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# Fire Risk Assessment - A Case Study of NCT Delhi

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**Abstract**

Fire risk assessment (FRA) is essential for ensuring safety in industrial urban areas, particularly in rapidly urbanizing cities such as New Delhi, where industrial facilities coexist with densely populated residential zones. Industrial hubs including Bawana, Naraina, Okhla, and Mundka face elevated fire risks due to inadequate safety infrastructure, poor electrical systems, improper hazardous material storage, and weak regulatory compliance. Major incidents such as the Anaj Mandi (2019) and Mundka (2022) fires highlight the urgent need for systematic fire risk assessment and effective enforcement of fire safety regulations. FRA provides a structured approach to identifying fire hazards, evaluating risks, and implementing preventive and mitigation measures through engineering controls, safety management, and emergency preparedness. This study presents a bibliometric analysis of fire risk assessment research to examine publication trends, influential authors, journals, institutions, and countries, collaboration networks, emerging research themes, and methodological advancements, including the application of artificial intelligence, machine learning, fuzzy logic, the Internet of Things (IoT), and simulation-based models.

**Keywords:** Fire Risk Assessment, Industrial Fire Safety, Bibliometric Analysis, Fire Hazard Management, Artificial Intelligence in Fire Safety

## 1 Introduction

The process of fire risk assessment has become essential for safety management in industrial urban areas which face high dangers of fire-related disasters. New Delhi, a city that has experienced rapid urban expansion and industrialization over the past few decades, the importance of this assessment not overstated. The capital city of India New Delhi contains numerous industries which include small manufacturing facilities and large production plants that handle flammable substances and heavy electrical equipment and advanced chemical operations. The industrial areas which border residential neighborhoods create a hazardous situation that endangers both residents and essential infrastructure during fire

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emergencies. The industrial areas of New Delhi, including prominent zones like Bawana, Naraina, Okhla, and Mundka, contribute substantially to the city's economy. However, many of these zones were developed without comprehensive planning for fire safety infrastructure. The inadequate unit spacing together with improper waste management and deficient electrical systems and hazardous material storage practices create a high fire risk in these locations. The city has experienced multiple industrial fires throughout its history which resulted in catastrophic destruction and human fatalities and severe injuries and substantial economic losses. The Anaj Mandi fire in 2019 and the Mundka fire in 2022 are poignant examples that underscored the urgent need for systematic fire risk evaluations and stricter regulatory oversight. The current situation demonstrates an extreme discrepancy between national fire protection regulations and their actual execution at operational sites. The regulatory system established by National Building Code (NBC) and The Factories Act and municipal safety bylaws needs better enforcement because current enforcement methods show inconsistent results. The risk to safety increases because factory owners and workers do not understand safety procedures and because they lack training and fire safety equipment fails to function. Many industrial units still operate without valid fire safety licenses and fire audits which take place serve as a formality instead of an actual evaluation of risk and preparedness. Fire risk assessment in industrial areas of New Delhi must be approached with a multi-dimensional strategy. The process requires three steps which include first identifying potential fire hazards and second assessing current safety measures and third evaluating both fire occurrence probability and fire incident outcome. The organization needs to develop specific control strategies which combine engineering solutions like fire alarms and sprinkler systems and fire-resistant materials with administrative solutions that include safety protocols and staff training and emergency response planning. Community awareness and preparedness also play a crucial role especially in areas where residential neighborhoods coexist with industrial facilities. Fire Risk Assessment (FRA) is a systematic process that identifies fire hazards within a specific environment and assesses the associated risks and establishes control measures to prevent or minimize fire-related incidents. The Fire Risk Assessment process in Delhi-NCR industrial areas which have high factory and warehouse and manufacturing unit density serves as both a regulatory mandate and an essential safety requirement. The Fire Risk Assessment process has one main goal which protects both human life and property and the environment by proactively addressing fire hazards. The need for fire risk assessment and management systems in Delhi-NCR arises from its high population density and fast urban development because industrial areas like Okhla and Bawana and Narela and Udyog Vihar exist with different levels of law compliance. The industrial fire risk assessment system enables businesses to meet national and local fire safety regulations while protecting their legal interests and sustaining their operations through fire event disruption management.

## 2 2. Objective of the study

The Primary objectives of the study are as follows:

- To analyze the publication trends in fire risk assessment research over time, identifying growth patterns, key developmental phases, and emerging themes.
- To identify the most influential authors, journals, institutions, and countries contributing to fire risk assessment literature based on citation analysis and publication output.

- To examine collaboration networks among researchers, institutions, and countries to understand the global research structure and knowledge-sharing patterns.
- To explore dominant research themes and keyword trends using co-occurrence and thematic mapping techniques to identify core and emerging topics in fire risk assessment.
- To assess methodological advancements in fire risk assessment studies, including the integration of AI, machine learning, fuzzy logic, IoT, and simulation models.

## 3 Literature Review

Cho et al. [1] introduced a fire risk assessment technique for high-capacity battery packs, leveraging an interquartile range filter to detect anomalies in energy storage systems. This method is particularly relevant for lithium-ion technologies where thermal runaway presents severe hazards. Huang et al. [2] combined fault tree analysis with fuzzy logic to evaluate fire risks during battery transportation and storage. Their hybrid model effectively addressed uncertainties in risk variables, aiding the design of safer logistics systems for lithium batteries. Liu et al. [3] conducted an experimental fire risk assessment of typical interior wallpapers, analyzing their pyrolysis and combustion characteristics. Using standardized flame propagation tests, they assessed the influence of silicone-based additives on fire behavior, providing valuable insights for fire safety in interior design and construction materials. Okamoto et al. [4] assessed fire risk due to arc-tracking at plug-outlet connections, using experimental methods to model interface failure mechanisms. Their study advanced understanding of electrical fire hazards and informed safer outlet designs. Ouache et al. [5] proposed a machine learning and evidential reasoning-based framework to assess fire incidents caused by human error in residential buildings. Their method allowed comprehensive fire risk prediction by integrating human factors into traditional models. Pérez-Guerrero et al. [6] used deep learning and infrared imaging to extract geometric features of large-scale jet flames for fire risk management. Their semantic segmentation methods facilitated accurate measurement of flame height and lift-off distance, contributing to advanced risk modeling in industrial environments dealing with jet fires. Ribeiro et al. [7] introduced a compound event-oriented framework for assessing tropical fire risk under climate change scenarios. Focusing on the Pantanal and Xingu regions, they analyzed how compound events such as drought and heatwaves synergistically increase fire risk. The study emphasized the necessity of incorporating multi-hazard interactions in fire risk assessment to better understand fire dynamics in tropical ecosystems. Silva et al. [8] evaluated fire vulnerability in Aveiro's historic city center in Portugal. Through qualitative and quantitative assessments, they proposed structural retrofits and policy measures to protect cultural assets and reduce urban fire risks. Song et al. [9] compared the exothermic behavior of fresh versus naturally aged pine wood using isoconversional analysis. Their thermal decomposition data informs fire modeling and material safety standards, particularly in historical or long-term wood storage contexts. Xie et al. [10] conducted a wildfire risk assessment in China's Liangshan Prefecture using an integrated machine learning framework. Combining random forest, support vector machines, and Bayesian optimization, the model delivered high spatial accuracy in identifying fire-prone regions. Alizade et al. [11] performed a fire risk assessment and educational intervention targeting operating room personnel in Isfahan hospitals. Their intervention improved staff awareness and reduced human error, demonstrating the effectiveness of targeted training programs in fire-prone hospital environments. Barmpoutis et al. [12] developed a suburban forest fire risk assessment method using 360-degree surveillance cameras and a multiscale deformable transformer model. Their deep learning approach enabled early fire detection and real-time monitoring, which is crucial for mitigating suburban forest fire risks in densely populated regions. Čavlina Tomašević et al. [13] compared meteorological drivers of two large wildfire events in Croatia and southeast Australia. Using numerical weather prediction models, the study revealed critical climate variables influencing fire spread and severity, aiding in transcontinental fire risk modeling. De Silva et al. [14] reviewed fire risk assessment methodologies applied to bridges, highlighting structural vulnerabilities and proposing performance-based mitigation strategies. Their study bridges the gap between structural engineering and fire safety, particularly for infrastructure exposed to wildland-urban interface fires or accidental vehicle fires. Di Filippo et al. [15] integrated fire risk assessment with life cycle analysis in building design, focusing on thermal insulation materials. Their framework linked fire performance with environmental impacts, providing a multi-dimensional perspective for safer and sustainable construction practices. Ding et al. [16] established a holistic value-at-risk assessment framework for fire risk in heritage buildings, combining analytic hierarchy process and text mining. Their model evaluated cultural and structural values to prioritize fire protection interventions in historically significant properties.

# 4 Research Methodology

The research study utilizes the bibliometric research design to investigate fire risk assessment. The researchers obtained bibliographic information from Scopus/Web of Science because it provides complete access to peer-reviewed publications. The researchers used specific keywords together with Boolean operators and inclusion-exclusion criteria to discover relevant publications which would maintain the dataset's quality and relevance. The researchers analyzed only English-language articles which existed between the designated time frame for their evaluation. The data extraction process collected information about publication year and author details and their institutional affiliations and country of publication and journal selection and citation records and selected keywords and reference materials. The research team used bibliometric indicators to evaluate research productivity and impact through their examination of publication patterns and citation data and authorship trends and country-specific research contributions and publication source impact. The researchers used bibliometric tools such as VOSviewer and Biblioshiny to perform network visualization and mapping procedures which included co-authorship and co-citation and keyword co-occurrence analyses for the purpose of identifying intellectual structures and collaboration networks and emerging research themes. The researchers used descriptive analysis together with performance analysis to create a complete depiction of how the field has developed from its past to its present state while predicting future research paths.

# 5 Research Method

The bibliometric overview is presented in a combination of descriptive statistical and network analysis regarding three different levels: documents, journals, and authors (Paul & Bhukya, 2021). The researchers assessed Fire risk assessment impact through statistical metrics that included citation counts and document citations and publication numbers and journal citation counts. VOSviewer serves as one of the many bibliometric analysis tools which has gained popularity among bibliometric researchers because of its advanced

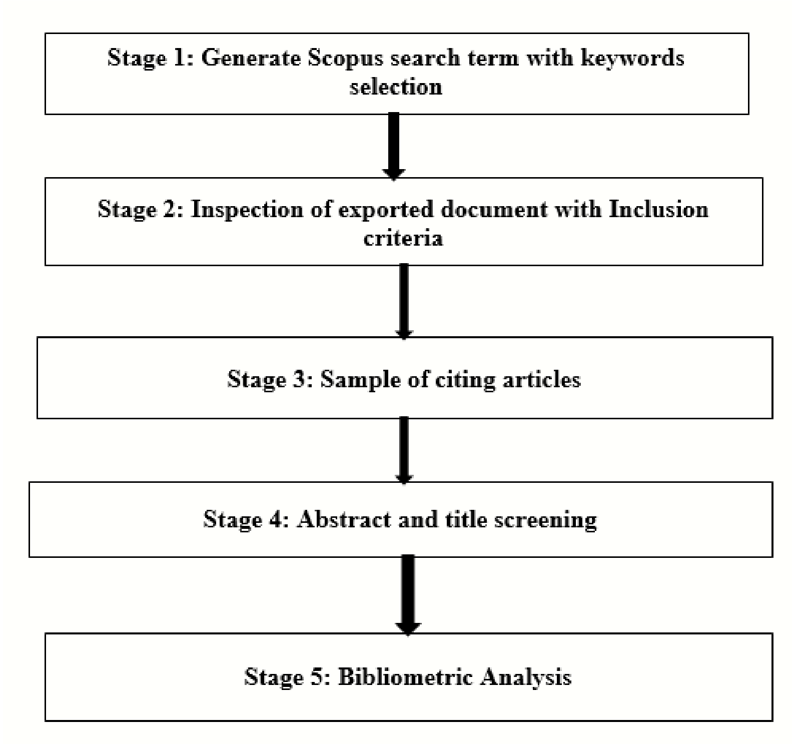


**Fig. 1**: Basic Workflow for Bibliometric Analysis

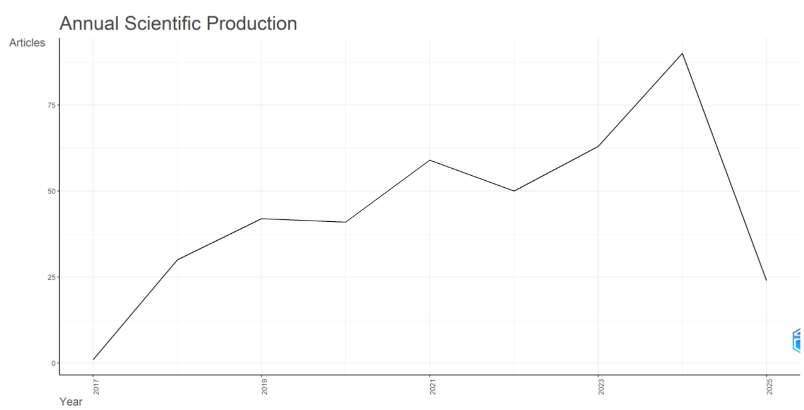


**Fig. 2**: Annual Scientific Production

mapping functions that enable efficient handling of extensive datasets (van Eck Waltman, 2010). The researchers used VOSviewer software version 1.6.19 to create and display bibliographic data which they obtained from Scopus in the 'csv' file format.

# 6 6. Performance Analysis

Performance analysis reveals the research field's publication and citation-related metrics (Cobo et al., 2011). Researchers commonly use performance analysis to evaluate the performance of authors, countries, organizations, and journals.

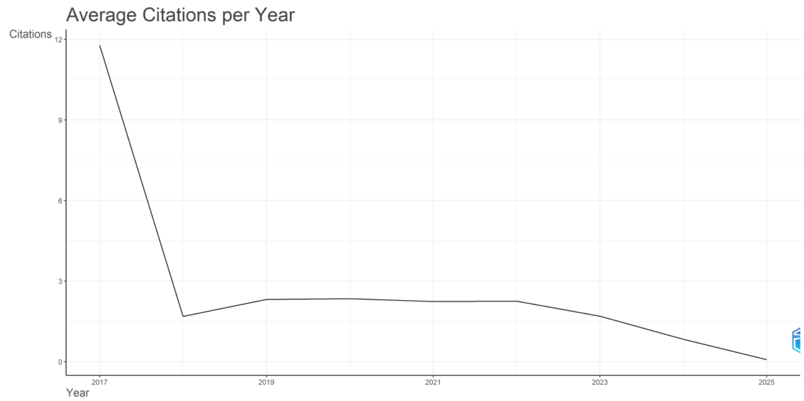


**Fig. 3**: Average Citation per Year

The line graph titled "Annual Scientific Production" provides a visual representation of the number of scientific articles published annually from 2017 to 2025. The research output during this time period shows both existing patterns and actual research output fluctuations. The research output in 2017 started at a minimal level because researchers published almost no articles. The first upward movement started in 2018 when the article production reached a level of about 30 articles. The initial period of growth transitioned into continuous output expansion which reached its highest point of 40 articles during 2019. The research output of 2020 showed a slight decrease which created an impression of no progress because research activities had reached their maximum capacity. The year 2021 brought a bigger boost to academic work which saw article output increase to about 60 articles. The trend showed upward movement from 2022 onwards although the article count dropped to about 50. The year 2023 witnessed another growth phase which pushed the article count to approximately 65 articles. The year 2024 reached its highest output level with a total article count that surpassed 85 articles which became the most articles produced during the entire observed period. The year 2024 became the most productive year because organizations received more funding and worked together with each other and institutions provided them with more support. The peak output period ended abruptly because 2025 saw a sudden and extreme decrease which resulted in output dropping to about 25 articles. The research activities experienced interruptions which resulted from changes in policies and reduced funding and outside elements that impacted their operations.

The line graph titled "Average Citations per Year" shows the average citations that scientific articles received from 2017 until 2025. This metric shows how academic research, which has been published, gains recognition over time regardless of how many articles are published. The year 2017 stands out distinctly, beginning with a notably high citation average of approximately 12 citations per article. The academic community recognized the few articles published during that year as particularly valuable resources. The period after 2018 sees citation averages experience a significant decrease which reaches a point of approximately 2.5 citations per article. The sharp decline happened because the new publications that came out in later years reduced the power of individual articles or researchers stopped studying the subjects that they had investigated in 2017. The period from 2018 to 2022 shows academic researchers who published work to study the research. The previous graph shows scientific productivity increased during this period but this growth did not lead to greater article impact. The research process faces limitations because of different factors

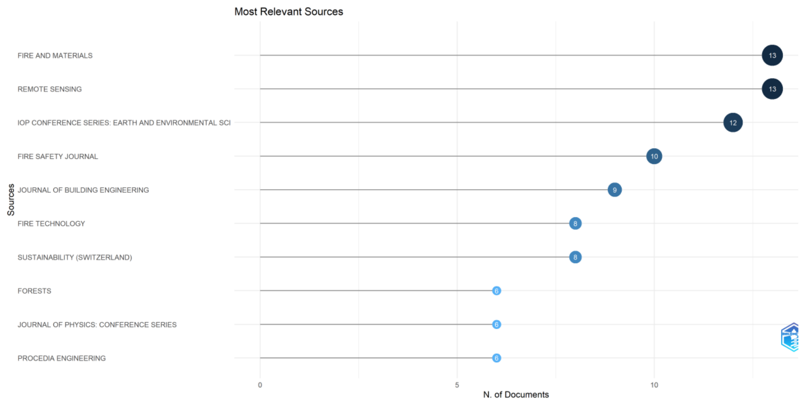


**Fig. 4**: Most Relevant Sources

which include research specifications, restricted research sharing, and low research citations in the discipline. The average citation rate starts to decrease in 2023, dropping below two citations and continuing to drop steeply until 2024 and into 2025. The average citations per article reach almost zero by 2025 because recent publications have not received enough time to gain citations and research papers fail to capture interest from academic researchers. The stark decline may also reflect a lag in the citation cycle, as newer articles often take time to accumulate references, or it may point to a possible decline in research relevance or quality.

The visual display shows the essential academic sources which support investigations about fire safety and fire risk assessment and their related environmental and engineering research areas. The horizontal bubble chart presents a ranked overview based on the number of documents published by each source, effectively showing the prominence and frequency of publications within these outlets. Fire and Materials and Remote Sensing together lead the list of sources because they each produced 13 documents. The research community shows high interest in studying how materials behave during fire testing because researchers now apply remote sensing methods to observe fire incidents which occur in forest and wildland areas. The IOP Conference Series: Earth and Environmental Science follows closely behind with 12 publications which demonstrate that fire research now includes interdisciplinary studies about environmental science and geospatial assessments. The Fire Safety Journal holds a notable position with 10 documents, underscoring its critical role in advancing theoretical and practical knowledge in fire safety engineering. The Journal of Building Engineering published 9 documents because fire safety needs to be included in building design and construction processes. The journals Fire Technology and Sustainability (Switzerland) both appear with 8 documents, showing a balanced interest in technological advancements and sustainable approaches to fire risk mitigation. The journals Forests and the Journal of Physics: Conference Series and Procedia Engineering present 6 documents each which show that environmental science and applied physics and engineering fields make consistent progress in their work. These sources demonstrate the diverse academic engagement with fire-related topics, ranging from fundamental physics and engineering applications to ecological implications and sustainability concerns. The chart named ”Most Cited Countries” shows how different countries use academic work in fire safety and fire risk assessment research fields. The horizontal bubble chart shows the ten highest citation countries in this research area who received the most citations. China

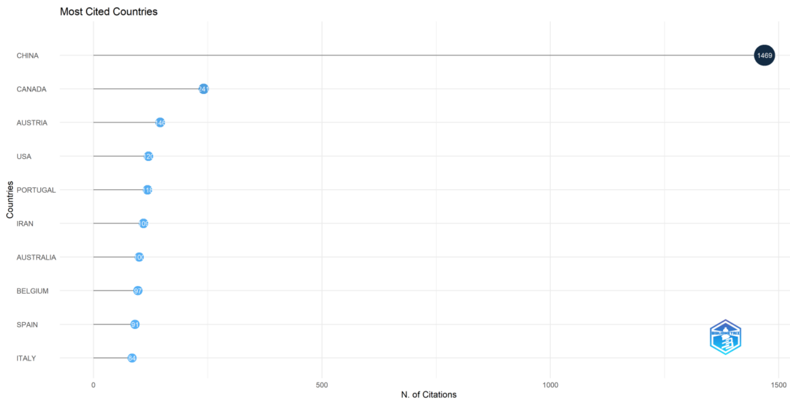


**Fig. 5**: Most Cited Countries

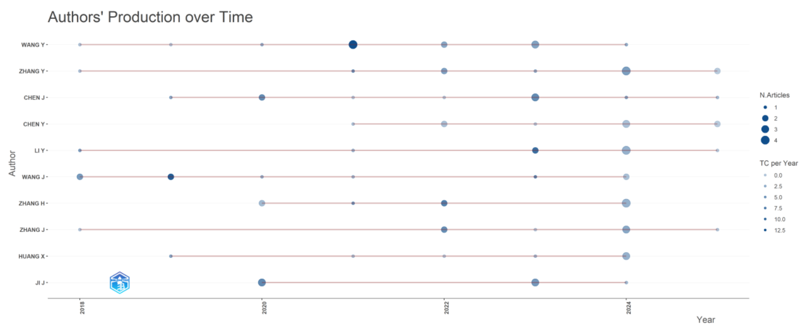


**Fig. 6**: Author Production Over Time

leads as the most cited country with 1469 citations which exceed all other countries in the study. China serves as the main force behind research progress in all fields of fire science. Researchers from this country produced numerous studies because they dedicated funds to fire science research while building strong academic institutions and fire safety research centers. China leads the research world because it takes initiative to solve fire safety problems that arise in developing industrial cities. ada holds the second place as the most cited country with 241 citations. The research output from ada serves as a major element in this field despite showing lower results than China. The research by ada focuses on wildfire danger and forest management and environmental monitoring because these elements are vital for a country that has extensive forests and faces increasing wildfires caused by climate change. Austria ranks third with 146 citations, reflecting a strong academic focus on fire dynamics, engineering, and possibly material sciences related to fire behavior. The United States maintains its academic value through fire safety engineering and emergency response system research which covers multiple scientific disciplines. approaches involving civil engineering and public safety. Portugal (118 citations), Iran (109 citations), and Australia (100 citations) all demonstrate solid contributions, likely due to their geographic and climatic vulnerabilities to wildfires and their focus on mitigation strategies and fire behavior modeling. Belgium (97 citations) and Spain (91 citations) also appear on the list, indicating their role in European research collaborations and environmental studies. Lastly, Italy rounds out the top ten with 84 citations, reflecting steady contributions in engineering and architectural fire safety. The visualization titled "Authors Production over Time"

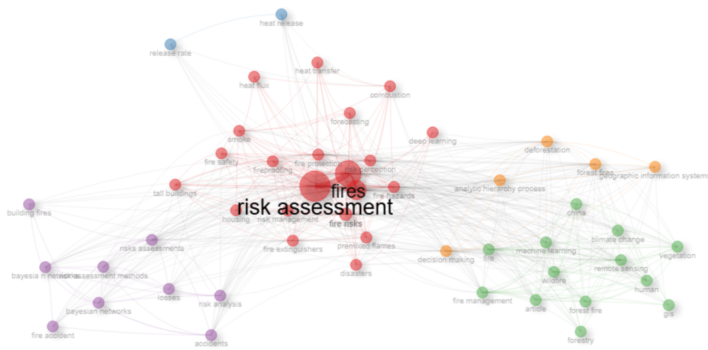


**Fig. 7**: Co Occurrence Network

shows how fire safety researchers and fire risk assessment experts published their work and created academic impact through their research between 2018 and 2024. The chart uses bubble size to display article quantities and bubble color intensity to show total citations which enables viewers to track both author output and their academic impact throughout different periods. Wang Y stands out among all authors as the top writer who has created significant work because his 2021 research output of four articles became his most important work which he produced with high citation results. Wang Y kept producing articles throughout the following years because his work from 2022 and 2023 stayed relevant to his professional field. Zhang Y also shows steady scholarly output through his regular publications which he started in 2018 and continues to his current work in 2024. Zhang Y's research from 2022 and 2024 shows higher citation results because his bubbles display darker tones. Their research contributions have earned them increasing recognition which has grown their impact with time. Chen J published important research in 2020 and 2023 which received high citation numbers based on medium-to-dark blue bubble data. Chen Y demonstrated a pattern of rising output which reached its peak in 2022 and 2024 through his many articles which received average citation numbers because he advanced in academic circles. Li Y shows ongoing work activity between 2018 and 2023 which reached its highest point during 2023 through increased article production and documentation. Wang J maintained his work output throughout the years but especially in 2018 and 2020 he demonstrated the citation impact seems to be moderate in comparison to Wang Y and Zhang Y. Zhang H and Zhang J appear with recurring contributions across multiple years, showing moderate publication output and growing influence, especially noticeable in the bubbles for 2022 and 2024. Huang X and Ji J contributed sporadically, but their few publications were relatively impactful, particularly Ji J's 2020 article, which had a visibly strong citation record.

The co-occurrence network visualization presented here shows all the keywords which researchers in fire research and risk assessment use most frequently. The node size represents keyword frequency, while link thickness with the link distance between nodes shows their co-occurrence strength. The network centers on the keywords "risk assessment" and "fires" which function as the most important interconnected terms linking their found research work. The keywords function as main points which connect different research fields that link to the main research topic.The network displays multiple thematic clusters which

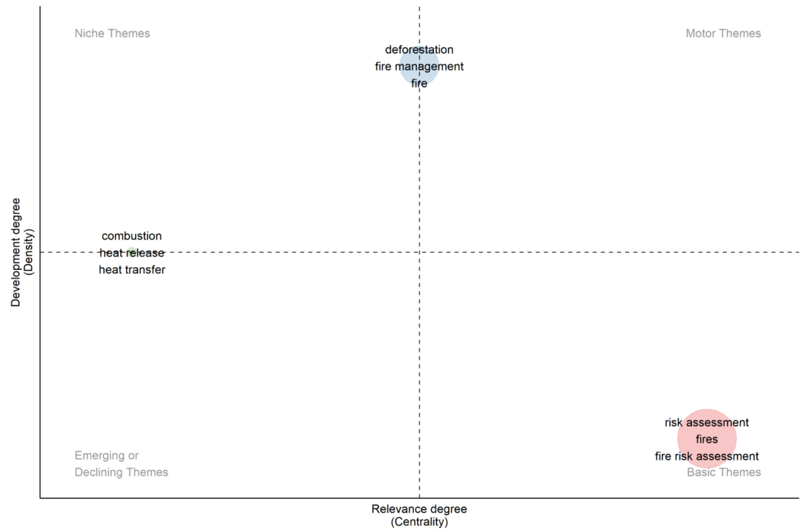


**Fig. 8**: Thematic Map

represent different research areas within fire risk assessment research. The central red cluster contains terms which connect closely to "fire protection" and "fire safety" and "risk management" and "fire risks" and "combustion" and "deep learning" The cluster includes fundamental subjects which provide direct links to engineering principles and safety system components and fire science predictive modeling. The field focuses on using artificial intelligence and deep learning technologies to improve fire prediction and management through advanced technology integration. The purple cluster which appears on the left side contains terms which include "building fires" and "bayesian networks" and "fire accident" and "risk analysis" and "losses" The segment focuses on developing fire assessment methods which specifically target built environments when assessing fire-related losses and accidents. The use of Bayesian networks and other probabilistic methods demonstrates a quantitative modeling method which predicts and assesses risk. The green and orange clusters on the right side contain terms which include "machine learning", "climate change," "wildfire," "deforestation," "geographic information systems (GIS)," and "remote sensing." These clusters point toward environmental and ecological aspects of fire research, particularly those related to forest fires and wildfires. The green cluster reflects research trends that address natural disasters through the use of data-driven decision-making tools, while the orange cluster highlights the relevance of GIS and spatial analysis in fire risk monitoring and management.

The thematic map depicted in the image provides a strategic visualization of the intellectual structure of research on fire risk and assessment, based on the co-word analysis of relevant themes. The two key dimensions relevance degree (centrality) on the horizontal axis and development degree (density) on the vertical axis allow for the classification of themes into four quadrants: motor themes, basic themes, niche themes, and emerging or declining themes. Each theme is represented as a bubble, with the size of the bubble indicating the frequency or significance of that keyword in the literature. In the bottom-right quadrant, which represents basic and transversal themes, we observe the presence of "risk assessment," "fires," and "fire risk assessment." These themes have high centrality but moderate-to-low density, suggesting that they are foundational topics in the field.


**Fig. 9**: Word Cloud

They are widely connected with other themes, indicating their importance and broad relevance across various research domains. However, their relatively lower density implies that while these themes are essential, they may not be fully developed or heavily diversified in terms of internal subtopics. This positioning confirms that fire risk assessment is a cornerstone concept in this area of research, serving as a basis for more specific investigations. The top-left quadrant, which includes “combustion,” “heat release,” and “heat transfer,” represents niche themes. These topics show a higher degree of internal development (density) but relatively lower centrality, meaning they are more specialized or isolated and not as extensively connected to the broader thematic network. These areas are technically rich and well-defined but are likely limited to more focused studies within fire dynamics, material behavior under fire conditions, or thermophysical modeling. In the top-right quadrant, which significanes motor themes, we find “deforestation,” “fire management,” and the generic term “fire.” These themes exhibit both high centrality and high density, indicating that they are well-developed and integral to advancing the field. Their strong internal cohesion and broad connectedness suggest that these topics are both conceptually mature and influential, potentially driving innovations in policy, environmental management, and disaster mitigation. Their placement reflects a growing emphasis on ecological and forest fire research, likely driven by concerns around climate change and land-use practices. Interestingly, the bottom-left quadrant, which typically captures emerging or declining themes, is nearly vat, indicating that there are currently no significant declining or underdeveloped areas in this domain, or that such themes have not yet gained sufficient traction to be mapped.

The word cloud visualization provides a graphical representation of the most frequently occurring terms in the literature on fire risk and risk assessment. This type of analysis is valuable for quickly identifying key themes, dominant concepts, and research focus areas within a given body of work. The size of each word in the cloud indicates its frequency and relative importance the larger the word, the more often it appears across the analyzed

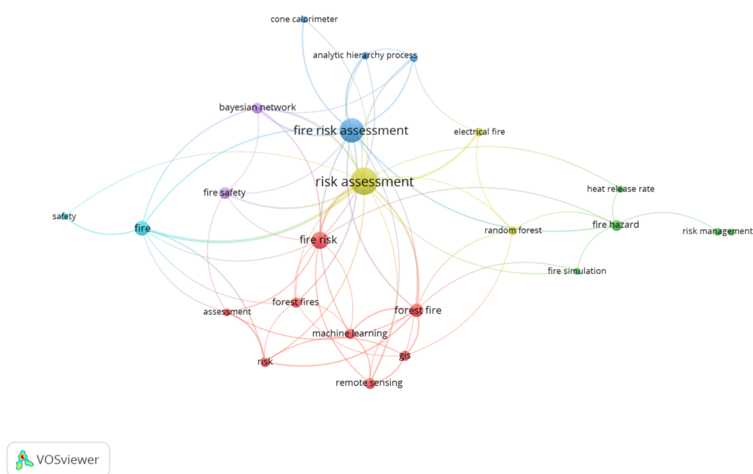


**Fig. 10**: Co - occurrence authors keywords

documents. At the center of this visualization, the terms “risk assessment,” “fires,” and “fire risk assessment” stand out as the most prominent and recurring keywords. Their significant size highlights their central role in the domain of fire safety and risk management research. These terms suggest that the core emphasis of the literature lies in assessing and managing the risks associated with fire incidents, whether in industrial, residential, or natural environments. Surrounding these central keywords, other notable terms include “fire risks,” “fire protection,” “fire hazards,” “fire management,” and “fire extinguishers.” These concepts reflect the broader scope of the research, which covers both preventive measures (such as fire protection and extinguishers) and risk evaluation methods (like hazard identification and management strategies). This suggests a comprehensive approach within the literature, focusing not only on assessing fire-related risks but also on developing mitigation strategies and implementing fire safety protocols. Additionally, words such as “deforestation,” “remote sensing,” “climate change,” and “wildfire” indicate the inclusion of environmental and ecological dimensions in fire risk studies. This points to a growing body of work focusing on wildfires and forest fires, often in the context of environmental change and land-use patterns. Furthermore, technical and methodological terms like “risk perception,” “risk analysis,” “bayesian networks,” and “decision making” also appear in the cloud, reflecting the interdisciplinary nature of the field, which combines elements of engineering, data science, and behavioral studies. This integration is indicative of a trend toward data-driven and systems-based approaches to fire risk assessment.

# 7 Science Mapping

It visualizes the relationships among frequently co-occurring author keywords in the field of fire risk assessment. Each node in the network represents a keyword, and the size of the node indicates the frequency of occurrence of that keyword. The links (edges) between the nodes represent the strength of co-occurrence relationships, while the colors signify different clusters or thematic groupings of keywords based on their interconnections. At

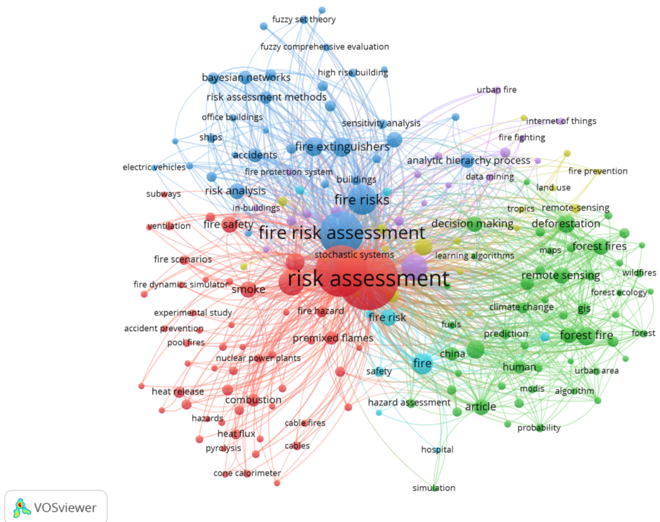


**Fig. 11**: Co - occurrence all keywords

the center of the network, the keywords "risk assessment", "fire risk assessment", and "fire risk" appear prominently. These keywords form the core of the research field and are highly connected with multiple other keywords, indicating that they are central topics in the literature. "Risk assessment" is the most influential node, serving as a bridge between various clusters, suggesting its broad applicability and fundamental role in fire-related studies. One significant cluster, marked by shades of red, revolves around "forest fire", "fire risk", "remote sensing", "GIS", "machine learning", and "forest fires". This cluster highlights a strong research focus on wildfire risk assessment using modern technologies. The presence of keywords like "remote sensing" and "GIS" reflects the integration of spatial analysis tools in mapping and monitoring fire-prone areas, while "machine learning" indicates the increasing use of predictive analytics in forest fire risk modeling. Another cluster, represented in blue, includes keywords such as "fire risk assessment", "analytic hierarchy process", "cone calorimeter", and "Bayesian network". This cluster significances a methodological orientation, emphasizing decision-making tools and experimental methods in fire risk evaluation. The "analytic hierarchy process" and "Bayesian network" keywords point toward multi-criteria decision analysis and probabilistic modeling approaches being applied in structured risk assessment. A separate green cluster groups "fire hazard", "fire simulation", "heat release rate", and "risk management". This theme appears to focus on the physical and simulation-based aspects of fire hazard analysis. The inclusion of "heat release rate" and "fire simulation" suggests that these studies delve into modeling fire behavior and dynamics, which are essential for understanding fire development and implementing mitigation strategies. There is also a cyan cluster connecting "fire", "fire safety", and "safety", which seems to be focused more on general fire phenomena and safety considerations. These keywords link both to practical safety concerns and to broader assessments of fire impact in industrial or domestic settings. A smaller yellow cluster includes "electrical fire" and "random forest", suggesting niche research areas. The presence of "random forest," a machine learning algorithm, near "electrical fire" may indicate attempts to apply advanced classification techniques to predict or detect specific types of fires.

The map visualizes the intellectual structure of the research field by clustering and linking keywords based on their co-occurrence patterns within academic literature. The size of each node (keyword) reflects its frequency of appearance across the dataset, while the proximity and connection between nodes indicate how often the keywords appear together. Different colors represent distinct thematic clusters, showing the diverse subfields and methodological focuses within the broader domain of fire risk assessment. At the heart of the map, "risk assessment", "fire risk assessment", and "fire risk" dominate in size and connectivity, confirming their central role and frequent citation across research publications. "Risk assessment" serves as the largest and most central node, functioning as the principal hub through which all major thematic areas are linked. This suggests that most studies in this domain revolve around or are fundamentally anchored in risk assessment frameworks. The red cluster, located to the left side of the map, focuses heavily on fire science, combustion, and experimental methodologies. Keywords such as "smoke", "premixed flames", "fire hazard", "heat release", "combustion", "heat flux", "cone calorimeter", and "pyrolysis" appear here. These terms indicate research that is deeply grounded in the physical and chemical behavior of fires, especially in industrial or laboratory contexts. This cluster reflects studies that investigate fire dynamics, thermal characteristics, and fire modeling tools (e.g., "fire dynamics simulator") to assess potential hazards and fire behavior scenarios. In contrast, the green cluster on the right side is largely oriented toward wildfire and environmental fire risk assessment. Central terms include "forest fire", "remote sensing", "GIS", "deforestation", "climate change", and "prediction", which suggest a strong focus on geospatial analysis and environmental monitoring. The presence of keywords like "MODIS", "maps", and "algorithm" further emphasizes the application of satellite data, spatial modeling, and machine learning techniques to predict and manage wildfire risks. This cluster reflects the growing importance of ecological and technological tools in managing large-scale fires in forested and rural areas. The blue cluster, situated to the top-left, is characterized by a more methodological and system-based perspective. It includes keywords such as "bayesian networks", "fuzzy set theory", "sensitivity analysis", "risk assessment methods", and "fire safety". This cluster illustrates how decision-making models and probabilistic approaches are used to evaluate fire risk, especially in built environments like "office buildings", "ships", and "electric vehicles". The integration of fuzzy logic and Bayesian inference models highlights the uncertainty management aspect of fire risk evaluation in complex infrastructure systems. The purple and yellow clusters are smaller but indicate emerging or niche domains. Keywords such as "internet of things", "data mining", "fire prevention", and "urban fire" in these groups suggest an emerging focus on smart technologies and big data analytics in fire risk monitoring and proactive mitigation. These studies likely explore how IoT devices and intelligent systems enhance fire detection, response, and decision-making in real-time. The cyan cluster, including terms like "fire", "safety", "hazard assessment", and "hospital", represents a blend of general safety concerns and specific fire-related implications in health or public sectors. This cluster likely includes cross-disciplinary research looking at fire incidents in sensitive or vulnerable settings.

Each node represents a country, with the size of the node reflecting the total number of publications attributed to authors from that country. The lines or edges between nodes indicate the presence and strength of collaborative ties, with thicker lines denoting stronger or more frequent collaboration. The color coding groups countries into clusters that frequently co-author together, signifying regional or research network affinities. At

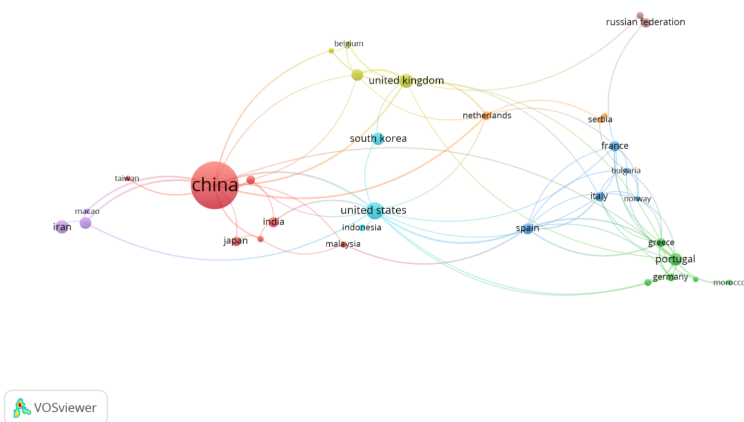


**Fig. 12**: Co authorship country

the center of the map, China emerges as the dominant hub, both in terms of publication volume and international collaboration. Its large node size significanes that it has the highest number of publications in the dataset, which aligns with China's increasing investment in fire safety, disaster risk reduction, and industrial risk research. China maintains particularly strong co-authorship links with countries such as the United States, United Kingdom, South Korea, India, and Japan, indicating a broad and diverse international research collaboration strategy. The United States, another major research player, also features prominently, though slightly smaller in node size compared to China. It connects strongly with European nations like the United Kingdom, Spain, and Italy, as well as with several Asian countries such as Malaysia, Indonesia, and China. This reflects the U.S.'s traditional role as a collaborative scientific partner and its global academic influence. The United Kingdom serves as a bridge between Asia and Europe in the collaboration network. It has strong links with China, Belgium, Netherlands, and South Korea, and is part of a broader cluster of European nations that work closely together on fire risk research. Other European countries, including France, Italy, Spain, Portugal, Germany, and Greece, form a tightly-knit sub-network, suggesting robust intra-European collaboration. These countries are frequently connected through EU-funded projects and initiatives focusing on fire prevention, forest fire monitoring, and environmental hazards. Interestingly, countries such as Iran, Taiwan, and Macao appear on the periphery of the network. Although smaller in node size and exhibiting fewer collaborations, they still show connections primarily with China demonstrating regional ties and emerging research interests. Similarly, India, Japan, and South Korea maintain medium-strength links and appear to collaborate more with China and the United States, which may reflect their growing roles in the fire safety and risk management research space. The Russian Federation and Serbia are somewhat isolated in the network but do maintain collaboration links with a few European countries like France and Netherlands. Countries like Morocco, Bulgaria, and Norway appear to engage mainly within European networks, especially with countries like Portugal, Spain, and Italy.

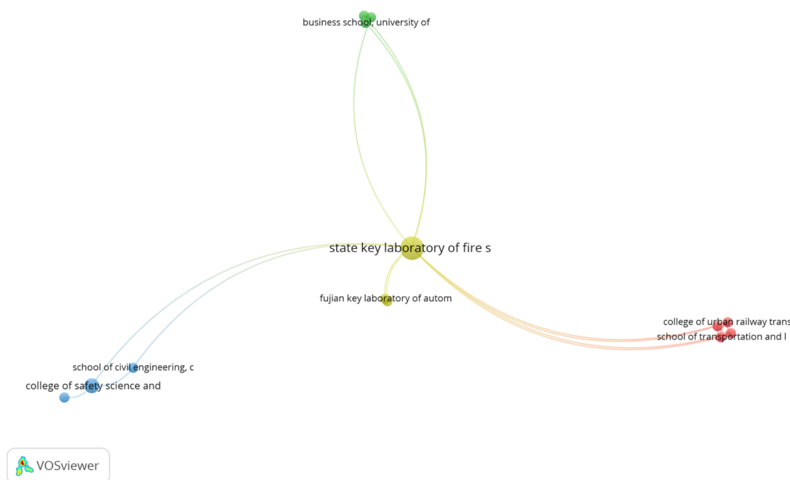


**Fig. 13**: Co authorship Organization

Each node on the map represents an organization, with the size of the node reflecting the publication volume or centrality of that institution in the collaborative network. The connecting lines (edges) indicate co-authored research papers, and the thickness of these lines significanes the strength or frequency of collaboration. Clusters are color-coded to show groups of institutions that tend to work closely together. At the center of this network lies the State Key Laboratory of Fire Science, which acts as a primary hub of research collaboration. Its prominent node size demonstrates its pivotal role in driving fire-related research, not only through its own output but also by fostering collaborative projects with other institutions. This laboratory appears deeply connected with several others, indicating a leadership position in China's fire science research community. It serves as a central nexus, linking institutions from various academic disciplines and geographical regions. Closely connected to it is the Fujian Key Laboratory of Automation, reflecting a growing interdisciplinary collaboration between fire science and automation technologies an emerging trend in modern fire detection, suppression systems, and predictive modeling. This partnership suggests a move towards the integration of engineering, automation, and safety science. The Business School, University of (name not fully visible) also appears as a significant partner, likely bringing in perspectives related to risk management, decision science, and economic implications of fire hazards. This indicates a cross-disciplinary approach where economic and managerial aspects of fire risk are being considered alongside engineering and technical concerns. Another noteworthy cluster includes institutions like the College of Safety Science and Engineering and the School of Civil Engineering. These nodes, while slightly smaller, highlight their strong collaborative relationship with the State Key Laboratory of Fire Science. Their involvement suggests an emphasis on structural fire safety, materials behavior under fire conditions, and engineering resilience, pointing toward a technical and applied science focus. On the opposite side of the map, the College of Urban Railway Transportation and the School of Transportation and Logistics form a distinct red-colored cluster. Their collaboration with the central node indicates a

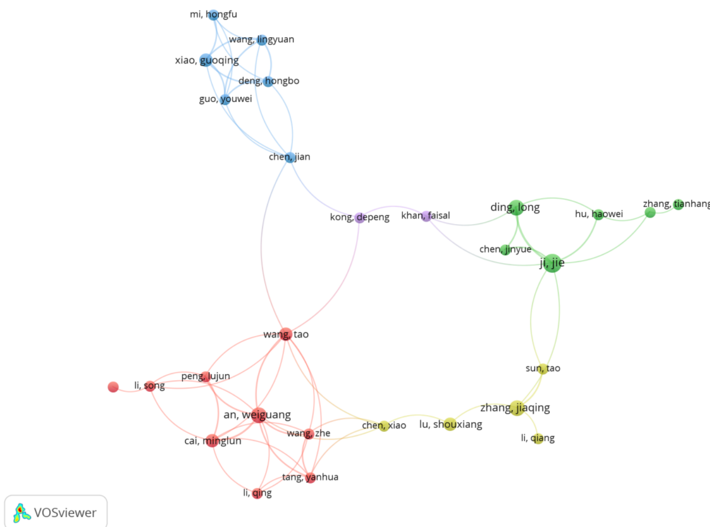


**Fig. 14**: Co authorship authors

specialization in transportation infrastructure safety, which is especially critical in the context of densely populated urban environments and the increased fire risks associated with underground and mass transit systems.

The size of each node reflects an author's influence or productivity typically based on publication frequency or citation impact while the connecting lines denote the strength of their collaborative relationships. The color-coded clusters highlight groups of authors who frequently collaborate with each other, often due to shared institutional affiliations or common research themes. At the center of the green cluster is Ji Jie, who emerges as a central figure with robust connections to other prominent researchers such as Ding Long, Chen Jinyue, and Hu Haowei. This group appears to be tightly connected, indicating a well-established research team that consistently collaborates. Their interlinkages and central positioning suggest a highly productive and cohesive research unit, likely focused on a particular specialization within fire risk assessment potentially in simulation modeling or experimental fire safety testing. On the opposite side of the map, the red cluster is anchored by An Weiguang, Wang Tao, and Peng Lujun. This cluster is relatively large and dense, suggesting a vibrant research team with diverse contributors. Their broad network of collaborators, including Li Song and Tang Yanhua, reflects an openness to cross-collaborative initiatives. This group involved in more engineering-oriented or applied fire safety research, possibly linked to infrastructure, fire protection systems, or industrial hazard assessments. The blue cluster, which includes Chen Jian, Guo Youwei, Xiao Guoqing, and Wang Lingyuan, also represents a coherent group with a strong internal collaboration pattern. Their connection to the red cluster through Chen Jian positions this author as a bridge figure who facilitates interdisciplinary or cross-institutional collaboration. This suggests that Chen Jian may be playing a leadership or coordination role across multiple research groups. A smaller but significant purple cluster includes Kong Depeng and Khan Faisal, who serve as a connecting link between the blue and green clusters. Their position suggests that they contribute to interdisciplinary research, possibly integrating global perspectives or international partnerships into the predominantly China-centered collaboration network. The yellow cluster features Zhang Jiaqing, Lu Shouxiang, and Chen Xiao, who appear to operate at the interface of multiple research domains. Their connections span both the green and red clusters, indicating that their work may cut across traditional boundaries perhaps dealing with hybrid approaches that involve both technical engineering aspects and theoretical risk modeling.

## 8 Conclusion and Scope for Further Research

This bibliometric study provides a comprehensive overview of the scholarly landscape on fire risk assessment and mitigation, highlighting key publication trends, influential authors, leading journals, and dominant research themes. The analysis reveals a steady growth in research output over recent years, indicating increasing academic and practical interest in fire risk management, particularly in relation to technological advancements such as artificial intelligence, machine learning, and data-driven risk assessment models. The findings also demonstrate that research contributions are geographically concentrated in a few developed countries, while developing regions despite facing higher fire vulnerability remain underrepresented in the literature. This study contributes to the existing body of knowledge by systematically mapping the intellectual structure of the field and identifying emerging research directions, thereby offering a valuable reference for researchers, policymakers, and practitioners engaged in fire safety and risk management. Based on the findings of this bibliometric analysis, several avenues for future research are identified. There is a need for more region-specific and context-driven studies, particularly focusing on developing countries where industrial growth and urbanization are rapidly increasing fire risks. Future research can also explore interdisciplinary integration by combining fire risk assessment with urban planning, climate change studies, occupational safety, and disaster resilience frameworks. While recent studies highlight the growing use of artificial intelligence and smart technologies, further empirical validation and real-world implementation studies are required to assess their effectiveness in diverse industrial settings. Longitudinal bibliometric studies incorporating dynamic citation and collaboration networks could also provide deeper insights into the evolution of research themes and knowledge diffusion over time. This study has certain limitations that must be acknowledged. The bibliometric analysis is limited to publications indexed in selected academic databases, which may exclude relevant studies published in non-indexed journals, regional databases, or grey literature such as technical reports and policy documents. The analysis relies primarily on quantitative indicators such as publication counts and citation metrics, which may not fully capture the qualitative depth or practical impact of individual studies. The use of predefined keywords may also have led to the exclusion of relevant research using alternative terminology. Consequently, the findings should be interpreted as a structured overview of the existing literature rather than an exhaustive representation of all research conducted in the field.

## Declarations


- The authors received no specific funding for this study.
- The authors declare that they have no conflicts of interest to report regarding the present study.
- No Human subject or animals are involved in the research.
- All authors have mutually consented to participate.

- All the authors have consented the Journal to publish this paper.
- Authors declare that all the data being used in the design and production cum layout of the manuscript is declared in the manuscript.

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