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REVIEW

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Drones in disaster management: Evaluating research patterns, impact, and knowledge structure

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ABSTRACT

This study presents a comprehensive bibliometric analysis of global research on the application of drone technology in disaster management from 2001 to 2024. Using bibliometric techniques, the study examines publication trends, influential sources, leading authors and institutions, collaboration networks, and the evolving thematic structure of the field. The results reveal a substantial growth in scientific output, particularly after 2018, with a sharp increase between 2021 and 2024, indicating rapidly expanding interest in drone-based disaster monitoring, emergency response, and risk reduction. Citation analysis highlights several foundational studies from the early 2000s that shaped the field, followed by a surge of newer contributions as drone technologies advanced. Leading journals such as *Proceedings of SPIE*, *Drones*, *Remote Sensing*, *ISPRS Archives*, and *Sensors* play a significant role in disseminating research in this domain. The analysis also shows strong contributions from major research institutions in China and the United States, reflecting the technological leadership of these countries. Thematic and conceptual analyses indicate a shift from early remote sensing and geospatial applications toward advanced technological themes including autonomous navigation, motion planning, reinforcement learning, and IoT-enabled disaster monitoring systems. Two dominant research clusters emerge: UAV technological development and disaster management applications. Collaboration network analysis further reveals strong international partnerships, particularly between the United States, China, and European research groups, alongside increasing participation from Asia-Pacific and Middle Eastern countries. The study identifies emerging research directions including multi-UAV coordination, improved communication resilience, regulatory frameworks, and integration of drone systems into emergency response and smart city infrastructures. These findings provide a comprehensive overview of the knowledge structure and future research pathways for drone-based disaster management.

KEY WORDS

Artificial intelligence; Bibliometrics; Disaster management; Drone technology; Global collaboration networks

ARTICLE HISTORY

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Introduction

The Disaster Management field is gaining importance in the contemporary world that it is being added to raise awareness in society through education, training and so on [1]. As the technological innovations are getting to their peak, drones are selected as a major research focus, as they provide advantages in disaster surveillance [2]. It is being recognised that they can be helpful in disaster management, from mapping, search and rescue, supply and delivery of essential needs [3,4]. The drone technology in disaster response that we see today was originally developed for military purposes [5]. This technology can enhance mountain rescue by reducing risk for the victims and has insights into civilian disaster response, particularly in harsh weather conditions [6]. An example of the transformative role of drones in disaster response was demonstrated by the response to the Noto Peninsula Earthquake; the mapping, communication, supply, etc., were managed and helped to reach even the isolated communities [7]. The drone routing in post disaster inspection genuinely undercuts the response efficiency, and it can be addressed as a valid model for disaster response [8]. This technology offers new possibilities for efficient disaster response[9]. As an example, India's urban disaster framework integrating with drone technology is addressed in studies related to Mumbai's situational awareness, speedy rescue and resource distribution in the global context [10]. Drones can be very effective because of obtaining a wide view or the aerial dimension, which helps in easily assessing information [11]. Adopting drone technology can enhance the benefits for public during health emergencies [12].

Analysing the research trends helps in finding the gaps in the research area which is needed to be addressed in future [13]. Bibliometric analysis act as a key tool in addressing the intellectual structures, mapping research knowledge, collaborations and the insights of traditional review techniques [14]. The exponential growth of such research in recent years made achievements but still the absence of standardized guidelines in the area shows inconsistencies [15]. The continuous advancements significantly increase the precision in bibliometric studies [16]. The initiation of tools such as Biblioshiny and SciMAT has marked a turning point in how researchers can visualize and interpret bibliometric data, allowing for detailed depiction and insights into academic contributions [17]. Platforms like Scopus and Web of Science further facilitates great mapping knowledge of research trends emerging in various academic fields become crucial [18].

Objectives

- To analyse the growth trends and publication patterns in drone technology in disaster management.

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- To identify the most influential authors, journals, and documents contributing to the scholarly development of this field.
- To map the thematic structure of drones in disaster studies by categorising the dominant and emerging research themes.
- To examine patterns of collaboration and co-authorship networks within the global research community.

Methodology

Bibliometric analysis is a quantitative research method used to evaluate the structure, impact, and trends within a scientific domain through statistical and network-based approaches [19]. This study presents a systematic review of the research landscape on drone technology for disaster risk reduction. The dataset was compiled from both Scopus and Web of Science (WoS), covering the period from 2001 to 2024. An initial total of 4,297 records from Scopus and 1,142 records from WoS were retrieved. After identifying and removing 1,042 duplicate entries, the final dataset comprised 4,257 unique documents sourced from 940 outlets, including journal articles, conference proceedings, book chapters, and review papers. Productivity is based on this method. It also measures the impact, relevance, bibliometric indicators such as growth rate per average year, timeline, average citation and collaborations [20].

Descriptive analysis was conducted to examine the publication data set in terms of publication patterns from year to year, document type and authorship, while keyword analysis was conducted using Author Keywords and Keywords Plus to examine thematic diversity and to identify emergent areas of focus. Co-authorship and international collaboration were evaluated using the co-authors per document measure and the percentage of internationally authored documents, both of which are illustrative of the collaborative and global nature of the data [21]. The methodological framework adopted established bibliometric principles to demonstrate reliability and reproducibility while permitting the evaluation of existent gaps in literature, knowledge structures and emergent trajectories in the literature [22] (Figure 1).

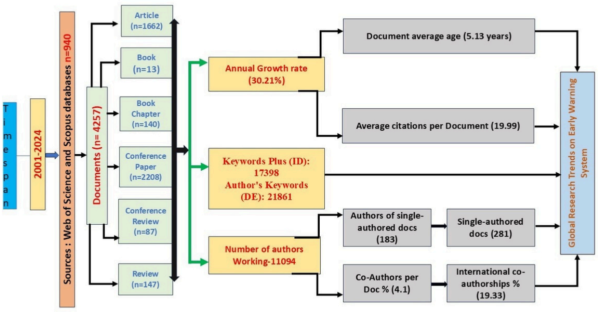

Figure 1. Methodology flow chart.

The data collection stage involves extracting relevant research articles from selected databases using well-defined search queries. The search query has been used for extracting documents from Scopus and Web of Science data sources, which are listed below:ss (("drone technology" OR "unmanned aerial vehicle" OR UAV OR "unmanned aircraft system" OR UAS OR "remotely piloted aircraft" OR RPAS OR "UAV photogrammetry" OR "UAV-based mapping" OR "UAV remote sensing" OR "drone imaging" OR "UAV monitoring") AND ("disaster management" OR "disaster response" OR "disaster risk reduction" OR "emergency management" OR "emergency response" OR "post-disaster assessment" OR "damage assessment" OR "search and rescue" OR "earthquake disaster" OR "flood disaster" OR "landslide disaster" OR "cyclone disaster" OR "wildfire disaster" OR "natural hazard")).

Data analysis

The study employed Biblioshiny, a bibliometric analysis interface built on the R package, to conduct a comprehensive examination of the literature [23]. The methodologies adopted included:

- **Descriptive analysis**

Examined publication trends, leading journals, influential authors, and citation patterns.

- **Co-occurrence analysis**

Investigated relationships among keywords to understand underlying conceptual structures.

- **Thematic mapping**

Classified research themes based on centrality and density into Motor Themes, Basic Themes, Niche Themes, and Emerging or Declining Themes.

- **Thematic evolution analysis**

Tracked the temporal progression and shifts in research focus across different periods.

- **Factorial analysis**

Identified and interpreted major thematic clusters through multivariate statistical techniques.

- **Collaboration network analysis**

Mapped prominent research institutions and international collaborative linkages.

Results and Discussion

Annual scientific production

The temporal distribution of publications reveals a progressive increase in research output on drone technology in disaster management from 2001 to 2024 (Figure 2). The field witnessed sporadic growth in the early 2000s, with fewer than 30 annual publications until 2007. A gradual increase followed between 2008 and 2014, ranging from 27 to 77 articles annually. A notable turning point occurred in 2015, with over 100 articles published, marking the onset of rapid growth. This acceleration can be attributed to technological advancements in UAV platforms, miniaturised sensors, and the rising frequency of natural disasters demanding innovative solutions. The period between 2015 and 2020 demonstrated sustained growth , culminating in 373 publications in 2020. The COVID-19 pandemic may have also acted as a catalyst, as UAVs gained attention for remote

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monitoring and contactless delivery in emergency contexts.

The most dramatic surge occurred after 2021, with publications rising from 421 (2021) to 867 (2024) representing a 106% increase within three years. This exponential rise underscores the mainstreaming of drone applications in disaster risk reduction, as well as the integration of UAVs with emerging technologies such as artificial intelligence, IoT, and geospatial analytics. The study highlights how research on drones for disaster management has transformed from a niche focus in the early 2000s to a highly dynamic and interdisciplinary field in the 2020s.

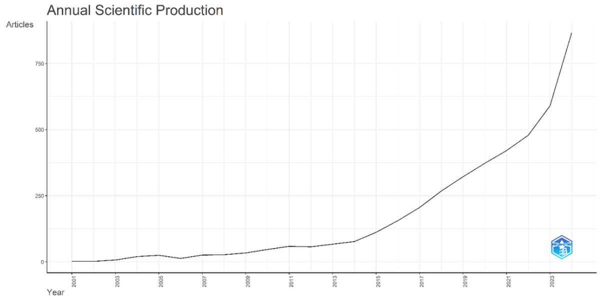

Figure 2. Annual scientific production (all figures in this paper, except Figure. 6 has been prepared using Biblioshiny) [23].

Average citations per year

The analysis of citation patterns reveals a dynamic evolution in the scholarly impact of drone-related disaster management research. During the early 2000s (2001–2005), despite the limited number of publications, articles tended to attract relatively higher citations per paper (e.g., 42.29 in 2003 and 22.15 in 2004). From 2006 to 2012, the citation averages fluctuated between 12 and 49 citations per article. Notably, 2008 marked the peak with 49.37 citations per article, likely driven by influential case studies and methodological advancements in UAV-based mapping and remote sensing. Between 2013 and 2017, the field expanded rapidly, but citation averages remained uneven. For instance, 2013 recorded a modest 11.10, whereas 2016 reached 43.84 citations per article indicating the publication of highly impactful papers in that year.

From 2018 onward, annual publication volumes surged, but the average citations per article gradually declined (35.46 in 2019, 28.02 in 2020, 20.28 in 2021, down to only 4.18 in 2024). This decline reflects a typical “citation dilution effect”: as the field matures and output increases, the relative share of citations per article decreases, particularly for the most recent years where citation windows are short. The citation trend demonstrates that while early studies had high per-article influence, the 2020s represent an era of rapid expansion with growing contributions but relatively fewer citations per article due to recency and saturation effects.

Most relevant sources

The Proceedings of SPIE – The International Society for Optical Engineering emerges as the most prolific source, contributing 102 articles. This reflects the strong presence of conference-driven research in the field, particularly focused on imaging technologies, sensors, and UAV-based photogrammetry. Among journals, Drones (82 articles) and Remote Sensing (76 articles) rank highly, underscoring the dominant role of remote sensing and UAV imaging applications. Both journals provide open-access platforms that attract interdisciplinary contributions spanning environmental science, engineering, and disaster studies. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Archives) and Sensors each contributed 71 articles, further consolidating the centrality of geospatial technologies and sensor integration in UAV disaster applications.

In addition, Lecture Notes in Computer Science (64 articles) and IEEE Access (58 articles) highlight the growing role of computer science, AI, and data-driven approaches in UAV disaster research. Emerging interest is also evident in journals like Applied Sciences (Switzerland) (37 articles) and IEEE Internet of Things Journal (30 articles), which emphasise the convergence of UAVs with IoT and smart technologies for disaster risk reduction. The International Geoscience and Remote Sensing Symposium (IGARSS) contributes 30 publications, further confirming the centrality of large-scale, geospatially focused conferences in advancing this research domain. The dominance of remote sensing, engineering, and computer science outlets illustrates the highly technical and interdisciplinary nature of UAV research in disaster management. The relatively lower representation of policy, social sciences, and humanitarian-focused journals suggests a gap in addressing regulatory, ethical, and societal aspects of UAV deployment.

Core sources by Bradford's law

According to Bradford’s Law of Scattering, scientific knowledge on a specific topic is distributed unevenly across journals, where a small number of core sources contribute many publications, followed by zones of moderate and peripheral sources. Figure 3 presents the distribution of journals publishing research on drone technology applications in disaster management. The steep initial slope represents a concentration of articles within a few core journals, which are the primary outlets for scholarly communication in this field [24].

The analysis identifies journals such as Proceedings of SPIE, Drones, Remote Sensing, and The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences as the core sources producing the highest number of articles. The gradual decline in the curve beyond the core zone indicates the presence of numerous peripheral sources journals that publish fewer but specialized studies integrating UAVs with disaster risk reduction, damage assessment, and emergency response. This pattern validates the Bradfordian distribution, emphasizing that UAV-disaster management research is highly concentrated in a limited set of specialized journals that integrate remote sensing, geoinformatics, and disaster science domains.

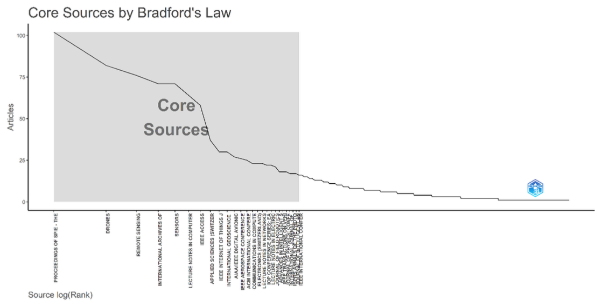

Figure 3. Core Sources by Bradford’s Law.

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Most relevant authors

The analysis of author productivity identifies the leading contributors to UAV and disaster management research (Figure 3). A strong presence of Chinese scholars is evident, reflecting the country's substantial investment in drone technologies and geospatial sciences. The most prolific author is Wang Y, with 49 publications (10.46 fractionalized), followed by Wang J (41 publications; 8.34 fractionalized), Zhang Y (40; 8.22), and Zhang J (37; 7.56). Other significant contributors include Li Y (31), Li J (30), Li Z (30), Chen Y (28), and Li X (28). The fractionalized publication count (which accounts for co-authorship) reveals a similar distribution, suggesting these authors frequently collaborate within larger teams, a trend characteristic of highly technical and interdisciplinary research domains such as UAV disaster applications. The dominance shows the existence of research clusters or schools of thought, particularly in China and East Asia, where UAV technology has been rapidly adopted and supported by national research funding.

Notably, the recurring surnames (Wang, Zhang, Li, Chen) highlight the possibility of author name disambiguation issues, a common challenge in bibliometric studies of Chinese authorship. This highlights the need for complementary analyses (e.g., institutional or ORCID-based mapping) to accurately represent collaboration networks. The author's analysis suggests that the knowledge base of UAV applications in disaster management is heavily shaped by a concentrated group of prolific researchers, whose contributions anchor the field's methodological and applied advancements.

Author productivity through Lotka's law

Lotka's Law describes the frequency distribution of scientific productivity, stating that the number of authors making n contributions is about 1/n2 of those making a single contribution. In other words, a small number of authors contribute a large share of publications, while most authors publish only one paper in the given field. Figure 4 illustrates the application of Lotka's Law to the dataset on drone technology and disaster management. The curve shows a steep decline, indicating that most authors have published only one article, whereas a limited number of prolific contributors have produced multiple papers on the subject [25].

The concentration of publications among a few active authors reflects the emerging yet specialized nature of research in this field dominated by experts working on UAV remote sensing, geospatial data analysis, and disaster response technologies The results also emphasize the need for collaborative networks and interdisciplinary research to balance contributions and promote wider dissemination of knowledge.

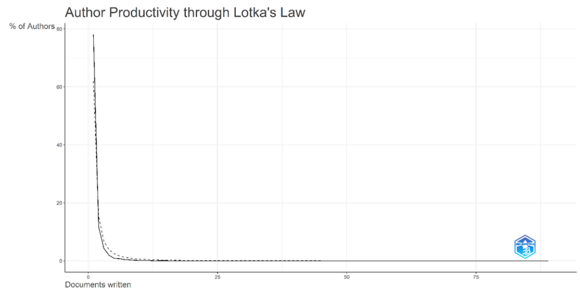

Figure 4. Author Productivity Through Lotka's Law.

Most relevant affiliations

The analysis of institutional contributions reveals several leading centres of research on UAV applications in disaster management. The College of Engineering, with 107 publications, emerges as the most prolific contributor, reflecting the dominant role of engineering faculties in advancing UAV technologies for disaster-related applications. The National University of Defence Technology in China follows with 49 publications, underscoring the strong influence of defence-oriented research on UAV development, particularly in areas such as remote sensing, communication systems, and operational deployment.

The NASA Ames Research Center is another prominent institution, with 43 publications highlighting the United States' leadership in aerospace and environmental monitoring research. European universities also play a significant role, with Politecnico di Torino (40 publications) and the University of Cyprus (39 publications) producing notable work in photogrammetry, geospatial science, and UAV-based disaster resilience. In China, Beihang University (35 publications), the Beijing University of Posts and Telecommunications (28 publications), and the Chengdu University of Technology (28 publications) stand out as active contributors, demonstrating the country's breadth of expertise across aerospace, telecommunications, and geoscience applications. The University of Klagenfurt in Austria, with 27 publications, highlights Europe's growing engagement in UAV research for disaster management, particularly through interdisciplinary collaborations in computer science, engineering, and environmental studies. The study dataset also records 35 publications without reported affiliations, reflecting gaps in metadata reporting. Taken together, these findings show that UAV research in disaster management is shaped by a combination of defence institutions, space and aeronautics research centers, and academic universities, emphasizing the interdisciplinary and multi-sectoral character of the field.

Corresponding author's countries

The findings differentiate between publications authored solely within a single country (Single Country Publications – SCP) and those resulting from international collaboration (Multiple Country Publications – MCP). The MCP ratio serves as an indicator of the extent of international research engagement among nations, reflecting varying capacities, priorities, and strategies in scientific collaboration (Figure 5). China emerges as the dominant contributor, followed by the United States and India, indicating a clear global hierarchy in research productivity. China's leadership in publication output underscores its significant investment in research and development and its strategic commitment to advancing technological innovation in disaster monitoring and management. The United States remains a major producer of scholarly work, supported by its strong institutional base and advanced technological infrastructure, while India's growing research output signifies an expanding national capacity and institutional engagement in UAV and disaster-related studies.

Contrasting patterns of collaboration are evident across countries. The United States, despite its high research productivity, records a notably low MCP ratio (0.3%), suggesting that most research is conducted domestically. This may reflect the country's self-sufficiency in research infrastructure and funding but also warrants verification, as the value appears unusually low and could result from database indexing inconsistencies or affiliation coding issues.

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In contrast, countries such as Canada (50.5%), Australia (47.1%), France (46.7%), Austria (46.2%), Pakistan (41%), and Brazil (39.2%) display high international collaboration rates. Several nations exhibit intermediate levels of collaboration, balancing domestic and international research engagements. Countries such as Germany (23.8%), Japan (28.4%), South Korea (18.7%), Italy (15.3%), and India (17.1%) demonstrate a moderate MCP ratio, indicating both established national research systems and selective participation in global collaborations.

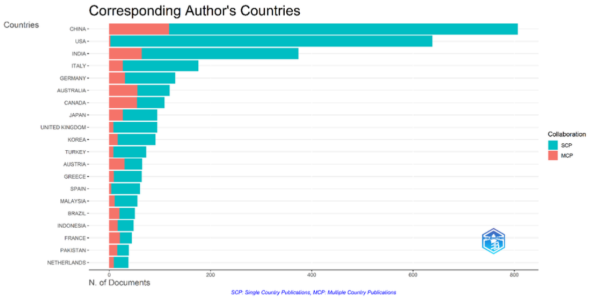

Figure 5. Corresponding Author's Countries.

The level of collaboration carries broader implications for scientific development and knowledge diffusion. At the country-specific level, China demonstrates the highest number of publications but a moderate MCP ratio (14.6%), reflecting its extensive domestic research ecosystem. The United Kingdom and Spain exhibit relatively lower MCP ratios (8.4% and 6.6%, respectively*), despite their strong research traditions. This may be linked to post-Brexit funding realignments in the UK or historically domestic-oriented funding structures in Spain. Meanwhile, developing economies such as India, Brazil, Indonesia, and Pakistan show increasing publication output accompanied by moderate to high collaboration levels, indicating growing participation in international research efforts. Their engagement suggests an emerging commitment to addressing development-oriented challenges, capacity building, and the pursuit of resilience-focused research through cross-border cooperation. The distribution of research output and collaboration intensity reflects the evolving landscape of global scholarship on drone technology in disaster management. Countries with established research ecosystems continue to dominate production, while developing nations increasingly contribute through international partnerships.

Countries' scientific production

In Countries scientific production China leads with 1865 publications, followed closely by the United States with 1665 publications. Together, these two countries account for nearly half of the global output, reflecting their significant investments in drone technologies, aerospace research, and disaster risk reduction initiatives. China's dominance can be attributed to its rapid adoption of UAVs for large-scale environmental monitoring and emergency response, supported by strong governmental and industrial collaboration. The United States, on the other hand, demonstrates leadership through technological innovation, integration of UAVs with AI and IoT, and deployment in both domestic and international disaster scenarios.

India ranks third with 713 publications, underscoring its growing research footprint in geospatial technologies and UAV-based disaster management, particularly in flood mapping and post-disaster assessments. European contributions are also notable, with Italy (400 publications), the UK (272), and Germany (263) emerging as leading centres of UAV research in the region. These countries often emphasize precision photogrammetry, civil protection applications, and collaborative EU-funded disaster resilience projects. In Asia-Pacific, Japan (249), Australia (188), and South Korea (178) represent important contributors, highlighting the role of technologically advanced economies in leveraging UAVs for disaster response and environmental risk management. Canada (172) also demonstrates a strong presence, with research often focused on wildfires, northern geographies, and remote-sensing-based monitoring.

The global distribution indicates that UAV research for disaster management is geographically diverse but concentrated in technologically advanced nations. The study suggests a growing trend of international collaboration particularly between Asia, North America, and Europe reflecting the cross-border relevance of disaster resilience.

Most cited countries

China ranks first in total citations with 14,315, reflecting its dominant publication output, although its average of 17.70 citations per article suggests that its high impact is spread across a very large number of contributions. The United States follows with 12,408 citations and a slightly higher average of 19.40 citations per article, highlighting both strong productivity and consistently influential outputs (Figure 6). India holds third place with 4,884 citations and an average of 13.10 citations per article, reflecting its growing role in the field, though its impact per publication is somewhat lower compared to Western countries.

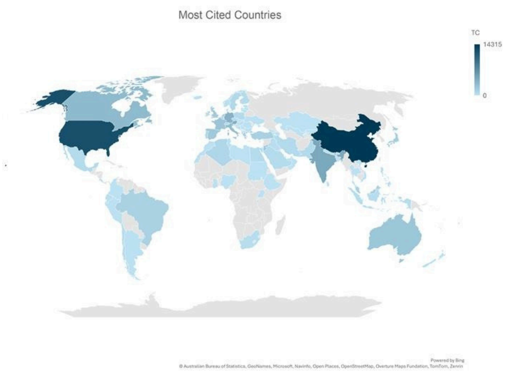

Figure 6. Most Cited Countries: World Map Illustration.

Most global cited documents

The analysis of the most globally cited documents highlights the foundational works shaping UAV research in disaster management and related fields. The most cited paper is Shakhatreh et al. (2019, IEEE Access, DOI: 10.1109/ACCESS.2019.2909530) with 1863 citations, offering a comprehensive survey of UAV applications and communication challenges. Hayat et al. (2016, IEEE Communications Surveys & Tutorials, DOI: 10.1109/COMST.2016.2560343) follow with 1182 citations, focusing on UAV communication systems. Chamola et al. (2020, IEEE Access, DOI: 10.1109/ACCESS.2020.2992341), cited 956 times, gained attention for UAV use during COVID-19.

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Other influential works include Kaltenbrunner et al. (2015, Nature Materials, DOI: 10.1038/nmat4388) with 895 citations on flexible electronics, and Erdelj et al. (2017, IEEE Pervasive Computing, DOI: 10.1109/MPRV.2017.11) with 863 citations on UAVs in disaster management. Tomić (2012, IEEE Robotics and Automation Magazine, DOI: 10.1109/MRA.2012.2206473) and Otto (2018, Networks, DOI: 10.1002/net.21818) address robotics and communication networks, with 760 and 734 citations respectively. Zhao (2019, IEEE Wireless Communications, DOI: 10.1109/MWC.2018.1800160), with 667 citations, contributes to UAV wireless strategies.

Recent contributions include Mohsan (2022, Drones, DOI: 10.3390/drones6060147) with 596 citations and Cabreira (2019, Drones, DOI: 10.3390/drones3010004) with 480 citations, highlighting UAV applications in environmental and disaster contexts. These works collectively underscore the balance of surveys, technological innovations, and applied research that define the UAV research landscape.

Most frequent words

A keyword frequency analysis (Figure 7) highlights the dominant themes in UAV-related disaster management research. The most frequently occurring term is "unmanned aerial vehicles (UAV)" (2406 occurrences), confirming the centrality of UAV platforms as the technological backbone of the field. Closely related terms such as "aerial vehicle" (944), "unmanned aerial vehicle" (782), and the acronym "UAV" (702) further reinforce this focus.

In terms of applications, "search and rescue" (875) and "disasters" (801) appear prominently, indicating a strong emphasis on operational deployment of UAVs in emergency response and crisis situations. The presence of "disaster prevention" (625) reflects a growing body of research extending beyond immediate response toward proactive risk reduction strategies.

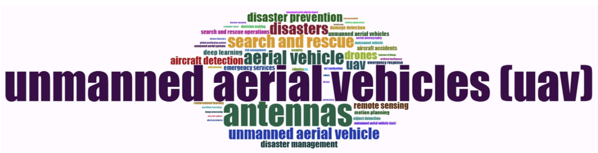

Figure 7. Keyword Frequency.

From a technical standpoint, "antennas" (1774) and "aircraft detection" (532) signal considerable attention to the engineering and communication dimensions of UAVs, including navigation, remote control, and collision avoidance critical requirements for effective UAV deployment in disaster zones. The keyword "drones" (597) also appears frequently, reflecting broader, interdisciplinary research that integrates UAV studies with policy, humanitarian, and applied disaster management perspectives.

The word cloud confirms that research in this domain is strongly technology-driven (antennas, aircraft detection, UAV platforms), but equally shaped by practical disaster applications (search and rescue, disaster prevention). This dual focus underscores the interdisciplinary nature of the field, bridging engineering innovation and disaster resilience practices.

Trend topics

The longitudinal distribution of keywords illustrates how the scientific focus has transitioned from foundational studies to advanced technological applications over the past two decades. A distinct pattern of thematic progression is evident, with the dominance of unmanned aerial vehicle (UAV) research emerging as the most significant trend. Keywords such as "unmanned aerial vehicle," "drones," "unmanned aerial systems," "aircraft detection," and "aerial vehicle" demonstrate a marked increase in frequency, particularly from the mid-2010s onward. The timeline also reveals a clear evolution of terminology, wherein broader early terms like "unmanned vehicles" gradually gave way to more precise and standardized expressions such as "unmanned aerial vehicles (UAV)" and "drones." This linguistic refinement signifies the maturation of the technology and the establishment of distinct research subfields.

The topic distribution also underscores the integration of UAVs with related technologies and applications. Frequent keywords such as "remote sensing," "aircraft control," "sensors," "control strategies," and "image processing" highlight the convergence of UAV research with communication systems, sensor technologies, and artificial intelligence. In the early stage (2005–2010), the focus was primarily on "military aircraft," "mathematical models," "standards," and "flight testing." This reflects a period of foundational research emphasizing theoretical frameworks, performance evaluation, and regulatory development. During 2010–2015, keywords like "intelligence," "algorithms," "sensors," and "image processing" gained prominence, highlighting the integration of AI-driven elements and data analytics capabilities into UAV systems. The period from 2015 to the present marks the full-scale emergence of UAV-centric research, with the dominance of terms such as "drones," "unmanned aerial vehicle," and "aircraft detection," indicating rapid technological progress and widespread scholarly interest.

The variety of recurring terms "sensors," "robotics," "algorithms," and "control strategies" emphasizes the cross-disciplinary nature of UAV research, requiring expertise from aerospace engineering, computer science, and environmental studies alike. It is important to acknowledge that the trends identified are based on SCOPUS-indexed data. Consequently, the patterns may be influenced by the scope and coverage bias of the database, as certain regional or domain-specific studies may be underrepresented. The emerging direction of UAV research points toward advanced automation, intelligent navigation, and system integration. Promising areas include autonomous flight control, edge computing, swarm coordination, reinforcement learning, and integration with Internet of Things (IoT) platforms. The trend analysis highlights a clear trajectory from early theoretical exploration to sophisticated, application-driven research, underscoring the pivotal role of UAV technology in shaping the future of disaster risk reduction and emergency response.

Co-occurrence network

The network structure reveals a well-organized thematic distribution, indicating the multidimensional nature of UAV research in disaster contexts. The application of the walktrap algorithm successfully identifies distinct clusters or communities and, in the visualization, these clusters are differentiated by colour, primarily red and blue, signifying two dominant research areas. Node size appears to correspond to degree centrality, suggesting that larger nodes denote more frequently co-occurring keywords and thus

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represent central concepts within the field (Figure 8). The varying edge thickness illustrates the strength of associations between keywords, where thicker connections indicate stronger thematic relationships and more frequent co-occurrence patterns.

The blue cluster is primarily centered around the keywords "antennas" and "unmanned aerial vehicles (UAV)". The presence of associated terms such as "computer vision," "artificial intelligence," "deep learning," "robotics," "air navigation," "aircraft control," and "drones" suggests that this cluster represents the technological and engineering dimensions of UAV research. It emphasizes areas such as UAV architecture, sensor systems, and autonomous flight mechanisms, as well as the integration of AI and machine learning techniques to enhance UAV efficiency, adaptability, and precision in dynamic environments. The red cluster is centered on the keyword "disasters," forming a distinct thematic community that focuses on the application of UAVs in disaster management, emergency response, and risk assessment. Prominent keywords such as "disaster prevention," "natural disasters," "emergency response," "risk management," "remote sensing," "photogrammetry," "damage detection," and "image processing" indicate an applied research orientation. The close association of terms like "remote sensing" and "photogrammetry" highlights the significant role of geospatial technologies in capturing, processing, and interpreting aerial imagery for disaster risk reduction and recovery operations. The clustering pattern confirms that much of the current research is concentrated on the use of UAV-generated imagery for disaster prevention, monitoring, and post-event assessment. Secondly, the presence of terms such as "machine learning," "remote sensing," "photogrammetry," and "image processing" demonstrates the methodological evolution of the field, indicating the increasing adoption of advanced computational and analytical tools for data processing and decision-making. These terms connect the technical development of UAV systems with their applied use in hazard detection, damage mapping, and emergency planning.

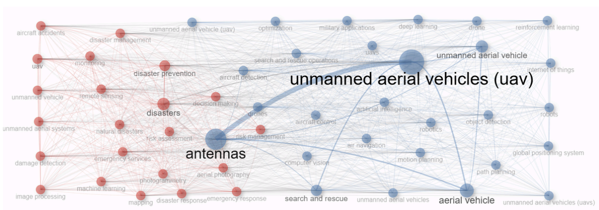

Figure 8. Co-Occurrence Network of Keywords.

Thematic map

The thematic map provides a strategic overview of the intellectual structure and evolution of research on drone technology in disaster management. The analysis highlights several distinct clusters. The first is the "drones" cluster, located in the bottom-left quadrant, which corresponds to emerging or declining themes. This group is centred on the broad keyword "drones" along with terms such as "simulations" and "aircraft." The generic term "drone" appears to have declined in centrality as the literature has matured into specialised directions. The second is the "human" cluster, situated in the top-left quadrant, reflecting a niche theme. This cluster relates to human-centred applications, including emergency health services and medical services. (Figure 9) Research in this area tends to focus on targeted applications such as medical supply delivery, emergency healthcare logistics, and human UAV interaction during crisis events. The third cluster, "motion planning," occupies the centre-right quadrant, aligning it with core or near-motor themes. This cluster encompasses terms such as robotics, air navigation, reinforcement learning, and motion planning. Its relatively high centrality and strong density highlight its importance as a technological foundation in UAV research. The "remote sensing" cluster is in the top-centre quadrant, reflecting a motor theme. It incorporates terms like disaster management, damage detection, and unmanned vehicles, indicating that UAV-based remote sensing and photogrammetry constitute a well-established and central research direction. This theme drives much of the current research agenda, given its indispensable role in damage mapping, hazard monitoring, and post-disaster assessment.

Finally, the "unmanned aerial vehicles (UAV)" cluster is positioned in the bottom-right quadrant, classifying it as a basic theme. This cluster includes terms such as antennas, aerial vehicles, and search and rescue. Its high centrality underscores the pivotal role of UAVs within this research field, while its lower density indicates that the theme remains underdeveloped and evolving. UAVs are recognized as an essential technological foundation, but further refinement in areas such as autonomous navigation, communication systems, and large-scale deployment is required to fully realize their potential.

The thematic map reveals a landscape characterized by both maturity and emerging potential. Remote sensing and motion planning are established and central themes, forming the technological and application-driven backbone of the field. Unmanned aerial vehicles represent a crucial but still developing area, pointing to significant opportunities for future research. The human-centered applications form a specialized niche, while the broad keyword "drones" is losing prominence as scholarship shifts toward more precise and impactful themes. Together, these clusters reflect an evolving field where UAV technology is increasingly integrated into disaster science, with growing emphasis on autonomy, sensing technologies, and applied resilience strategies.

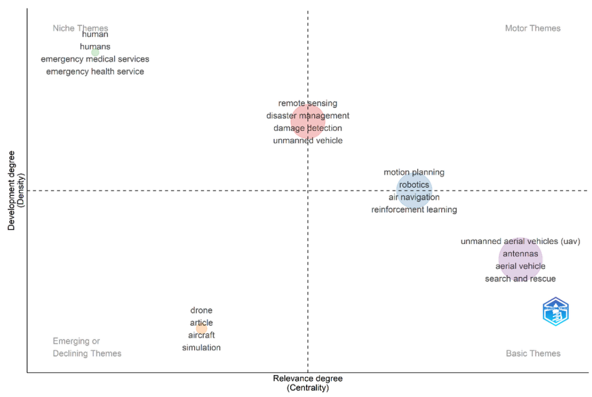

Figure 9. Thematic Map.

Thematic evolution

During the 2001–2009 period, research was characterized by foundational exploration and the establishment of UAVs as a potential tool for data collection and disaster applications. Topics such as cameras, remote sensing, and sensor

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networks indicate a focus on fundamental technologies, while emergency response, human factors, and personnel training suggest an interest in practical applications. The inclusion of systems analysis and data transfer reflects theoretical and infrastructural considerations. In the strategic map for this period, unmanned aerial vehicles and remote sensing appeared as motor themes, confirming their central importance, while areas such as personnel training and project management remained underdeveloped as basic themes. At the same time, NASA and decision support systems occupied niche positions, reflecting specialized but less central roles. Themes such as intelligent agents and computational complexity emerged at the periphery, showing early experimentation or declining interest (Figure 10).

The 2010–2019 period marked a phase of consolidation and focus, as UAV research became more centered around specific technologies and applications. Unmanned aerial vehicles emerged as a dominant keyword, while computer simulation gained prominence, reflecting methodological advancements through modelling and testing. Remote sensing retained its importance, highlights its enduring role in UAV-based disaster monitoring and assessment. The strategic map analysis identified remote sensing, damage detection, and mapping as motor themes, confirming their centrality and maturity. In contrast, UAVs and disasters remained basic themes, signifying their importance but relatively lower development. Computer simulation appeared as a niche theme, highlighting its specialized application, while human-related terms such as human, humans, and procedures shifted to the emerging or declining quadrant, suggesting reduced centrality in UAV-focused research.

The 2020–2024 period represents a stage of specialization and advanced application. Research increasingly incorporates cutting-edge methods and targeted use cases. Topics such as motion planning and reinforcement learning indicate a shift toward autonomy, advanced control, and intelligent decision-making in UAV systems. Emergency medical services emerged as a niche theme, reflecting the integration of UAVs into healthcare and emergency logistics. Basic themes such as aerial vehicle and antennas point to ongoing work on UAV hardware and communication systems. At the same time, broad terms like drone and human occupy the emerging or declining quadrant, showing that general or less-defined topics are losing ground to more sophisticated, application-oriented research.

The strategic progression from remote sensing and damage detection toward motion planning, reinforcement learning, and emergency medical services illustrates a shift from basic data acquisition to intelligent, autonomous, and application-driven systems. Moreover, the incorporation of computational methods such as computer simulation and reinforcement learning underscores the field's methodological evolution, reflecting the increasing reliance on artificial intelligence and machine learning. The emphasis on advanced autonomy and specific disaster-related applications indicates that future work will continue to integrate UAVs into operational frameworks for disaster preparedness, response, and recovery, thereby enhancing both scientific advancement and practical resilience outcomes.

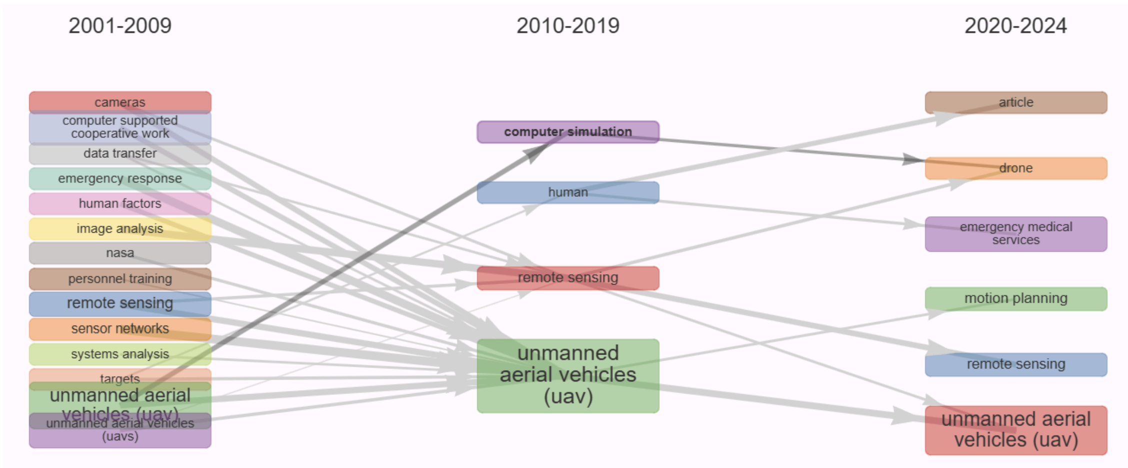

Figure 10. Thematic Evolution.

Factorial analysis

The factorial analysis provides a multidimensional view of the relationships among key concepts in the literature on UAVs and disaster management. The first two dimensions explain approximately 59.53% of the variance (Dim 1: 31.36%, Dim 2: 28.17%), which suggests that the two-dimensional representation captures the structure of keyword relationships reasonably well. While a significant proportion of variance remains unexplained, the map offers a useful overview of the thematic organisation of the field, with additional dimensions likely representing finer substructures not captured here. (Figure 11).

Interpretation of the two axes indicates meaningful thematic divisions within the research domain. Dimension 1 (horizontal) appears to represent a continuum from data acquisition and sensing methods on the left to autonomous systems and applications on the right. Keywords such as photogrammetry and remote sensing are positioned on one end, while motion planning and reinforcement learning occupy the opposite side, reflecting a shift from information capture to advanced autonomous navigation. Dimension 2 (vertical) seems to distinguish between disaster-related applications at the top (keywords such as disaster prevention, disaster management, natural disasters) and robotics and navigation at the bottom (keywords such as robotics , aircraft control , search and

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rescue). This division underscores the dual focus of UAV research: disaster risk reduction and technological development in robotics.

Several coherent clusters emerge from the analysis. The disaster management and prevention cluster (top-left) includes terms like disaster prevention, disaster management, and natural disasters, highlighting the applied dimension of UAV research in risk reduction and hazard management. The remote sensing and mapping cluster (mid-left) is represented by photogrammetry, remote sensing, damage detection, and mapping, emphasizing the importance of geospatial technologies for data acquisition and impact assessment. At the center, the core UAV technologies cluster comprises terms such as unmanned aerial vehicles (UAV), drones, antennas, global positioning system, and machine learning. This cluster anchors the field, reflecting the technological backbone of UAV operations and their integration with computational methods.

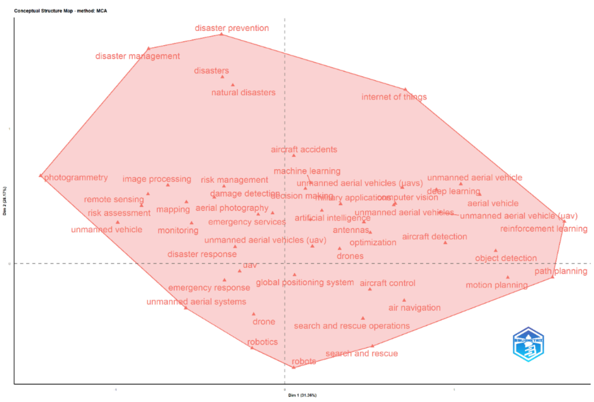

Figure 11. Conceptual Structure Map.

On the lower right, the robotics and autonomous navigation cluster includes terms such as robotics, robots, search and rescue, air navigation, aircraft control, motion planning, and reinforcement learning. This grouping reflects the increasing prominence of intelligent autonomy, with UAVs being applied to search and rescue operations, navigation in complex environments, and adaptive control. Finally, a smaller but distinct IoT and aerial vehicle cluster (top-right) links terms such as Internet of Things and deep learning with aerial systems, suggesting an emerging research direction where UAVs are integrated into smart, connected infrastructures for real-time disaster monitoring and data processing. The placement of terms relative to the origin provides additional insights into their significance. Central terms such as drones, UAVs, and global positioning system are located near the origin, underscoring their ubiquitous presence and fundamental role across multiple subfields. In contrast, peripheral terms such as disaster prevention and reinforcement learning are positioned farther from the origin, indicating their more specialized but highly characteristic associations with disaster management and autonomous navigation, respectively.

Taken together, the factorial analysis highlights both the core technological backbone of UAV research and the specialised thematic branches that extend into disaster prevention, geospatial data acquisition, and autonomous robotics.

Collaboration network

The relatively dense network structure indicates that international cooperation is well established, with frequent co-authorship among countries. A distinct core-periphery structure is evident in the network. At the centre, the USA and China dominate as the largest nodes, underscoring their position as central hubs of international collaboration. These two nations act as anchors of the global research landscape, shaping the flow of knowledge and resources. Surrounding them are secondary hubs such as Australia, South Korea, Germany, and other European nations, which also occupy prominent positions but are slightly less central. At the periphery, countries like Croatia, Romania, and Ukraine appear with fewer and weaker connections, reflecting their lower publication output, resource constraints, or more specialised research agendas. The application of the walktrap clustering algorithm reveals clear community structures within the collaboration network (Figure 12). The green community, led by the USA and China, includes countries such as Australia, Korea, Pakistan, Canada, Egypt, and Israel, along with several Asian and Pacific nations, including Thailand, Hong Kong, the Philippines, Bangladesh, and New Zealand. This grouping suggests a blend of collaborations shaped by both geopolitical and regional priorities, including technological innovation, disaster preparedness in the Asia-Pacific regions, and partnerships supported by US- or China-led funding initiatives.

The red community, representing Europe, comprises Germany, Italy, Spain, France, the Czech Republic, Poland, Finland, Sweden, the Netherlands, Austria, and Greece, along with Iraq. This reflects the impact of EU-funded frameworks and cross-national cooperation fostered by proximity and shared policy agendas. The inclusion of Iraq is likely tied to targeted collaborations supported through EU research programs addressing regional or post-crisis reconstruction needs.

The blue community, consisting of Romania and Ukraine, reflects a small but distinct grouping, potentially explained by targeted bilateral or regional funding schemes, as well as a shared focus on specific research challenges. Similarly, the purple community, represented by Croatia, highlights relative isolation, possibly due to language barriers, fewer resources for international engagement, or a narrower research focus that does not strongly intersect with global trends.

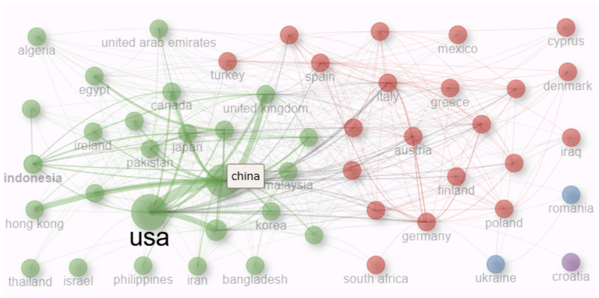

Figure 12. Collaboration Network of countries.

Among the most connected nodes, the USA and China stand out as global leaders, shaping not only research productivity but also international collaboration patterns. Their collaborations may be driven by large-scale technological and environmental research programs , with co-publications

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reflecting both data-sharing initiatives and joint scientific projects. Australia is also highly connected, with strong ties to both the USA/China community and other regions. This bridging role reflects Australia's dual position as a research-intensive nation and a strategic partner in Asia-Pacific collaborations, frequently participating in disaster management projects with regional relevance.

The collaboration network demonstrates a highly interconnected research field dominated by the USA and China, with Europe forming a strong secondary hub and several smaller communities operating at the periphery. The structure illustrates both the concentration of scientific influence within a few leading countries and the gradual integration of developing and transition economies into the global research landscape. This balance of strong central hubs and emerging peripheral participation underscores the importance of fostering broader inclusivity in UAV and disaster management research to ensure diverse perspectives and equitable knowledge exchange.

Conclusion

The timeline for research using drone technology in disaster management shows that these studies have moved from largely exploratory works focusing on remote sensing and simple hazard uses to a vibrant interdisciplinary domain predominantly powered by AI, IoT, robotic navigation, and sophisticated geospatial analytics. The steady rise in the number of papers, with the growth after 2020 being particularly impressive, is evidence of the worldwide push to use drones for disaster monitoring, damage assessment, and emergency response. In addition, analyses of authors and countries point out that the scientific work is mostly done by a handful of prolific authors and technologically advanced countries, mainly China and the United States, and this is made possible by their increasing networks of collaboration cutting across Europe, Asia, and emerging economies.

The analyses of the conceptual, thematic, and factorial aspects starkly highlight a progression of UAV usage from generic to more intelligent, autonomous, and hybrid models that assimilate simulation, reinforcement learning, motion planning, and IoT-enabled sensing. There are two significant thematic trajectories that become evident: one that concentrates on technological innovations in UAVs and their automation and the other that deals with the disaster applications such as search and rescue, disaster prevention, and emergency medical services. The collaboration network shows a well-linked worldwide research structure in which the USA and China play the role of central hubs, and Europe is the major secondary cluster. The presence of countries, such as Canada, Australia, Jordan, and Brazil, making relatively modest but still noteworthy contributions, is indicative of the field's growing international footprint.

While the overall worldwide progress has been quite impressive, there are still some unresolved research issues. Apparently, the areas that have a high risk of disasters, especially South Asia, Africa, and Latin America, are in a situation where they are significantly less represented not only in research leadership but also in collaborative networks. From a methodological point of view, the issues they face include author disambiguation, metadata completeness, and the establishment of standardized measures for the performance of UAVs in different types of disasters and settings. Moreover, they also face technical issues, which are multi-UAV coordination, long-endurance operations, resilient communication systems that are resilient, and integration with the existing infrastructures for early warning and emergency response.

Research in the future ought to concentrate on the formulation of uniform regulations that address ethical concerns, provide guidance for operations, and support the safe, fair, and widespread use of UAVs in disaster zones. The development of collaborations across regions that span and mostly consist of low-resource and data-scarce areas, would be very important in guaranteeing worldwide inclusiveness in UAV research and utilization. Additionally, there is quite a bit of room for the progression of intelligent systems like the autonomous coordination of swarms, AI onboard for making decisions in real-time, and linking with smart city and climate-monitoring infrastructures. By reinforcing these fields, the reliability, flexibility, and social worth of UAV technologies will be improved, thereby making a significant contribution to the overall accomplishment of disaster preparedness, response, and long-haul resilience at a global level.

Limitation

This study is limited to research indexed in Web of Science and Scopus, which do not cover all global publications; however, these databases are considered the most authoritative and reliable sources for high-quality scholarly data. Differences in their indexing policies, subject coverage, and language preferences may exclude relevant studies from other sources, and thus the findings reflect only the literature available within these two databases.

Credit Author Statement

Adarsh T: Conceptualisation, Methodology, Data Collection, Bibliometric Analysis, Factorial Analysis, Visualisation, Writing – Original Draft, Writing – Review & Editing; Neenu S Pillai: Contribution to Methodology, Assistance in Data Collection, Writing – Review & Editing.; Suresh S: Supervision, Guidance in Methodology and Interpretation, Writing – Review & Editing.

Data Availability

This study is based on bibliometric data retrieved from the Scopus and Web of Science databases. Due to licensing restrictions of the databases, the full datasets cannot be shared publicly; however, processed data and analytical outputs used in the study are available from the corresponding author upon reasonable request.

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Disclosure Statement

The Authors declare that there is no conflict of interest.

AI-Assistance Disclosure

No AI tool was used for data analysis, interpretation, or drawing of conclusions. All responsibility for the content rests with the authors.

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