societal aspects to reduce the likelihood and impact of major industrial disasters.

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CONCLUSION

Systematic mapping of three decades of scholarly work from 1995 to 2025 reveals the evolution, dominant clusters, international collaboration patterns and emerging directions of industrial disasters research in high-risk industries. Despite technological advancements, the bibliometric results reveal that clusters related to technical failures, human factors, and organizational culture remain significant, implying a persistent scholarly consensus that these elements are critical vulnerabilities in preventing industrial accidents. The analysis further identifies key publications, influential collaboration networks, and the interconnections among research themes, highlighting the complexity of risk analysis and safety practices in high-risk industries. The findings demonstrate the global distribution of research efforts and the integration of themes such as process safety and human factors. However, there is uneven regional representation and comparatively limited attention to integrative socio-technical and organizational perspectives within technically dominant risk assessment. These insights facilitate researchers in identifying underexplored themes and regions, while providing an evidence base that can conceptually guide policymakers in prioritizing regulatory focus and industry stakeholders in aligning their safety management practices. This ultimately supports more targeted risk mitigation and sustainable development efforts within existing academic frameworks. Overall, this study contributes to industrial disaster management research on three distinct levels. First, it provides a comprehensive 30-year mapping of collaboration networks and publication trends across high-risk sectors. Second, it demonstrates the literature's gradual shift from isolated technical studies toward multidimensional risk frameworks. Ultimately, by integrating these two elements, this research extends beyond the limitations of earlier works, narrowly focused bibliometric reviews, presenting a well-founded agenda for future interdisciplinary research and global collaboration.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest regarding this manuscript.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request, subject to data sharing agreement.

DECLARATION OF AI TOOLS USAGE

During the preparation of this manuscript, the authors used SciSpace to support literature exploration, document comprehension, and reference-based summarization, and ChatGPT to assist with language refinement, text restructuring, and summarization. These tools were used solely to improve the clarity, readability, and organization of the manuscript and were not used to generate research data or formulate scientific conclusions. All AI-assisted

outputs were critically reviewed, verified, and edited by the authors to ensure factual accuracy, clarity, and compliance with academic standards. The authors take full responsibility for the integrity and content of this manuscript.

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