ORIGINAL ARTICLE

Analysis of Forensic and Drowning Death Studies Using VOSviewer: A Bibliometric Study

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ABSTRACT

Background. Drowning is a significant cause of accidental death worldwide, and forensic investigation plays an important role in determining the circumstances and causes of these deaths. Despite its importance, research in forensic investigations related to drowning remains fragmented and insufficiently characterized.

Objective. This study aimed to examine trends and patterns in publications on forensic examinations related to drowning deaths. Specifically, it sought to identify research gaps, highlight key contributions, and determine major thematic areas in the field.

Methods. A total of 116 articles published between 2014 and 2023 were retrieved from the PubMed database using search terms related to forensic science and drowning deaths. Bibliometric analysis was performed using VOSviewer (version 1.6.20) to identify research clusters, patterns of author collaboration, and keyword co-occurrence. Filtered data were exported in .txt format to facilitate analysis and visualization.

Results. Visualization analysis identified seven thematic clusters. China had the highest number of publications on this topic. The Academy of Forensic Science in Shanghai was the most productive institution, while Fa Yi Xue Za Zhi had the highest number of publications. Lippmann J. was the most prolific author. The most frequently cited source received 180 citations. The three most commonly discussed topics were drowning, forensic pathology, and autopsy, while the most frequent terms overall were forensic pathology, autopsy, and people.

Conclusion. The findings indicate substantial initial research interest in forensic investigations of drowning. However, publication output during the study period showed a downward trend, with a decrease of 16.4%. This decline suggests a notable gap in the literature and highlights the need for further research in this field.

Keywords: forensic science, drowning death, bibliometric analysis, VOSviewer

INTRODUCTION

Advances in technology have brought substantial changes across many sectors, including healthcare. In modern practice, technology can be used as an effective tool for the prevention, diagnosis, and treatment of diseases. Forensic science serves as a bridge between the medical and legal disciplines and plays a crucial role in resolving complex issues in criminal investigations. The application of forensic science integrates principles from biology, chemistry, physics, and psychology to assist in corpse identification, determination of the cause of death, and reconstruction of the circumstances surrounding a person's death.[1]

Forensic medicine significantly contributes to the investigation and resolution of cases involving homicide, suicide, accidents, sexual violence, and drowning. It is also applied in civil and family law, criminal law, and mass-casualty disaster management.[2] This multidisciplinary

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approach provides a framework for systematic investigation, evaluation of evidence, and resolution of complex questions across various forensic disciplines.

Drowning remains an important public health concern worldwide. According to the 2019 report of the World Health Organization, approximately 236,000 people die from drowning each year.[3] In Indonesia, drowning accounted for 4,518 deaths in 2020, representing 0.27% of total deaths and placing the country 123rd globally in terms of drowning mortality.[4]

In Indonesia, it is often difficult to determine whether deaths occurring in water are caused solely by drowning or by injuries sustained before the victim entered the water. Data from Sanglah General Hospital in Bali between 2010 and 2012 showed that only 20 of 71 drowning fatality cases (28.2%) underwent autopsy examination.[5] Only a small proportion of cases received additional laboratory or internal examinations. Among suspected drowning cases recorded at RSUP Sanglah Bali between 2012 and 2014, only 17 cases underwent internal examination of lung secretions, and were identified in 5.88% of cases.[6] These findings indicate limited forensic capacity for the investigation of drowning deaths in Indonesia. Such limitations may lead to misclassification of the cause of death, delays in investigations, and failure to identify deaths related to criminal activity or other contributing factors.

Drowning occurs when the respiratory tract is submerged or flooded with water, leading to impaired gas exchange. Most drowning deaths result from asphyxia and severe cerebral hypoxia caused by prolonged oxygen deprivation.[7] Timely rescue and medical intervention are therefore critical for survival. However, forensic diagnosis becomes increasingly challenging when the body is recovered after prolonged submersion or decomposition. In such situations, external physical findings may be minimal or absent, making the determination of the cause of death difficult for forensic pathologists. Consequently, forensic investigation often relies on both macroscopic and microscopic examinations. Recent evidence-based reviews have emphasized that no single postmortem finding is sufficiently specific for drowning diagnosis; therefore, interpretation should integrate macroscopic, microscopic, biochemical, and molecular findings within the medico-legal context.[7] Initial assessment typically involves macroscopic examination of the body and surrounding circumstances, although this may not always allow precise identification of the drowning site or mechanism.[6]

In forensic investigations, bodies recovered from water are not automatically classified as drowning deaths. Determination of drowning requires assessment of whether the victim was alive at the time of submersion, evaluation for other causes of death or violence, and correlation of external, internal, and supporting examinations. Postmortem foam may be found in drowning cases, including freshwater drowning, but it should be interpreted as part of the overall forensic assessment rather than in isolation. External foam is not pathognomonic for drowning and should not be interpreted as definitive evidence on its own; however, it may still serve as a useful supportive finding when considered together with other autopsy and circumstantial evidence.[8] Therefore, postmortem drowning investigations require appropriate controls and additional analytical approaches, including advanced morphological analysis.

Laboratory techniques such as diatom analysis may assist in the diagnosis of drowning and may help suggest the likely drowning site.[8] Recent studies have shown that quantitative diatom analysis may provide stronger supportive evidence for drowning diagnosis and may improve diagnostic interpretation when combined with case circumstances and autopsy findings.[9] In addition, diagnostic interpretation may consider the differing pathophysiological effects traditionally described in freshwater and saltwater drowning. Freshwater drowning has been associated with rapid fluid absorption, hemodilution, and electrolyte disturbance that may contribute to ventricular fibrillation, whereas saltwater drowning is associated with movement of fluid into the alveoli, leading to pulmonary edema, hemoconcentration, and hypovolemia.[8,10]

The study of drowning in forensic medicine remains open to further scientific investigation through a range of research approaches. One such approach is bibliometric analysis, which provides a systematic method for examining publication patterns and mapping research topics within a field of study using tools such as VOSviewer.[11]

Bibliometric theory offers a quantitative framework for examining the development of scientific knowledge and scholarly communication. Price proposed that scientific productivity follows a pattern in which a relatively small number of authors contribute a large proportion of publications, a concept known as Price's Law.[12] Garfield expanded this perspective through citation analysis, suggesting that the frequency with which a study is cited reflects its relevance and impact within the academic community.[13] These theoretical foundations enable the analysis of knowledge development through citation patterns, collaboration networks, and research dissemination.

Building on these concepts, Waltman and Van Eck developed advanced visualization techniques for bibliometric mapping that enable exploration of relationships among authors, publications, and research themes.[14] Software tools such as VOSviewer allow these relationships to be represented as networks, revealing the intellectual structure of a research field. In the present study, bibliometric analysis was used to examine forensic research related to drowning by analyzing keyword associations, institutional collaborations, and publication trends. This approach enables identification of influential contributors, major thematic areas, and potential research gaps in the literature.[15]

Although numerous studies have addressed forensic aspects of drowning, relatively few investigations have examined how this body of knowledge has evolved and

been disseminated globally. Understanding these patterns is important for guiding future research directions and improving investigative approaches in forensic practice.

Despite the growing literature on drowning in forensic contexts, existing studies remain fragmented and lack systematic synthesis. Bibliometric analysis provides a useful method for quantitatively and visually mapping global research trends, identifying collaboration networks, and highlighting gaps in the literature. This approach is particularly valuable for multidisciplinary fields such as forensic science, which integrate medicine, law, and technology. Furthermore, bibliometric analysis may reveal emerging research areas (e.g., diatom analysis, virtual autopsy, and artificial intelligence) that are shaping modern forensic investigations. By providing a meta-level understanding of the field, bibliometric analysis can complement traditional literature reviews and support the strategic development of future research.

MATERIALS AND METHODS

Study Design and Data Source

This study analyzed the development of scientific literature on drowning-related deaths within the field of forensic science over a ten-year period from 2014 to 2023 using a bibliometric approach. All data were retrieved from PubMed, one of the largest online databases of biomedical literature, which contains more than 38 million citations from MEDLINE, life sciences journals, and online books.

Search Strategy

The literature search was conducted in April 2024 using the keywords "forensic," "drowning," and "death." The search was restricted to articles published between January 1, 2014 and December 31, 2023. This period was selected to represent the most recent decade of publications relevant to contemporary forensic practice while minimizing the inclusion of older literature with limited current applicability.

Eligibility Criteria

Inclusion criteria

1. Articles written in English;
2. Studies involving human subjects;
3. Full-length articles with accessible full text; and
4. Studies clearly addressing forensic aspects of drowning-related deaths.

Exclusion criteria

1. Studies not directly related to forensic aspects of drowning (e.g., purely clinical or environmental studies);
2. Conference abstracts or unpublished reports;
3. Duplicate records; and
4. Studies involving animal models.

Study Selection

The initial search in PubMed yielded 1,335 publications (Figure 1). After removal of duplicates and screening for relevance based on the inclusion and exclusion criteria,

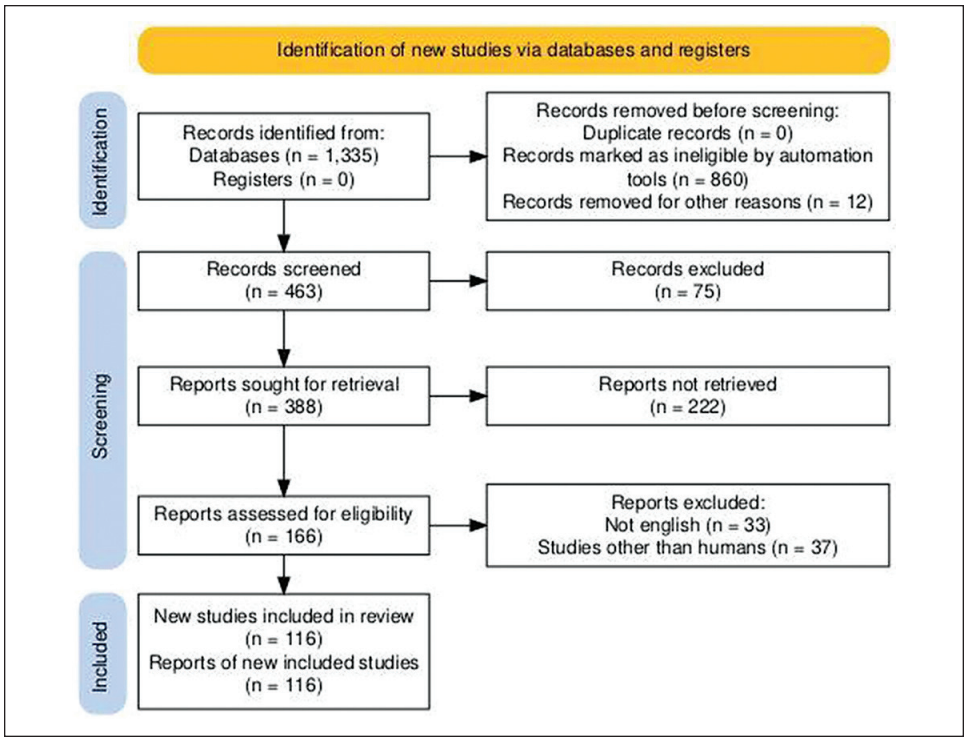

Figure 1. Flowchart of the bibliometric analysis.

246 full-text articles were assessed for eligibility. Following a detailed evaluation, 116 articles met all criteria and were included in the final bibliometric analysis.

Bibliometric Analysis

Bibliometric analysis was performed using **VOSviewer** version 1.6.20, a software tool for scientific visualization. Bibliometric research provides an objective and quantitative approach to assessing the development of research within a specific field. This method allows systematic evaluation of publication trends, collaboration networks, and thematic development, which is particularly useful for topics with limited and scattered literature, such as forensic investigations of drowning deaths.

Visualization of the results was conducted using three approaches:

1. **Network visualization** – to display the relationships between elements, such as authors, institutions, or keywords.
2. **Overlay visualization** – to illustrate temporal trends and developments in research.
3. **Density visualization** – to depict the frequency and intensity of term occurrences within the literature.

These visualizations collectively provide a comprehensive overview of global research trends, institutional and international collaborations, and key thematic areas in forensic drowning research.

Ethical approval was not required for this study, as it did not involve human or animal subjects. Overall, the study provides a quantitative and visual mapping of the scientific landscape in forensic drowning research and may serve as a reference for guiding future investigations.

The field of bibliometric analysis has expanded rapidly and is increasingly recognized as a robust research methodology. Using VOSviewer, we identified research trends, gaps, and collaboration networks, enabling assessment of contributions at the level of countries, institutions, journals, and authors. Keyword selection and mapping facilitated the creation of visual networks, which support the extraction of key information from large volumes of literature. This approach also aids in predicting emerging topics and identifying areas that warrant further investigation in forensic drowning research.

RESULTS

Global Publication Trends

Key information from all articles can be seen in Table 1. The table shows that the annual publication growth rate decreased by -16.4%. This means that despite an initial high interest in the topic, the focus of research on forensic drowning declined after a certain year. Furthermore, there are 13.52 citations per document on average, indicating that despite the small number of publications, articles in this field have a significant impact on the academic community. The total number of 735 authors across 116 articles indicates a high level of collaboration, as evidenced by the 6.94 co-authors per document, indicating that forensic drowning research is generally conducted by multidisciplinary teams.

Table 1. Main Information of Included Studies

Description	Results
Timespan	2014:2023
Documents	116
Annual Growth Rate (%)	-16.4
Average citations per doc	13.52
Authors	735
Co-Authors per Doc	6.94

Table 2. Total Number of Published Research by Country and Region

Country	Documents
China	23
United States	16
Germany	14
United Kingdom	13
Australia	10
Japan	8
Poland	6
Ireland	5
Sweden	5
Italy	3
France	2
South Korea	2
Switzerland	2
Bosnia and Herzegovina	1
Brazil	1
Czech Republic	1
Egypt	1
Lithuania	1
Netherlands	1
Turkey	1

Annual publication trends are visualized in Figure 2. The graph shows a significant increase in 2020, likely related to increased attention to autopsy procedures and death investigations during the COVID-19 pandemic. After 2020, the graph shows a consistent decline, reflecting a reduction in focus or funding for these topics in recent years.

Country and Institutional Distribution

The analysis indicates that a total of 20 countries and territories contribute to forensic drowning research worldwide (Table 2). By number of publications, China tops the list with the highest number of articles (23), followed by the United States (16), Germany (14), the United Kingdom (13), and

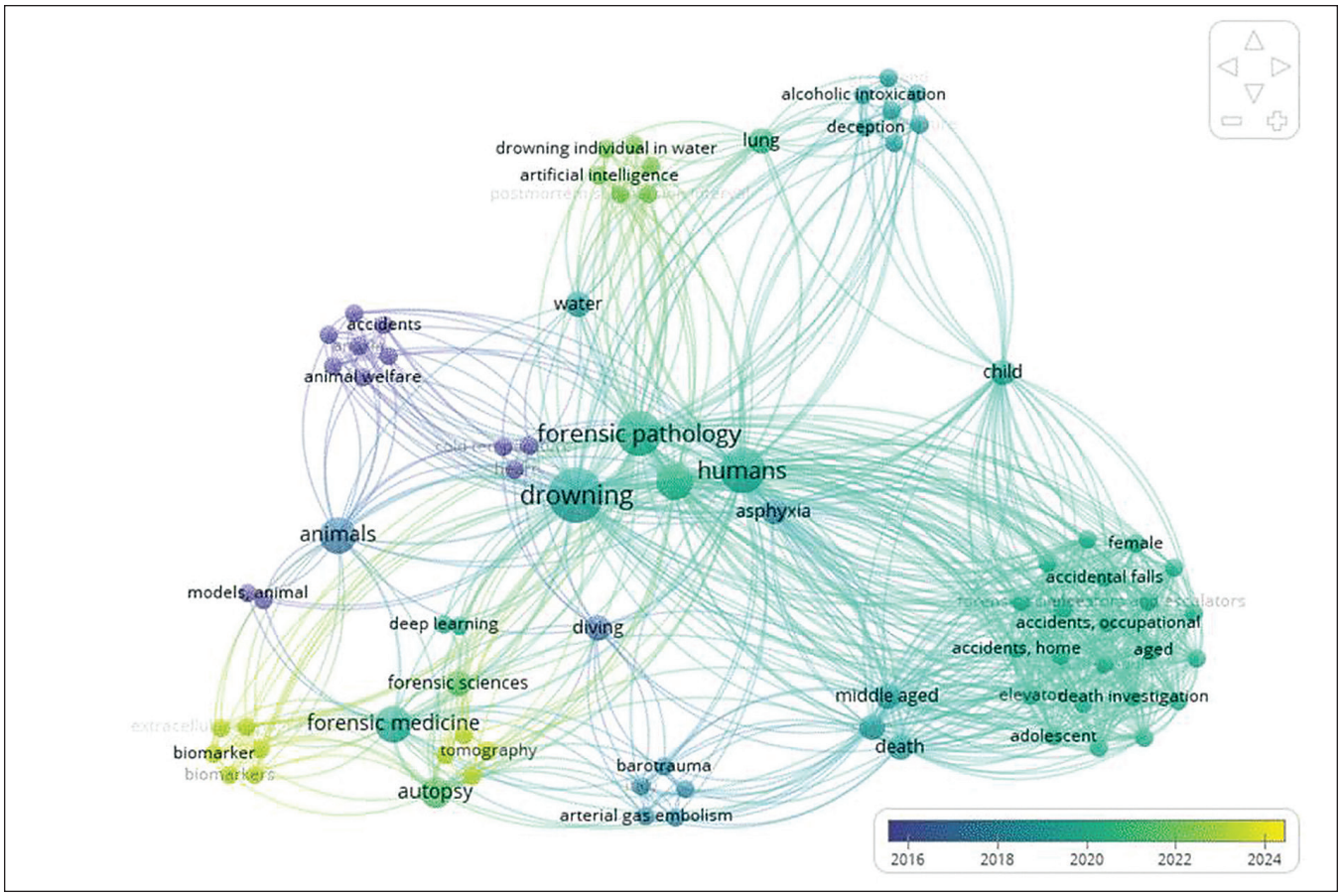

Figure 2. Trends in global publications on forensic drowning deaths.

Australia (10). Others, of which countries made at least one contribution, each contributed fewer than 10 publications.

A total of 448 institutions contribute to research publications related to forensic drowning deaths. The largest contributor was the Shanghai Academy of Forensic Sciences, corresponding with nine publications. This is followed by the Australasian Diving Safety Foundation and the Department of Public Health and Preventive Medicine at Monash University, Victoria, respectively, with eight publications each. Further, Guangzhou Institute of Forensic Sciences and the corresponding author, Dr. John Lippmann, contributed seven articles each. Other institutes also contributed to the development of research in this area (Figure 3).

Publication Analysis in Journals

One hundred sixteen (116) articles on forensic drowning deaths were featured from 49 journals over the period ranging from 2014 to 2023. The data shows the compound annual growth rate (CAGR) of the number of articles published by each journal during the 2014–2023 period and a list of journals that publish articles on the topic of forensic drowning deaths. The journals are sorted from top to bottom in descending order based on the rate of growth in their publications. (Figure 4)

Among them was the journal Fa Yi Xue Za Zhi, which recorded a total of 23 publications. According to the graph, in terms of Compound Annual Growth Rate (CAGR), Fa Yi Xue Za Zhi published articles the most rapidly in recent years, at a CAGR of 56.51 percent. It was followed by Forensic Science International with a CAGR of 44.22 percent, and two other journals, Diving and Hyperbaric Medicine and PLoS One, which both recorded a CAGR of 12.25 percent. Journals at the bottom of the list do not show a bar on the graph, which means that there was no year-over-year increase in publications throughout the research period, and their CAGR was either 0% or stationary.

Author Analysis

Authors contributing to forensic drowning research come from a diverse range of countries, with the United States, China, Japan, Italy, and Germany dominating (Figure 5). This distribution illustrates that countries with more advanced forensic infrastructure tend to have higher research output.

Figure 6 shows the authors with the most publications, with Lippmann J. being the most prolific. This demonstrates that the field is supported by several key researchers who consistently contribute to diving, autopsy, and drowning investigations.

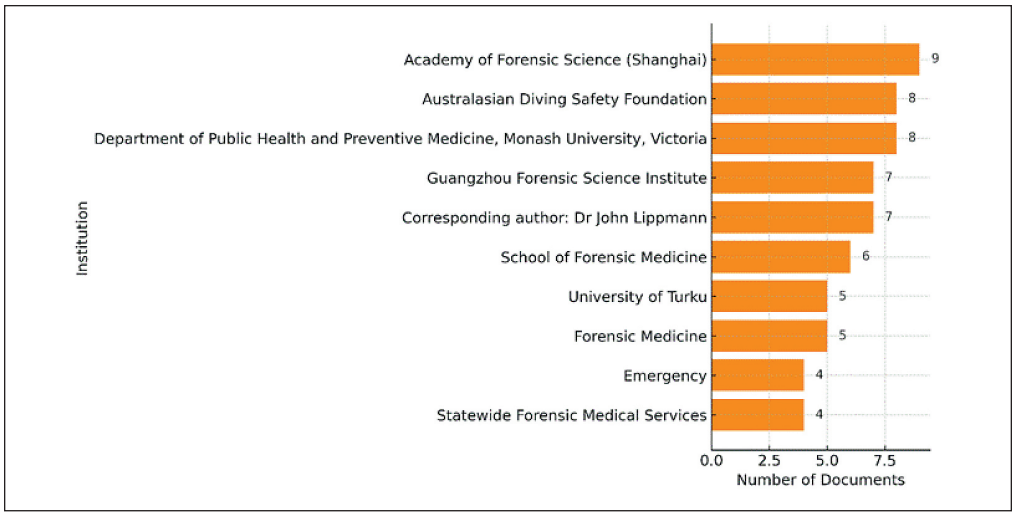

Figure 3. Top 10 research institutions by number of published studies.

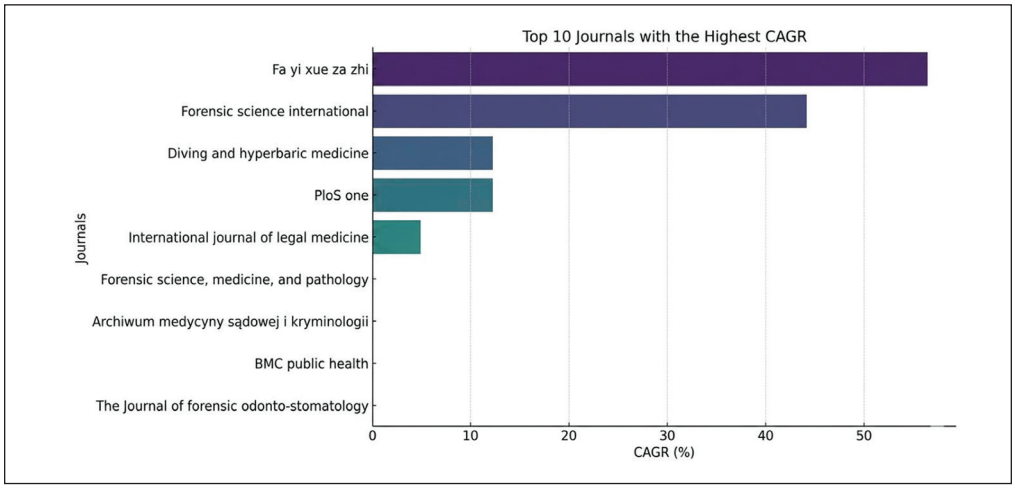

Figure 4. Compound annual growth rate (CAGR) of journals.

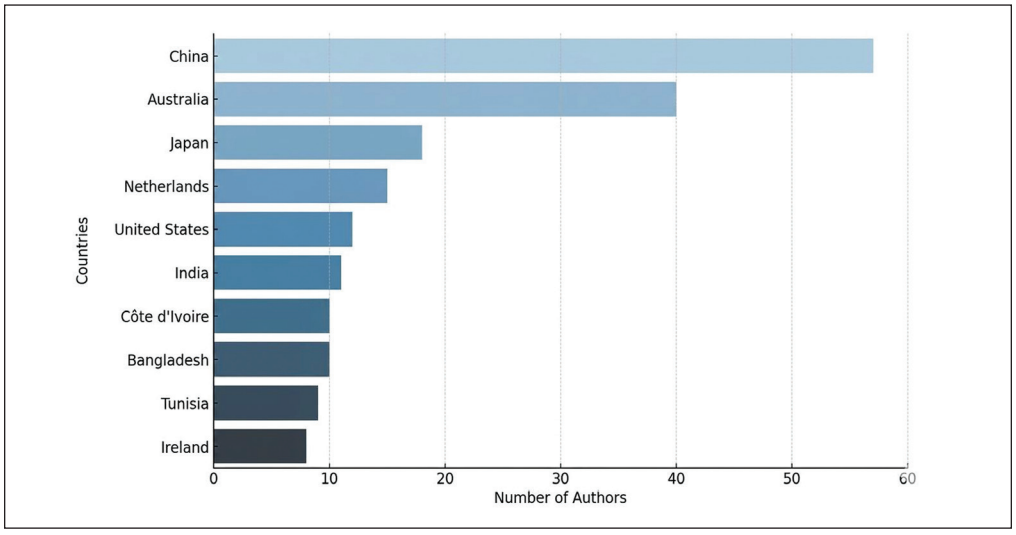

Figure 5. The top ten countries with the highest number of contributing authors.

This consistency is further reflected in Figure 7, which shows the authors' annual publication streaks, indicating a long-term research focus in this field.

Figure 8 shows the collaboration patterns between authors, forming several thematic clusters. This indicates that forensic drowning research is generally conducted collaboratively, involving multiple disciplines and institutions. However, it appears that collaborations still tend to cluster around specific topics or regions, opening up opportunities for broader international collaboration in the future.

Citation and Co-Citation Analysis

The citation analysis results show that three articles have received more than 100 citations. The ten publications with the highest number of citations are shown in Figure 9. Of all these, the article titled "Unintentional Drowning Burden: Global, Regional, and National Mortality Estimates from the Global Burden of Disease Study 2017" takes first place with 180 citations. Next comes the article "Physiology of Drowning: A Review," and after it comes the third article in the line with 144 citations. Last in the line, but still among the top, is "Microbial Forensics: New Breakthroughs and Future Prospects" with 111 citations.

Co-occurrences and Author Keyword Analysis

A total of 619 keywords were analysed for co-occurrence patterns. Density visualization shows the mapping of keywords according to the frequency of occurrence. Of the keywords that appeared more than thrice, "drowning" had the highest link strength (79), followed by "forensic

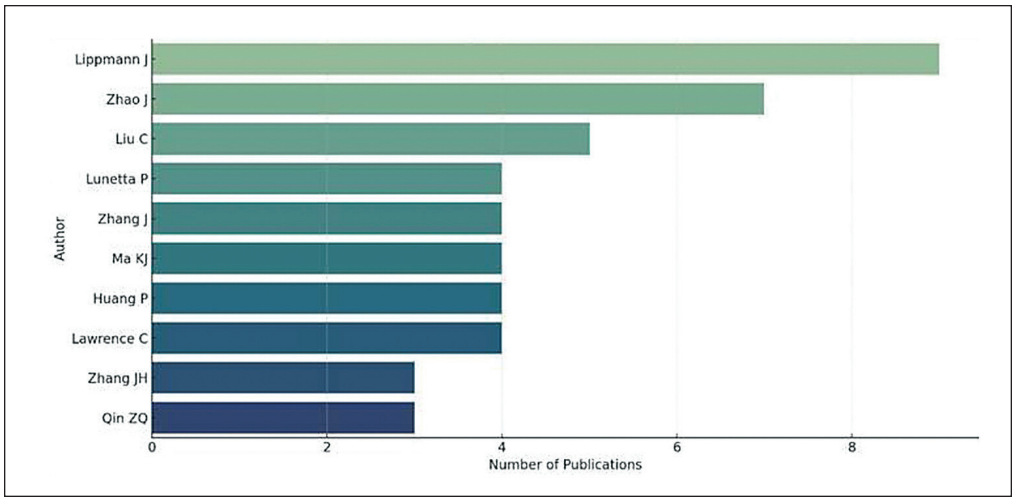

Figure 6. The top ten most published authors.

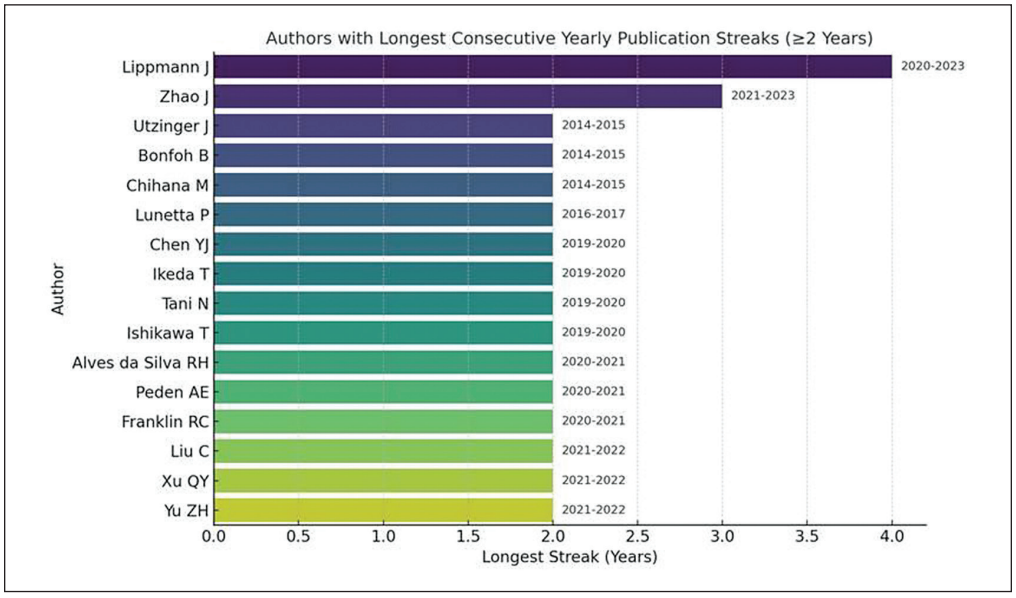

Figure 7. Authors with the longest consecutive yearly publication streaks (≥2 years).

pathology" (56), "autopsy" (20), "diving deaths" (20), "diatom testing" (19), and "cause of death" (16). These findings are visualized in Figure 10.

Keyword Trend Analysis

The visualization of the most commonly appearing keywords in this study is shown in Figure 11. The five most commonly occurring keywords were "human", "drowning", "male", "female", and "autopsy." An analysis of temporal trend reveals that the major recent focus of research has surrounded "human," "autopsy," and "forensic pathology," with contributing keywords like "asphyxia," "cause of death," and "diatoms." These keywords are an extension of the authors' original keywords, and their distribution provides insight into current and future research directions. These findings indicate that "diatoms" and "forensic pathology" have the potential to be important elements in deepening our understanding of the causes of drowning, particularly in the context of forensic diagnostics, which has evolved in recent years.

Thematic Analysis Clusters

Seven themes were grouped in the VOS viewer software on forensic drowning death research data (Table 3). The clusters highlight events and interrelationships between subjects. Participation also indicates where the different research foci and priorities within the discipline are. With the help of VOSviewer, we can see a clearer picture of how forensic research related to drowning is developing

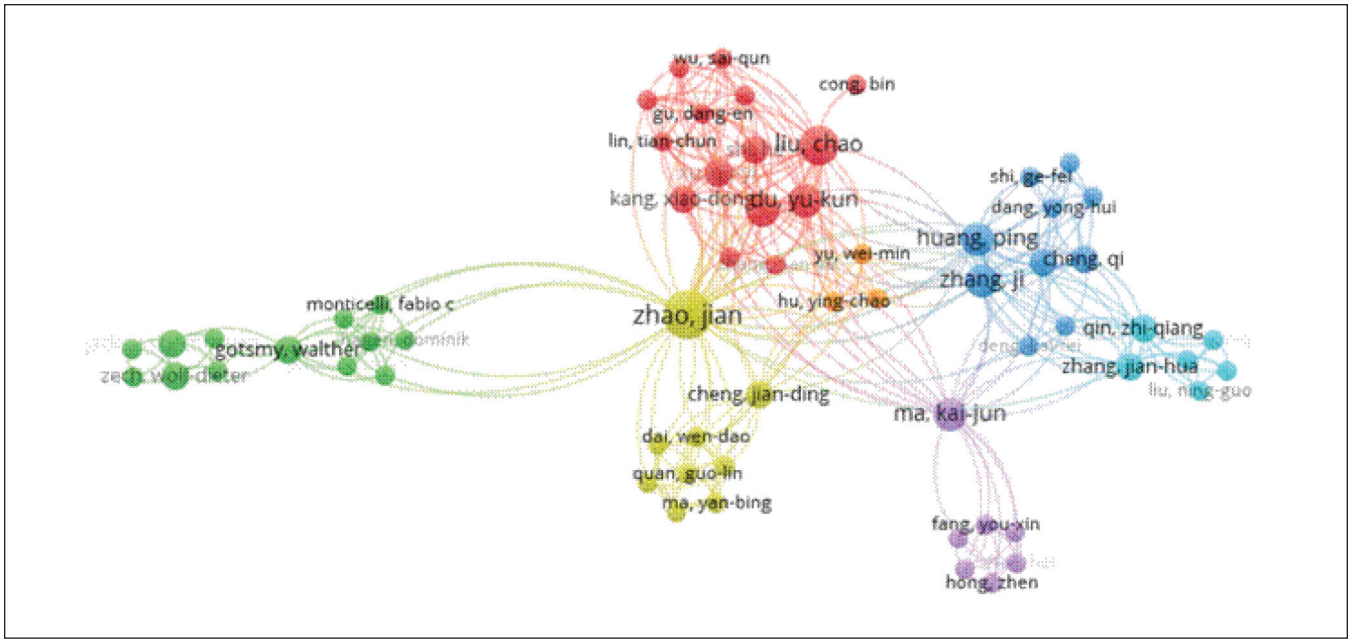

Figure 8. Mindmap of collaborative author clusters.

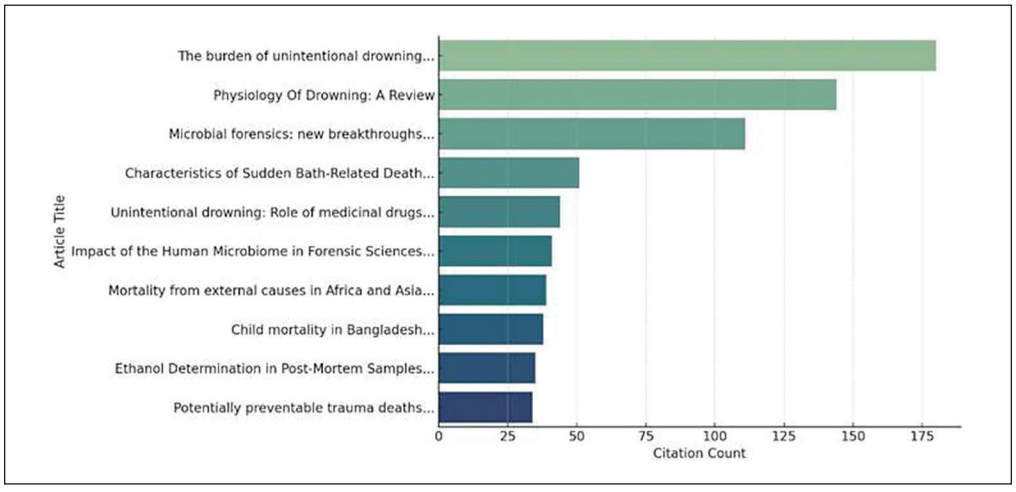

Figure 9. Top ten most cited articles.

from the important studies that are used as references, collaborations between researchers, and topic trends that continue to change over time.

DISCUSSION

The results of bibliometric mapping indicate that the emergence of major themes in forensic research on drowning deaths reflects methodological developments and evolving scientific demands over the past decade. Interdisciplinary collaboration among forensic scientists, IT specialists, and medical professionals is evident in these trends. In Table 3, Cluster 1 highlights epidemiology and accidents, while Cluster 2 emphasizes molecular biology and the use of biomarkers in drowning diagnosis. Clusters 3 and 7 illustrate advances in forensic technology, such as computed tomography and deep learning for determining the cause of death. The predominance of clusters related to epidemiology, accidents, and cause-of-death determination aligns with classical literature, which notes that drowning investigations remain diagnostically challenging due to the absence of a single pathognomonic sign. Accurate determination of the cause of death is essential to distinguish drowning from other underlying or contributing factors, including homicidal or fabricated events. These findings underscore the importance of understanding situational context and human factors while expanding research frameworks around forensic methodologies.

Research continues to focus on situational factors, patterns of occurrence, and differentiation among accidental,

Table 3. Keywords of each Cluster

Cluster	Items	Keywords
1	22	accidental falls, accidents, home, accidents, occupational, adolescent, adult, age distribution, aged, aged, 80 and over, crush injuries, death investigation, electric injuries, elevator, elevators and escalators, female, forensic science, injury prevention, multiple trauma, occupational health, risk-taking, sex distribution, substance-related disorders, young adult
2	12	animals, autopsy, biomarker, biomarkers, drowning, extracellular signal-regulated kinases, forensic medicine, mitogen-activated protein kinases, models, animal, phosphorylated erk2 (p-erk2), postmortem submersion, water microbiology
3	11	artificial intelligence, cold temperature, diatoms, drowning individual in water, drowning site inference, heart, humans, postmortem submersion, reflex, review, water
4	10	alcoholic intoxication, child, crime victims, deception, exposure, forensic pathology, greenland, homicide, lung, skin
5	9	accidents, animal welfare, anoxia, asphyxia, aspiration, cause of death, immersion, pathology, veterinary
6	9	arterial gas embolism, barotrauma, death, diving, Italy, male, middle-aged, pulmonary barotrauma, scuba diving
7	7	deep learning, diatom, forensic sciences, paranasal sinuses, tomography, x-ray computed, x-ray computed

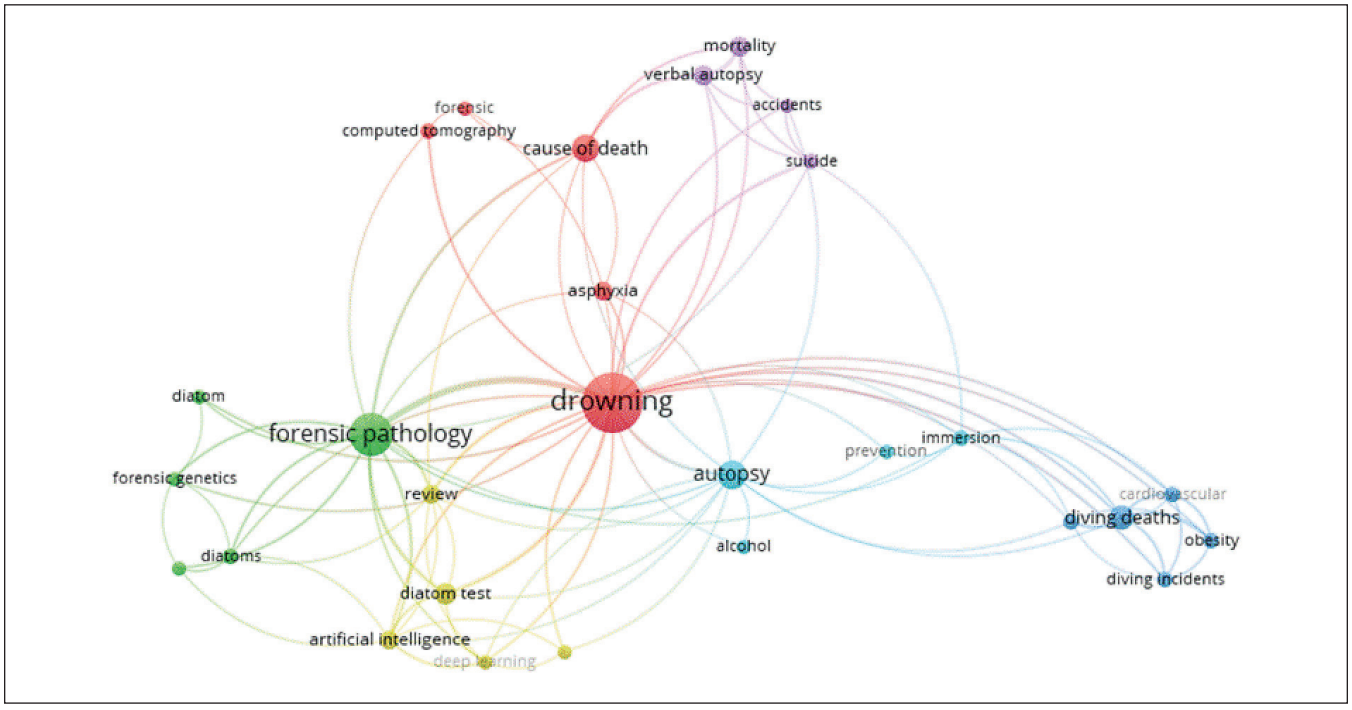

Figure 10. Mindmap of the author's keywords appearing more than three times.

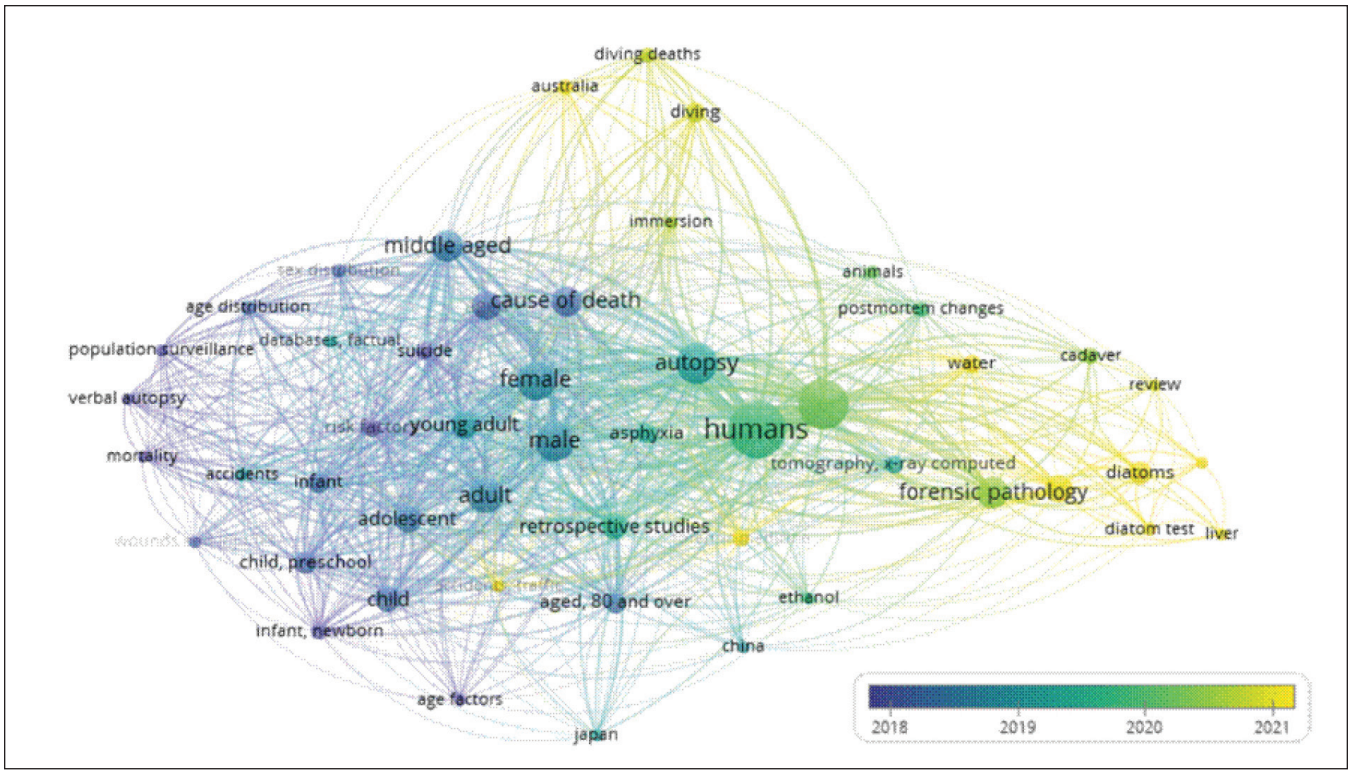

Figure 11. Mindmap analysis of all keywords.

suicidal, and homicidal drowning. The emergence of clusters on biomarkers and molecular biology reflects a methodological shift from traditional macroscopic approaches to more objective microscopic and molecular examinations.

The increase in publications observed in 2020 corresponds with broader global publication trends during the COVID-19 pandemic.[16] During this period, postmortem imaging and enhanced autopsy safety protocols received increased attention in forensic and pathological practice. Virtual autopsy and postmortem CT were increasingly used during the COVID-19 pandemic as minimally invasive approaches that could help reduce infection risk and, in some settings, triage the need for full conventional autopsy.[17] In drowning investigations, postmortem chest CT with three-dimensional reconstruction has also shown potential as a supportive tool for identifying thoracic findings associated with drowning, although it should be interpreted alongside conventional autopsy results.[18]

The adoption of artificial intelligence (AI) in forensics has also accelerated, particularly for postmortem image classification, identification of bodily fluids, and development of virtual forensic analyses.[19] AI-assisted diatom testing has been proposed to improve the objectivity, speed, and consistency of qualitative and quantitative analyses, indicating a promising direction for future forensic applications.[20] These technological advancements are consistent with trends observed in VOSviewer mapping, where technology-based topics have emerged as a new focus in forensic research.

Clusters related to diatoms, biomarkers, and molecular analysis are also supported by existing literature. Diatom analysis can help distinguish postmortem drowning from other causes of death, and recent studies advocate the use of high-throughput sequencing to characterize microalgal profiles more precisely. This aligns with the emergence of "molecular biology" clusters in the bibliometric results, illustrating two parallel streams of research: traditional approaches (macroscopic autopsy, classic drowning signs, injury patterns) and modern approaches (imaging, AI, biomarkers, and molecular techniques).

Interestingly, the topic of "cause of death" remains relatively underrepresented and inconsistent in the literature. Biomarkers for drowning diagnosis are often evaluated inconsistently, resulting in conflicting findings. Despite numerous studies on drowning, bibliometric mapping highlights persistent gaps in definitively determining the cause of death. This has prompted research into complementary themes such as situational context, human factors, psychology, toxicology, and environmental variables to enhance the accuracy of forensic investigations.

The observed decline in publications in recent years may reflect saturation with traditional approaches. Classical methods, such as macroscopic examination of lungs, foam in the airway, or evidence of water aspiration, have reached diagnostic limits and offer limited opportunities for innovation. Without the integration of modern technologies, growth in forensic research may stagnate.[16] The scarcity of

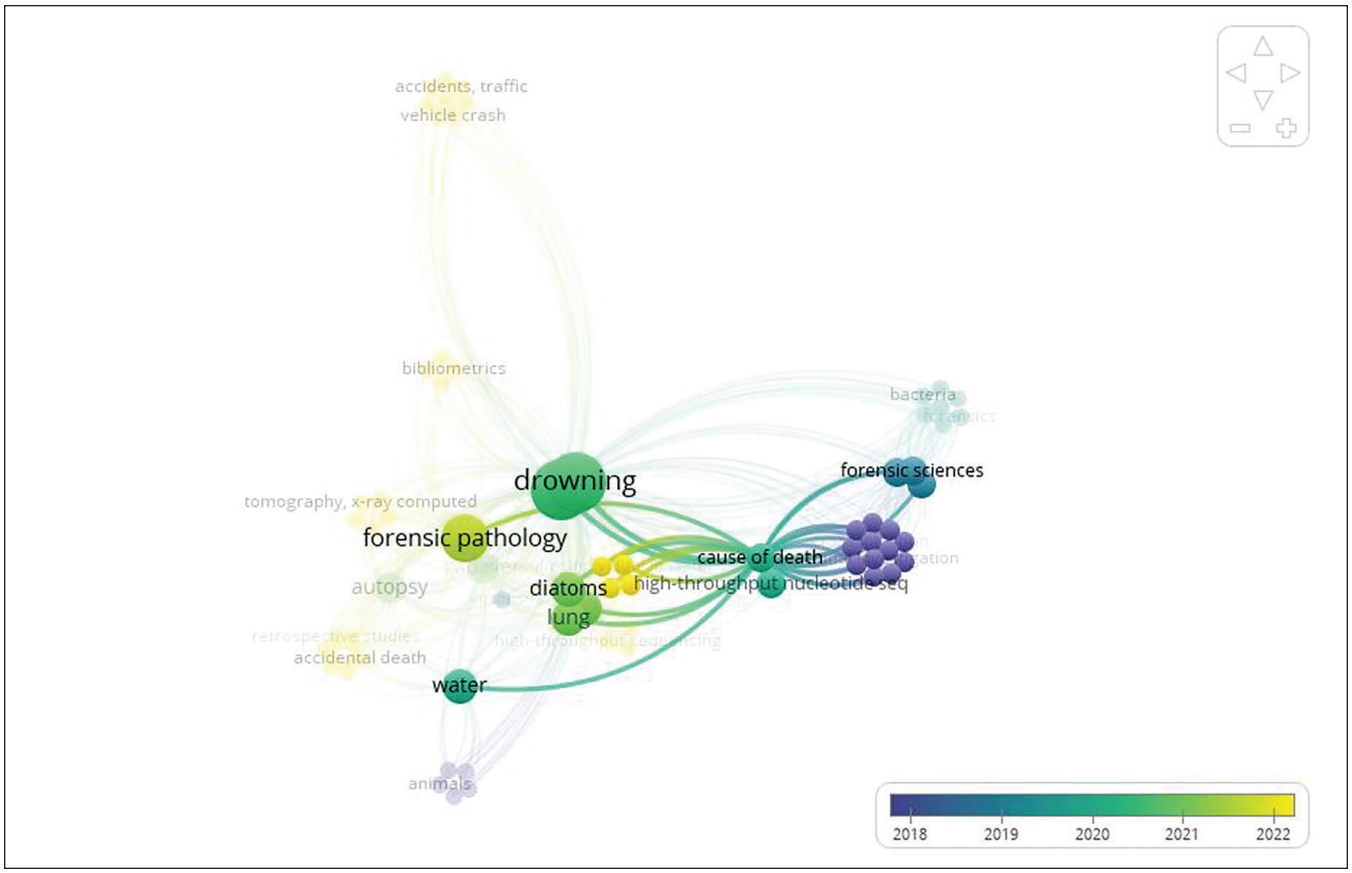

Figure 12. Visualization of limited research and intermittent discussion on the cause of death.

keywords such as "deep learning," "virtual autopsy," or "high-throughput screening" in bibliometric maps likely reflects that these approaches remain underexplored and are not yet mainstream in forensic research.

Collaboration patterns revealed by bibliometric analysis, particularly consistent contributions from small research groups such as the Shanghai Academy of Forensic Sciences and authors like Lippmann, conform to Price's Law, which posits that most scientific production originates from a small number of highly productive researchers. This indicates that forensic submersion research remains largely author-driven, with limited diversification. Overall, these bibliometric findings reflect the current landscape of forensic literature: a shift toward multidisciplinary approaches, stagnation in traditional techniques, potential for innovation via digital technologies, and the urgent need for well-validated biomarkers.

Figure 12 illustrates how study subjects have changed throughout time, revealing sporadic talks and little research on the subject of "cause of death." The "cause of death" node, represented by purple and dark blue nodes from 2018–2019, seems to have a close relationship with the topic cluster of older publications based on the color range of publishing years. The lack of bright hues (yellow) surrounding this cluster suggests that, in a recent study from 2021 to 2022, the precise investigation of "cause of death" tends to be stationary or not show a significant trend.

This study has several limitations. First, the use of specific search terms ("forensic," "drowning," and "death") may have excluded relevant studies using alternative terminology or broader investigative frameworks, introducing potential selection bias. Second, limiting inclusion to English-language and free full-text articles may underrepresent contributions from countries where forensic research is primarily published in local languages. Finally, reliance on a single database, PubMed, may not fully capture the global scope of research on forensic investigations of drowning deaths.

CONCLUSION

The findings indicate a sustained initial interest in forensic research related to drowning. However, over the past decade, publications on this topic have shown a downward trend, with a significant decrease of 16.4%, highlighting a conspicuous gap in the literature that requires urgent attention. Strengthening collaboration between the forensic and health sciences communities is essential to address this gap. Future research should adopt an interdisciplinary approach, integrating advanced investigative techniques

and modern methodologies to enhance forensic drowning investigations and improve public health outcomes.

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Statement of Authorship

All authors certified fulfilment of ICMJE authorship criteria.

Author Disclosure

All authors declared no conflicts of interest.

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