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Quantitative Analysis of Global Research Trends in Crowd Management for Tawaf: A Bibliometric Study (1997–2023)

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ABSTRACT

This research delves into the global research trends on crowd management, specifically focusing on the Tawaf ritual at the Kaaba, through a bibliometric analysis of papers cataloged in the Web of Science. Employing Biblioshiny and VOSviewer, we analyzed publication and citation dynamics, the most cited countries and prolific authors, and the collaboration patterns within and across countries. This study reveals that technological advancements have become pivotal in proposing innovative crowd management strategies, particularly in Tawaf. This insight is crucial, as it suggests a significant shift towards integrating technology with traditional crowd management practices to enhance safety and efficiency in managing large crowds. Prominent figures in this domain include researchers Zafar, B. and Manocha, D., with the USA and Umm Al-Qura University, being the most-cited country and institution, respectively. With multi-authorship being prominently observed in 91.30% of the articles, indicating a strong collaborative network among researchers and institutions worldwide, the findings offer valuable insights for evaluating the impact and productivity of journals and institutions within this research domain. This study underscores the potential for leveraging emerging technologies in developing more sophisticated crowd management solutions, paving the way for future research that could enhance safety and efficiency in high-density events.

1. INTRODUCTION

Crowd management is a critical factor in the successful organization and safety of large-scale events, where the convergence of a large number of individuals presents complex challenges. Effective strategies to administer these gatherings are crucial to prevent incidents that could lead to injuries or fatalities. Hundreds of thousands of people visit Makkah, Saudi Arabia, every day to perform Umrah, which consists of Tawaf (extracted from the Arabic word Tauf, meaning "to walk around") of Kaaba and Saee. Tawaf consists of circumambulating the Kaaba in an anti-clockwise manner seven times, and Saee is performed between the hills of Safa and Marwa. The annual hajj pilgrimage is performed from the 8th to the 12th day of the month of Zhul-hijjah and also consists of performing Tawaf [1].

During Tawaf and other rituals of Hajj, there is an intense concentration of pilgrims within a confined space. Hajj is considered one of the largest gatherings in the world. Through the pilgrim experience program as part of Saudi Arabia's Vision 2030 [2], the plan is to host 15 Million international Umrah pilgrims annually by 2025. Despite its importance, the existing research on the crowd dynamics and management of Tawaf remains sparse, leaving a gap for comprehensive analysis.

Hawkins [3] defined bibliometrics as the quantitative analysis of the bibliometric features of a body of literature. Bibliometric analysis provides a means to analyze a research area using various entities such as authors, citations, affiliations, funding bodies, and words found in the publications [4].

Many bibliometric studies related to the general field of crowd management have been previously performed, such as the one by Haghani [5] and Mirhashemi et al. [6]. Most of these research studies usually obtain thousands of related papers. On the other hand, we aim to study the global research trends in crowd management during Tawaf, a very specific research area, utilizing bibliometric and scientometric methods to aggregate and study literature from the past few decades. We got only 23 papers, owing to the research in a particular field. A related work by Haidar and Satifa [7] considered 142 papers related to Hajj services.

Furthermore, Sa'dom et al. [8] obtained 81 papers about Umrah. Tawaf is just a component of Hajj and Umrah. This is one of the reasons for obtaining a relatively small number of related publications. By conducting a comprehensive bibliometric analysis and revealing collaboration networks, this article fills a gap in research related to crowd management of Tawaf of Kaaba. We also observed that most of the research [7, 8] does not present the word clouds, variation in the number of pages and authors, and word growth over the years. These patterns can depict the progress of a domain.

This research improves comprehension by offering valuable insights into research patterns and collaboration dynamics.

Consequently, it serves as a valued resource for developing future crowd management initiatives and research agendas that specifically cater to the challenges of managing large crowds typically seen in the Kaaba. Given the intricacies involved in governing religious congregations of this magnitude, the study is not only timely but also necessary for the advancement of crowd management methodologies.

Relying on the globally recognized Web of Science (WoS) database as the primary data source, this research collected twenty-three relevant publications from 1997 to 2023. By employing an array of analytical tools, including Biblioshiny [9], VOSviewer [10], and MS Excel, the study provides a macroscopic view of research patterns, underlining significant contributions, identifying key stakeholders in the field, and uncovering trends in collaboration and authorship.

The rest of the article contains the following sections: Section 2 details the objectives and the specific research questions guiding this bibliometric study. Section 3 synthesizes the related literature, whereas Section 4 elucidates the methodology. Section 5 presents the results, narrating the story that the data tells through various metrics such as publication counts, citation analysis, collaboration patterns, and keyword frequencies. Finally, Section 6 discusses the implications of the findings, offering a perspective on future research directions.

2. OBJECTIVES AND RESEARCH FOCUS

The main objective of this study is to systematically map and evaluate the existing body of research on crowd analysis during Tawaf via bibliometric analysis. To align our bibliometric analysis with a focused inquiry into the dynamics of crowd management during Tawaf, we propose the following central research question and hypothesis:

Research Question: What are the predominant trends, gaps, and collaborative networks in the global research landscape of crowd management during Tawaf, as evidenced by bibliometric analysis of publications from 1997 to 2023?

Hypothesis: Given the unique challenges posed by Tawaf in managing large crowds in a religious context, we hypothesize that:

(1) Research on Tawaf crowd management is characterized by a limited but growing body of literature, indicating an emerging interest in addressing the specific challenges of managing large crowds in religious settings.

(2) There is a significant variation in research focus over time, with recent studies increasingly emphasizing the application of technological solutions and collaborative international efforts to enhance crowd safety and efficiency.

(3) The collaborative networks among researchers, institutions, and countries are central to advancing the field of Tawaf crowd management, with certain key institutions and countries playing pivotal roles in the research community.

This hypothesis and research question aim to guide our bibliometric analysis, allowing for a targeted investigation into the evolution, current state, and future directions of crowd management research during Tawaf. By examining these aspects, the study seeks to uncover insights that could inform the development of more effective crowd management strategies, thereby contributing to the safety and well-being of pilgrims during one of the largest religious gatherings in the world.

Our research tries to address some specific goals as provided next:

(1) Data Extraction and Analysis: What is the volume and scope of research publications related to crowd analysis during Tawaf, as extracted from the WoS database until January 19, 2024?

(2) Annual Publication Trend: How has the volume of publications on Tawaf crowd analysis evolved from 1997 to 2023?

(3) Citation Impact Assessment: What is the citation impact of collected publications, and which specific papers have significantly influenced the field of Tawaf crowd analysis? How have citation trends evolved, reflecting the impact and evolution of research in this domain?

(4) Authorship and Collaboration Patterns: What are the patterns of authorship and collaboration among researchers, institutions, and countries involved in Tawaf crowd analysis research? To what extent do international collaborations contribute to the research output in this field?

(5) Publication Characteristics: What are the characteristics of publications related to Tawaf crowd analysis, including the proportion of conference and journal articles, language distribution, average paper length, and authorship trends?

(6) Journal Productivity Assessment: Which journals are the most productive in publishing research on Tawaf crowd analysis, and how do they rank based on citation impact?

(7) Mapping Keywords and Phrases: What are the core topics and emerging areas of interest in Tawaf crowd analysis research, as revealed by the mapping of keywords and phrases associated with the literature?

3. LITERATURE REVIEW

This section presents details of related research works. We present related bibliometric studies and research related to crowd management and pedestrian safety.

Haghani [5] performed a comprehensive scientometrics analysis involving pedestrian, crowd, and evacuation dynamics. He studied approximately 6200 articles from the WoS Core Collection. According to this research, crowd dynamics research dates back to the 1970s. The influx of papers in this field has increased to more than 500 papers each year since 2015.

Gazzawe and Albahar [11] discussed how Artificial Intelligence (AI) could reduce traffic congestion in Makkah during the Hajj season. The researchers developed a force model incorporating internal and external forces and the forces coming from obstacles, including the walls. They also proposed a system involving image classification using Convolutional Neural Networks (CNN), which helps categorize the nature of the crowd into normal, light-crowded, semi-crowded, crowded, or heavily crowded. Furthermore, they advocated using smart cameras to monitor the crowd in real time. Smart cameras can perform image processing, automatically estimate crowd densities, and detect anomalies. Nevertheless, this research presented no experiments and results based on the proposed system.

Feliciani et al. [12] analyzed the trends in crowd accidents from 1900–2019. However, they focused on the press and media reports rather than using bibliometric data. The researchers analyzed the occurrence and geographical location of crowd accidents and the fatalities. Only those accidents were considered, including injuries to more than ten people or

more than one fatality. During the last 120 years, the number of crowd accidents has increased. The share of sports events in these accidents has reduced, whereas the share of religious gatherings has increased. The research found no relationship between the large crowd size and the risk of injury or death per person.

Furthermore, they found that crowd accidents are more common than traffic accidents in low- and middle-income countries like India and West Africa. In such regions, a quick increase in population has been observed, whereas the infrastructure has not kept pace with this increase. The researchers also worked on the impact of population density on the probability of a crowd-related accident. Many accidents were found in Northern India, one of the world's most densely populated areas.

Mirhashemi et al. [6] performed a bibliometric analysis of pedestrian safety and studied 6,311 papers obtained from the WoS. The data included papers indexed till Oct 3, 2021. The analysis was performed using tools like VOSviewer and Bibliometrix R-package. According to this research, the first article on pedestrian safety was published in 1948 in the Sociometry journal. The prediction regarding the future articles was also made.

In related research, Haidar and Satifa [7] performed a bibliometric analysis of 142 papers related to Hajj services during the COVID-19 pandemic. They found that the papers on the Hajj services showed an increasing trend from 2019 to 2022. The researchers also employed the VOSviewer for analysis. The articles' metadata was obtained from the Dimensions database (https://www.dimensions.ai).

Sa'dom et al. [8] worked on a bibliometric analysis of 81 articles related to Umrah. The articles were obtained from the Scopus database and dated from 2012 to 2023. The number of years closely coincides with the current research.

Durr-e-Nayab et al. [13] performed a sparse crowd flow analysis of Tawaf of Kaaba during the COVID-19 pandemic. They tried to find the anomaly considering persons going against the usual counterclockwise flow using Lucas-Kanade (sparse optical flow analysis algorithm) and Shi-Tomasi (corner-detection) algorithms. Nevertheless, they did not use machine learning algorithms, and the thresholds were manually determined to be specific to the videos considered. This paper did not appear in our bibliometric database.

Hughes [14] analyzed the flow of human crowds. A crowd is different than the classical fluid since it can think. Therefore, the crowd motion is described as "thinking fluid". However, it resembles the fluid motion in many aspects.

Showail [1] conducted an extensive survey comprising 330 references to solve hajj and umrah challenges using Information and Communication Technology (ICT). Over 30 technologies currently used to address various hajj and umrah issues are analyzed. The research papers are divided into ten categories, one being crowd management. Many challenges, including the language barrier, harsh weather, and waste management, are briefly discussed.

Additionally, incorporating advanced text mining and network analysis techniques in bibliometric methodologies could offer deeper insights into collaboration patterns, emerging research themes, and the overall evolution of research in these fields.

4. METHODOLOGY

This section outlines the methodology employed for the bibliometric analysis of research related to crowd analysis of Tawaf. The dataset was extracted on Jan 19, 2024. The search query was framed as follows: crowd AND tawaf. Two specific terms were used since we wanted to analyze the publications related to the general theme of crowd analysis and the particular topic of tawaf.

Twenty-three relevant publications were retrieved from the WoS database. If we replaced the word tawaf with a more comprehensive ritual of Umrah or Hajj, we would have received many more publications (46 in Umrah and 251 in the case of Hajj). The decision not to explicitly include Umrah or Hajj in the search query was intentional, aiming for a concentrated exploration of Tawaf-specific literature. While this choice limited the dataset to 23 publications, it allowed for a more in-depth analysis of the nuances within the Tawaf ritual. The discussion acknowledges the trade-off between specificity and inclusivity, paving the way for potential future studies that encompass a broader scope.

We did not exclude any year because of fewer relevant publications. On the other hand, more than 72,000 records were obtained if only the word "crowd" was included in the search. Adding the word tawaf reduced the publications to less than 0.035%. No irrelevant records or duplicates were found. The entire research process is shown in Figure 1.

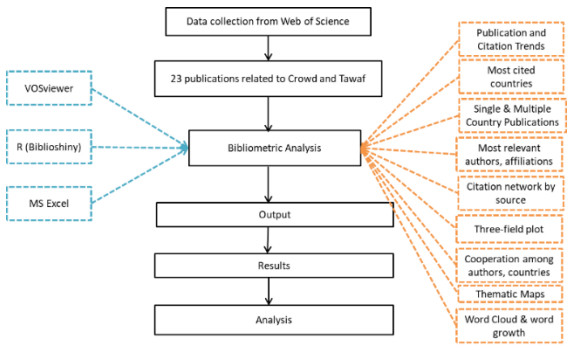

Figure 1. Flowchart of the research process

The publications metadata included titles, authors' names and affiliations, the date of publication, journal/conference details (volume, issue), page numbers, keywords, keywords plus, abstracts, and funding statement—the papers date from 1997 to 2023.

We used many visualization and analysis tools, including Biblioshiny, VOSviewer, and MS Excel. No significant difference or discrepancy was observed between the results obtained by Biblioshiny and VOSviewer.

5. EXPERIMENTS AND RESULTS

Here, we discuss the results obtained by performing a detailed bibliographic analysis related to Tawaf crowd analysis publications.

5.1 Overview of research dynamics

The total number of publications related to the crowd analysis of Tawaf was only 23, published in a time span of 26 years (1997–2023), as shown in Figure 2. No paper appeared between 1998 and 2010, both inclusive. The maximum number of papers (4) was written in 2011. This shows much room for research in this area. Three documents were

published in 2019 and 2021, representing peaks in document publication numbers. Figure 1 illustrates the number of research documents published yearly, reflecting the scholarly attention to Tawaf crowd dynamics over time. No publications were observed in 2014 and 2020, as well. Only one paper was published in 1997, 2013, 2017, and 2023, representing the lowest points in the dataset and are considered troughs.

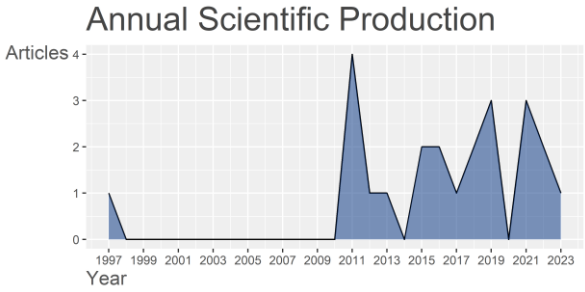

Figure 2. Annual publication trends for research on Tawaf crowd analysis (1997-2023)

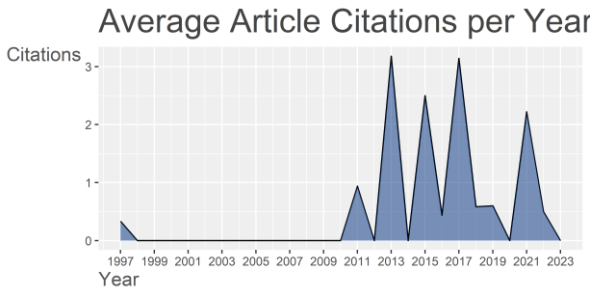

Figure 3. Citation metrics over the years

Figure 3 presents the average article citations per year for various years. No citations were received between 1998 and 2010, corresponding to the absence of any related publications. Starting from 2011, there has been an apparent resurgence in publication activity, with some years indicating a relatively higher mean total citations per article (2011, 2013, 2015, and 2017), suggesting these articles have been cited frequently. The 2015 peak could be explained by the Mina stampede, which caused more than 1000 deaths and many more injuries [15]. The major peaks in the average citations were observed in 2013 and 2017, showing more than 3 citations and relatively minor ones in 2015 and 2021. The average citation per document was 8.9, and the average citation per year per document was 0.997.

5.2 Classification of documents by type and language

It was observed that a majority of the publications (73.9% or 17) consisted of journal articles. The rest (26.1%) were all conference papers. While looking at the Sustainable Development Goals (SDGs), 16 (69.6%) of the articles correspond to the (11) "Sustainable Cities And Communities" field. Only three represent (03) "Good Health And Well Being," whereas a lone publication talked about (04) "Quality Education".

Moreover, all but one article was published in English. The other paper was written in the Turkish language. Furthermore, only two papers were published in the Visual Computer journal, fetching 79 citations. Apart from that, no other source (21 in total) contained more than one publication. We measured the h-index and the g-index for the journals and conferences. The h-index measures the productivity and citation impact of the publications from that particular source. The g-index is similar to the h-index but gives more weight to the highly cited articles. The maximum values of h-index and g-index are 2 each for the Visual Computer journal.

5.3 Citations by country and most relevant institutions

Figure 4 shows the most-cited countries. The highest number of citations (82) was observed for the USA. Malaysia came second on the list, having 55 citations. The papers published by researchers from Pakistan garnered 22 citations. Saudi Arabia (20) and the United Arab Emirates (UAE) also got more than 10 citations. We also calculated the average article citations, considering the total citations and the number of publications. Whereas the USA appeared at the top with 27.33 average article citations, Pakistan came second in the list with a score of 22. Pakistan, while having fewer total citations, has relatively higher average citations per article. This indicates that the publications from Pakistan are highly cited per article, which could suggest influence or quality content within their specific research areas.

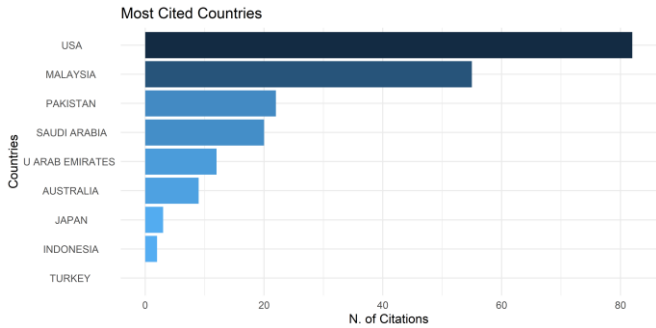

Figure 4. Most cited countries

It is essential to consider that these numbers might be influenced by various factors, such as the size of the country's research community, the number of high-impact journals in the country, and the publication year of the articles considered (newer articles might have had less time to gather citations).

Figure 5 portrays the ten most relevant affiliations according to the number of publications. Most papers (9) were written by Universiti Teknologi Malaysia, also known as the University of Technology, Malaysia. Umm Al-Qura University, Makkah, Saudi Arabia, and University North Carolina, USA, published seven papers. Six other universities were able to publish more than three related papers. Three of the ten universities are from Saudi Arabia, whereas two are Malaysian.

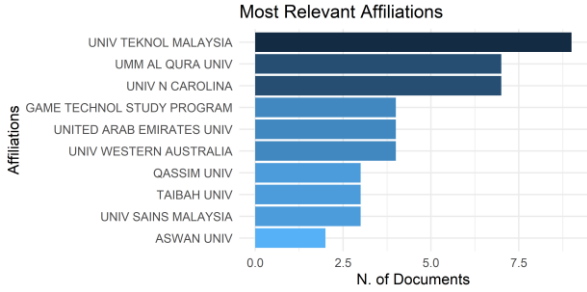

Figure 5. Most relevant affiliations

5.4 Research impact and collaboration

Figure 6 depicts the most relevant authors while considering the number of publications. Most papers (4) were published by Zafar, B. Similarly, Manocha, D. managed to publish three papers. Moreover, seven researchers published two documents each.

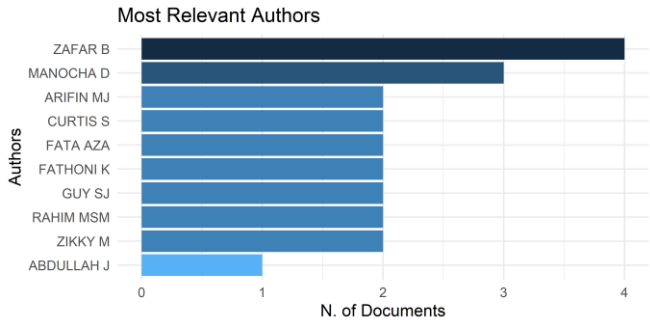

Figure 6. Most relevant researchers

Figure 7 shows a timeline showing the publication record of the top 10 authors over time. The size of the dots represents the number of articles, while the lines connect the dots to illustrate an author's continuous contribution over the years. We can observe that four articles by Zafar, B. were published in 2011, 2013, 2015, and 2018. Similarly, the three publications by Manocha, D. appeared in 2011, 2013, and 2015 (each with a gap of two years). Arifin, M.J., Fathoni, K., and Zikky, M. are the other researchers who have published recently (after 2017) and at least two articles.

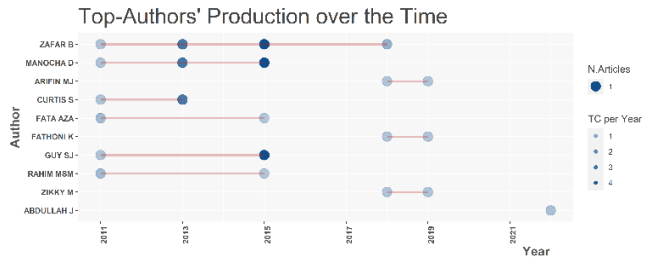

Figure 7. Top researchers' production over time

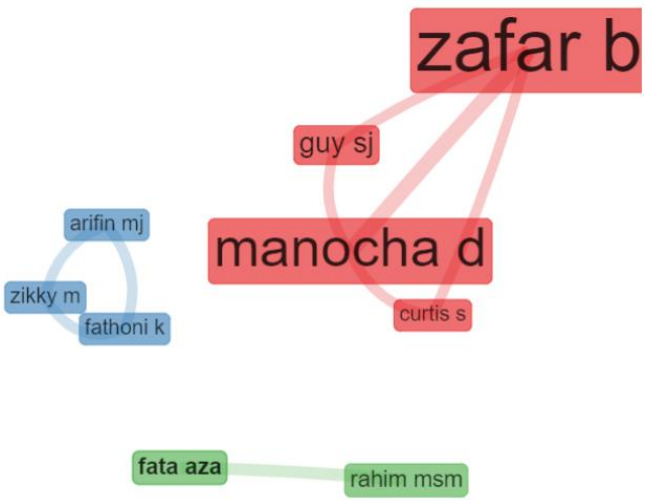

Figure 8. Cooperation among researchers, as shown by Biblioshiny

We discovered three distinct clusters while observing the authors' collaboration network, as shown in Figure 8. In one of the clusters, we found Zafar, B., Manocha, D., Guy, S.J., and Curtis, S. Cluster 2 contained three researchers, namely, Arifin, M.J., Zikky, M., and Fathony, K. Similarly, Fata, A.Z.A and Rahim, M.S.M. were found in yet another cluster. Each cluster suggests a strong collaborative relationship, potentially indicating a research group or frequent co-authors. We noticed the absence of any inter-cluster collaboration, indicating specialized research domains within Tawaf crowd analysis.

We used VOSviewer to generate a graph similar to that shown in Figure 9. Most citations (88) were obtained from papers by Zafar, B. The publications of Manocha, D. received 82 citations, whereas Guy, S.J.'s papers got 47 citations. Curtin, S.'s publications were able to get 38 citations in total. The maps obtained by Biblioshiny and VOSviewer (Figure 9) are the same. The consistency observed between the results obtained by Biblioshiny and VOSviewer ensured the reliability of the visualizations, reinforcing the validity of the collaborative networks and identified citation patterns.

Regarding the collaboration between universities, we observed a strong collaboration between the University of North Carolina, USA, and Umm Al-Qura University, Saudi Arabia.

5.5 Citations analysis

Figure 10 shows the visualization map obtained by VOSviewer, showing the citations by source network. The minimum number of documents of a source was 1, and the minimum citations were 2. Only 14 of 22 sources (63.64%) met the chosen criteria and have been divided into four clusters. The most citations (79) were received by Visual Computer, followed by Simulation Modelling Practice and Theory (36) and the 2017 ACM SIGSIM Conference on Principles of Advanced Discrete Simulation (22). The rest of the sources have received less than 15 citations. Interestingly, the 2019 International Conference on Innovative Trends in Computer Engineering (ITCE) held in Aswan, Egypt, appeared at center stage, though it got only eight citations.

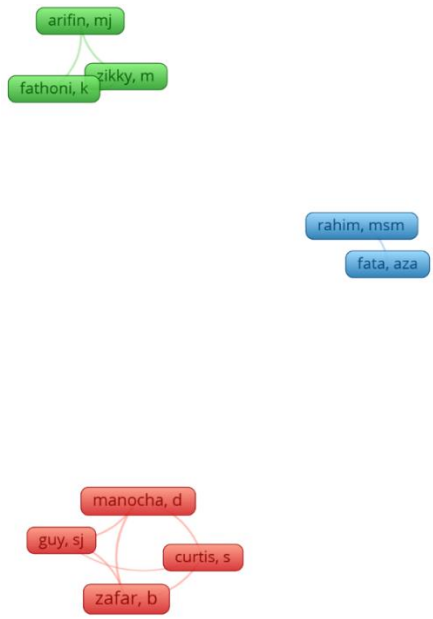

Figure 9. Researchers' cooperation depicted by VOSviewer

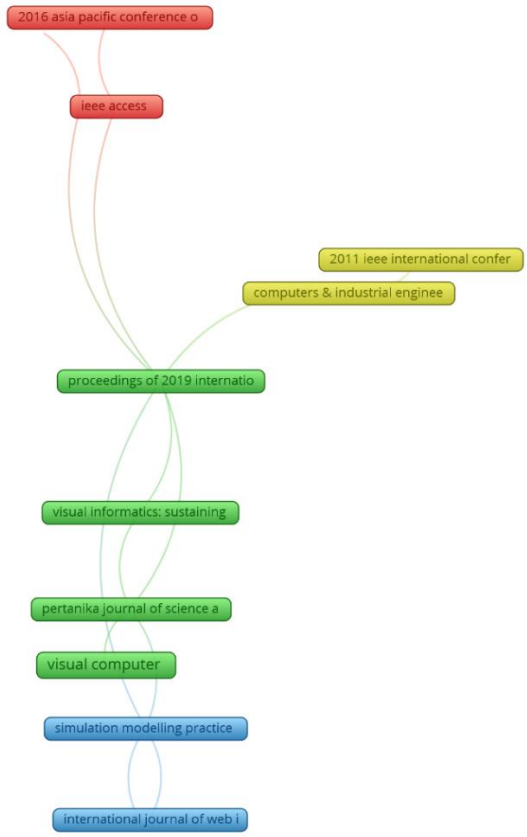

Figure 10. Visualization of the citation network by source

We also analyzed the funding required for these researches. More than 50% (13) papers mentioned some funding source for research.

Figure 11 depicts the bibliographic coupling obtained by VOSviewer while considering the institutions. Of 32 organizations, only six were represented while having at least two documents. Umm Al-Qura University, Saudi Arabia, got the maximum citations (92). The University of North Carolina, USA, received 82, whereas Taibah University, Saudi Arabia, and Univ Sans Malaysia got 38 and 36 citations, respectively.

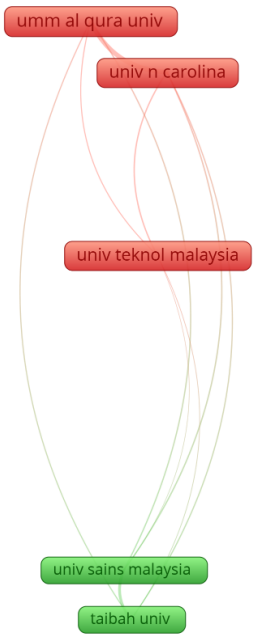

Figure 11. Citation network by institution

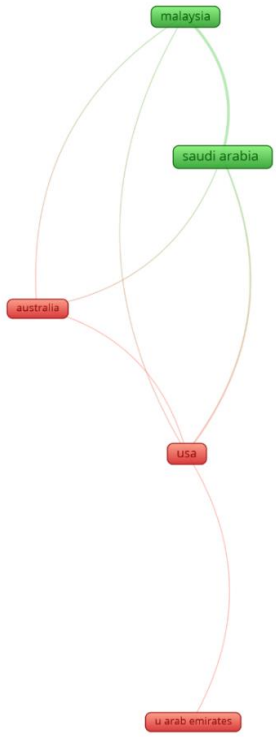

Figure 12. Visualization of the citation network by country
Note: Minimum number of documents of a country = 2;
Minimum number of citations of a country = 0

Figure 12 shows the citation network by country. Only those countries that appeared in at least two publications are considered. Moreover, we did not shortlist the countries based on the minimum number of citations. The maximum number of citations was received by Saudi Arabia (147 for 9 documents), followed by the USA (116 for 6 documents) and Malaysia (55 for 7 documents). Researchers from Saudi Arabia mostly cited works by the USA, Malaysia, and Australia. People from the USA cited research works from all of the selected countries.

5.6 Geographical distribution and cooperation

Figure 13 shows the scientific production across different countries. We want to mention an important point: if a publication contains authors from Countries A and B, it would be counted separately for both countries. Malaysia and Saudi Arabia appeared the most prolific, with 19 documents each. The USA published 12, whereas Australia published 7. Indonesia published 5 related papers. In total, only 11 countries appeared on the list.

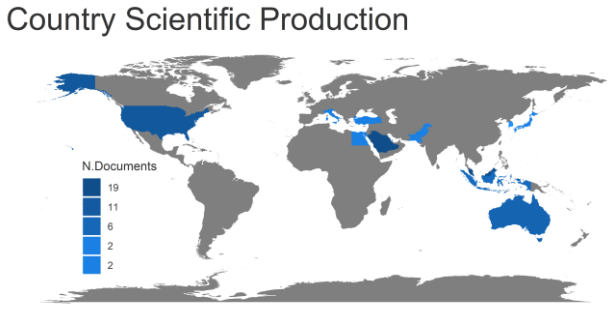

Figure 13. World map showing the geographical distribution of related research

Nevertheless, they are geographically distributed across the world map, confirming the international scope of this research area. No countries appeared from South America. Similarly, the contribution of Africa and Europe was observed to be quite limited. This also indicates that there is much scope in this research area.

As shown in Figure 14, we generated three-field plots using Biblioshiny to study the interaction between the countries, keywords, and sources. The plot is essentially a flow diagram showing the bibliographic coupling between these elements. Moreover, it depicts which universities focus on which topics and where the research is being published. Australia, Malaysia, and Saudi Arabia contributed the most to this research topic. The most common keywords included "crowd simulation," "tawaf," hajj," and "crowd management". Whereas the first three keywords were used by Australia, Malaysia, and Saudi Arabia, "crowd management" was only observed for Australia and Saudi Arabia. Moreover, IEEE Access published articles on all keywords, making it a truly multidisciplinary journal.

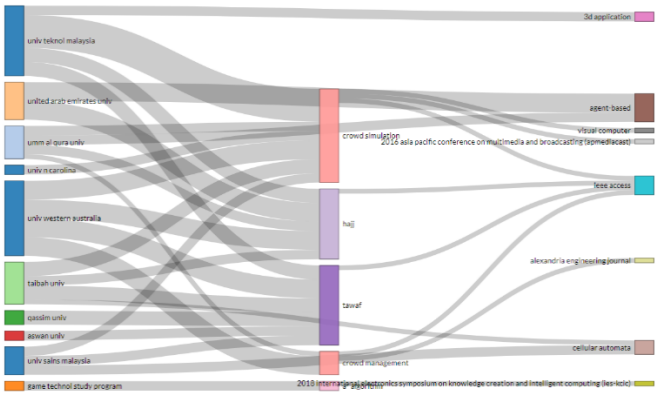

Figure 14. Three field plot – Affiliation (left), Keywords (Middle), and Sources (Right)

Similarly, the contribution of the universities was also studied in detail. The keyword "Hajj" was used by UAE University (UAE), Umm Al-Qura University (Saudi Arabia), University of North Carolina (USA), University of Western Australia (Australia), and Taibah University (Saudi Arabia). Furthermore, the keyword "Tawaf" was employed by Universiti Teknologi Malaysia (Malaysia), University of Western Australia (Australia), Taibah University (Saudi Arabia), Qassim University (Saudi Arabia), Aswan University (Egypt), University Sains Malaysia (Malaysia).

5.7 Detailed analysis of most cited works

Table 1 shows the top five papers according to the number of citations. These are the only papers that have received more than ten citations. Citations measure a paper's impact and recognition in the scholarly community. The titles, authors, the year of publication, and the journal where it is published are provided. We also provide the average number of citations per year each paper has received since its publication. This metric helps normalize the citation count by accounting for the age of the paper, allowing for fair comparison between older and newer papers.

The papers focus on different aspects of crowd behavior, physical interactions, pedestrian movements during religious rituals, emergency evacuation strategies, and the spread of diseases in large gatherings. Two of the papers appeared in the Visual Computer journal. The 2022 impact factor of this journal is 3.5. Similarly, only one paper appeared in a conference. The paper by Kim et al. [16] got the most citations. The title of this paper was generic and just mentioned the dense crowds. They presented an ensemble approach combining a velocity-based collision avoidance algorithm with external physical forces. However, Sarmady et al. [17] developed a model based on cellular automata to represent the pedestrian movement during Tawaf. The paper was published in the Simulation Modelling Practice and Theory journal by Elsevier. The journal has an impact factor of 4.2. Curtis et al. [18] developed an exciting approach called the Right of Way, modeling the asymmetric relationships between pedestrians. Like Kim et al. [16], they presented a model dependent on velocity obstacles. Tawaf was considered to confirm the working of the models. Three of the authors (Zafar, B., Gutub, A.A., and Manocha, D.) are the same as present in Kim et al. [16].

The citation impact of older publications may seem diminished over time compared to more recently published ones. However, their influence can persist or become foundational within a field. Furthermore, the recent publications may have yet to amass many citations but show promise based on their citations per year.

5.8 Terms analysis

Here, we concentrate on examining the commonly utilized terms within related research papers, providing an understanding of the shifting trends and central themes in this domain.

Table 1. Citation analysis of research papers

Paper	Journal	Total Citations (TC)	TC per Year
Velocity-based modeling of physical interactions in dense crowds, Kim et al. [16], 2014	The Visual Computer	44	4.4
A cellular automata model for circular movements of pedestrians during Tawaf, Sarmady et al. [17], 2011	Simulation Modelling Practice and Theory	36	2.571
Right of way Asymmetric agent interactions in crowds, Curtis et al. [18], 2012	The Visual Computer	35	2.917
Analyzing emergency evacuation strategies for mass gatherings using crowd simulation and analysis framework: Hajj scenario, Mahmood et al. [19], 2017	2017 ACM SIGSIM Conference on Principles of Advanced Discrete Simulation	22	2.750
Agent-based modeling of the Hajj rituals with the possible spread of COVID-19, Al-Shaery et al. [20], 2011	Sustainability	12	3

Table 2 shows the frequency of the most common words in the Abstracts. The most common word is crowd, which is unsurprising given the data context. This is followed by words like "hajj," "tawaf," "pilgrims," and "model," and could be considered as the central theme of this research. Whereas "pilgrims" underline the human aspect of the publications, "model" indicates the computational or theoretical models used to simulate or describe crowd behavior and dynamics. Similarly, "study" reflects the academic nature of the papers.

Table 2. The frequency of the most common words found in the Abstracts

Most Common Phrases	Frequency
Crowd	64
Hajj	49
Tawaf	48
Pilgrims	41
Model	38
Simulation	28
Study	20
Proposed	18
Movement	17
System	17

Four clusters were found while studying the co-occurrence network observed in the Titles, depicted in Figure 15. Cluster 1 included words like "simulation," "hajj," "rituals," and "mass". Cluster 2 described words such as "crowd," "model," "analysis," "deep," "dynamics," and "management". Similarly, cluster 3 only discussed "dense" and "crowds". Lastly, cluster 4 included terms like "tawaf," "virtual," "algorithm," "behavior," "case," "pedestrians," "simulating," and "study". Three of the clusters appeared connected. The most prolific terms for cluster 1 are "hajj" and "simulation". Similarly, for cluster 2, "crowd" was the most important term. Lastly, "Tawaf" was the most critical term for cluster 4.

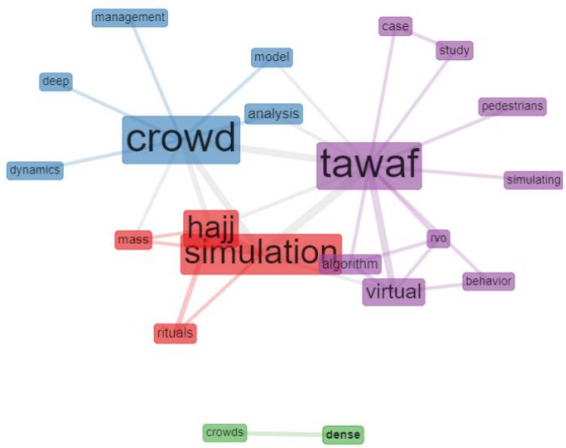

Figure 15. Co-occurence network according to the titles

We use VOSviewer to generate a network visualization map for all the keywords, including the keywords used by the authors and the KeyWords Plus. Any word that occurred at least twice was considered. Figure 16 shows the map for all the keywords, divided into two clusters. Cluster 1 (represented in red) contains words like "behavior," "cellular automata," "congestion," "crowd dynamics," "dynamics," "model," and "simulation". Similarly, Cluster 2 (shown in green) included "crowd management," "crowd simulation," "tawaf," and "hajj".

Figure 17 depicts the thematic map obtained from the titles of publications. The themes are divided into four quadrants based on their density and centrality, which can be interpreted as their relevance and development within the field. Seven clusters are obtained. "Tawaf" and "crowd" are central and well-developed. "Model" and "deep" appeared as niche themes, indicating emerging research areas. Similarly, "tawaf" and "simulation" are basic or primary themes.

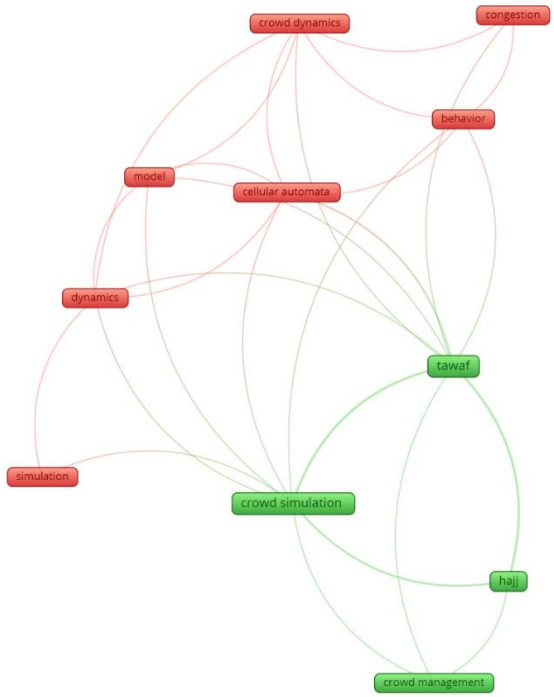

Figure 16. Visualization map for all of the keywords

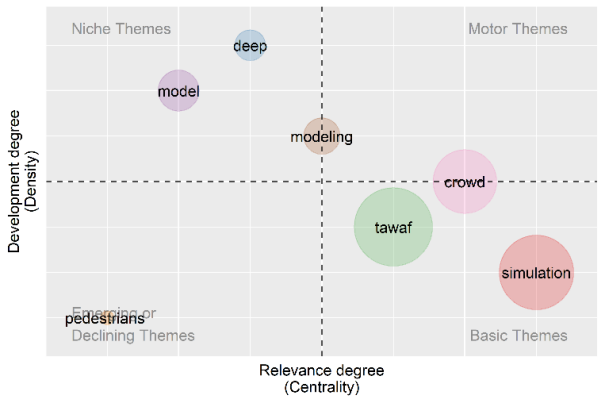

Figure 17. Thematic map based on the titles

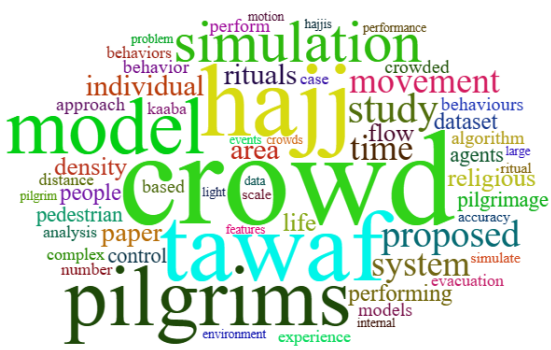

Figure 18. Word cloud obtained from the abstracts

Word clouds offer a quick way to visualize the field's key focus areas and terminologies. The word cloud obtained after processing the text in Abstracts is shown in Figure 18. One can notice that the most prominent terms are "crowd," "tawaf," "hajj," "pilgrims," and "model". These words are all related to crowd management in Makkah. Focusing on these terms could result in further improvement in crowd management.

In a similar context, Figure 19 shows the common words used in the titles of research papers. We observed words like "tawaf," "crowd," "simulation," "hajj," "model", "algorithms", "virtual", and "ritual". The words are mainly similar to the ones obtained in the Abstracts. Nevertheless, it is worth noting that the absence of the term "virtual" in the abstracts, though present in titles, hints at a potential research focus shift between abstracts and titles.

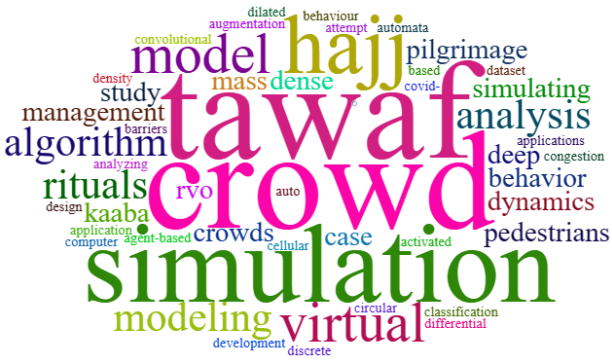

Figure 19. Word cloud obtained from titles

Next, we show the word growth as observed in the titles of the research papers in Figure 20. The word "crowd" appeared to be ever-increasing during the last ten years. Similarly, the use of "hajj" also showed an increasing trend. On the other hand, a decreasing trend could be seen for words such as "simulation," "tawaf," "analysis," and "virtual".

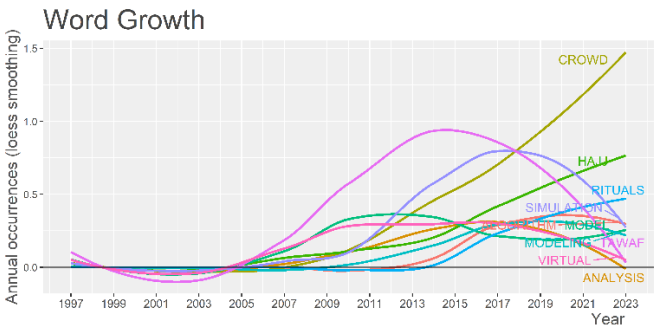

Figure 20. Word growth for the titles

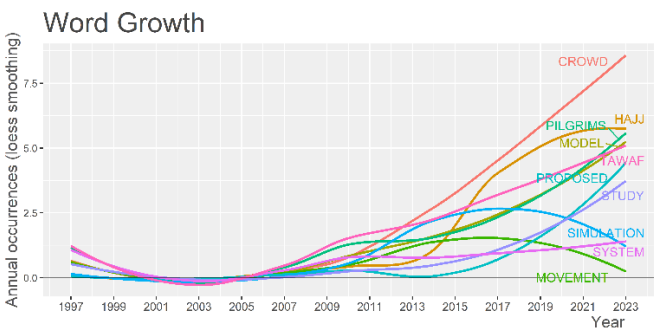

Figure 21. Word growth for the abstracts

We also compared the word growth in the Abstracts, as shown in Figure 21. Interestingly, words like "crowd" and "hajj" showed the maximum growth, just like observed in titles. However, words like "pilgrim," "model," and "tawaf" have also shown increasing trends during the last few years. Words like "movement" and "simulation" have shown decreasing trends during the last six years. This indicated the research trends.

5.9 Collaborative networks' visualization

Similarly, Figure 22 shows the collaboration world map. The strongest collaboration (4 publications) was observed between Saudi Arabia and the USA. A significant partnership was also found between Malaysia and Saudi Arabia, as well as between the USA and the United Arab Emirates. Most countries have a substantial Muslim population.

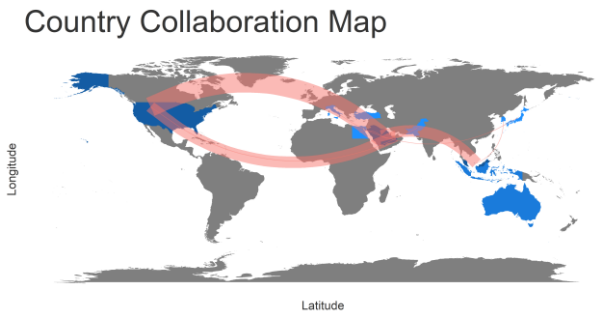

Figure 22. World collaboration map

Figure 23 shows the corresponding author's country. We show the Single and Multiple Country Publications (SCP and MCP are shown with Orange and Blue bars, respectively) for various countries. Countries like the USA, UAE, Japan, and Pakistan show a propensity for international collaborations. In contrast, Australia, Indonesia, and Turkey have an MCP Ratio of 0.00, indicating that all their listed publications are domestic with no international collaboration. The ratio of SCP to MCP for Malaysia was 1.33. The values for Saudi Arabia are 3. This data can help understand the openness and collaborative nature of research within and across countries. Higher MCP ratios indicate a country's greater integration into the global research community. On the other hand, lower ratios portray more insular research environments or strong domestic research capabilities.

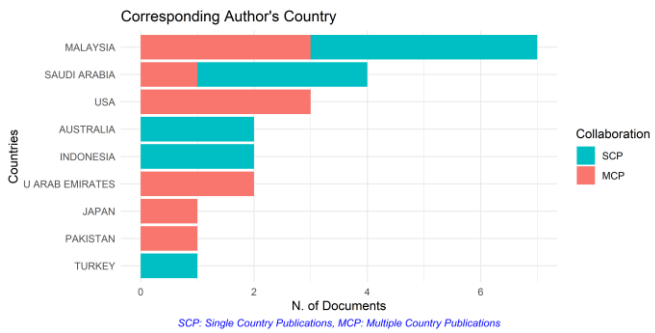

Figure 23. Proportion of single and multiple country publications

5.10 Page and authorship variations

We also discuss the variations observed in the number of

pages and authors. Figure 24 displays the variation in the number of pages. The minimum number of pages was only 4, whereas the maximum was 45. The average number of pages was 14.7. Moreover, only two papers appeared in a Special Issue.

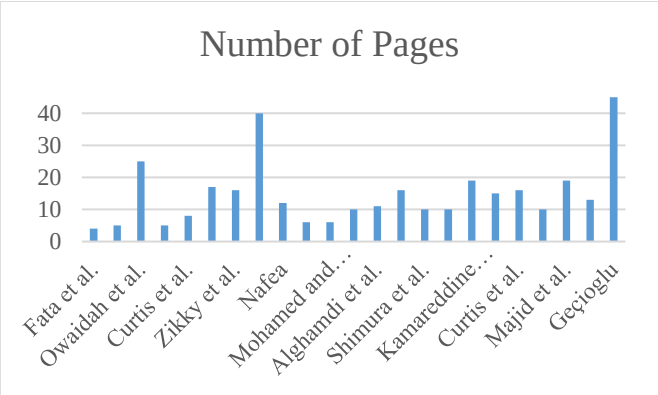

Figure 24. Variation in the number of pages

Figure 25 depicts the variation in the number of authors for different papers. The maximum number of authors (7) was found in Bhuiyan et al. On the other hand, there were only two single-author papers. 91.30% of the papers were multi-authored. The average number of researchers was 3.4. Sixty-four authors appeared in the entire dataset. Their appearances amounted to 76. On the other hand, the documents per author were observed as 0.359.

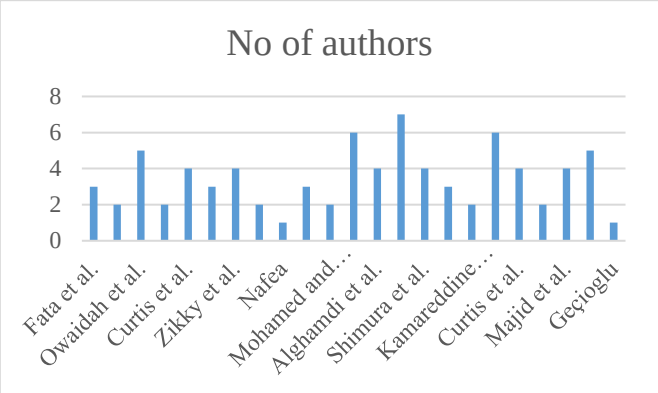

Figure 25. Number of researchers for different publications

6. DISCUSSION

Our bibliometric analysis reveals several key insights into the research landscape of crowd management during Tawaf, aligning with and expanding upon existing literature in this domain. This section interprets these findings, juxtaposing them with current knowledge and discussing their broader implications, including direct impacts on Tawaf crowd management strategies and the potential for generalizing these strategies to other mass gatherings.

The identified research trends and gaps highlight the evolving nature of crowd management studies, particularly in the context of Tawaf. The hiatus in research between 1998 and 2010, followed by a noticeable increase in publications, suggests a growing academic and practical interest in addressing the unique challenges of managing large crowds in religious settings. This trend is consistent with the literature indicating an increased focus on crowd safety following significant crowd-related incidents globally. The emphasis on technological advancements in recent studies reflects a broader shift towards leveraging digital solutions for complex problems, a theme recurrent in contemporary crowd management research.

The significant role of collaborative networks, particularly among key institutions and countries, echoes findings in related fields where interdisciplinary and international collaboration has been pivotal in advancing research and practice. The USA and Umm Al-Qura University, Makkah's prominence in this research domain aligns with their recognized contributions to crowd management and safety literature, underscoring the importance of geographical and cultural contexts in shaping research outputs.

Utilizing particular methodologies and models highlighted in the most cited works, such as Kim et al.'s ensemble approach [16] and Sarmady et al.'s cellular automata model [17], carries practical implications for Tawaf crowd management. These techniques could improve safety and efficiency during large gatherings.

The findings from our bibliometric analysis, mainly the focus on technology and collaborations, directly impact the improvement of crowd management during Tawaf. Incorporating technology, as seen in the increasing literature on digital solutions, can significantly enhance the safety and efficiency of Tawaf. For example, crowd simulation models can help predict and address potential congestion and high-risk areas, allowing for proactive crowd control.

Furthermore, the analysis depicts the importance of global and interdisciplinary collaborations in improving crowd management techniques. Using insights from various fields can create innovative solutions customized to the distinct challenges of Tawaf, including cultural and religious factors influencing crowd behavior. Collaborations between institutions in highly cited countries and key contributors in the field can facilitate the sharing of knowledge and best practices.

Although Tawaf's distinctive religious context poses unique challenges, many of the strategies and technologies uncovered in this study can be modified and employed in various mass gatherings. The fundamental principles of crowd simulation, real-time monitoring, and data-driven management are universally relevant to events hosting large crowds.

The study emphasizes collaborative networks and interdisciplinary approaches that provide a model applicable to diverse settings. Encouraging partnerships across different disciplines allows mass-gathering organizers to tap into a broader range of resources and insights, thereby improving participants' safety and overall experience.

Nevertheless, it is essential to consider the unique characteristics of each event, including the crowd's nature, the layout of the venue, and the cultural and social context. Tailoring the implementation of technology and management strategies to align with these variables will guarantee their effectiveness and acceptance by the crowd.

7. LIMITATIONS

The current research has several strengths, but it is necessary to acknowledge certain limitations that could impact the interpretation and generalizability of the findings. Some

potential limitations are given next:

(1) Small database size: The dataset comprises merely 23 publications. The restricted number of publications may not comprehensively encompass the extensive range of research on crowd analysis during Tawaf.

(2) Database selection: The study relies solely on WoS for data extraction. This decision could introduce bias by excluding possibly relevant publications from other databases.

(3) Focus on Tawaf: This research focuses on crowd analysis during the Tawaf ritual. While this is a valid and specific focus, the results may not be readily applicable to other crowd analysis contexts.

(4) Citation metrics as the only impact measure: The impact assessment predominantly hinges on citation metrics. While citations measure academic influence, they may only partially incorporate the practical implications or real-world applications of research. Furthermore, various factors, such as self-citations, can influence citation metrics.

8. CONCLUSIONS

This paper presents an extensive bibliometric analysis of the research related to crowd management during Tawaf over the last 26 years. With 23 publications, it is clear that this specialized field is still in its early stages, showing significant potential for growth and exploration. By studying publication trends, analyzing citations, exploring collaborations, and investigating themes, this research has thoroughly depicted the scholarly landscape within this particular domain.

The results show that although there has been a considerable amount of research on Tawaf crowd dynamics, there is substantial potential for further exploration, with identified periods of limited publication activity. The average citation per document was 8.9, which shows that the contributions have been impactful despite the low research volume. The distribution of document types underscores a stronger preference for dissemination through journal articles, comprising 73.9% of total publications. The global interest in Tawaf crowd management research is evident in the geographical distribution of citations and contributions from various countries and institutions, with notable input from the USA, Malaysia, and Saudi Arabia. This distribution also indicates potential areas for international collaboration and knowledge exchange to address the challenges of crowd management in densely populated events.

Authorship and collaboration analyses pinpointed key contributors to the field and outlined the nature of global research partnerships. With a predominant focus on journal articles in English, literature demonstrates diverse methodologies and approaches, underscoring the multidisciplinary nature of crowd management research. The term analysis performed by tools like VOSviewer and Biblioshiny uncovered prevalent keywords and themes. This bibliographic analysis maps the current state of Tawaf crowd analysis research and identifies critical gaps and opportunities for future studies. By addressing these areas, researchers can contribute to developing safer, more efficient, and sustainable crowd management practices for Tawaf and similar large-scale events, ultimately enhancing participant safety and experience.

This study's reliance on specific databases may have overlooked non-indexed publications, potentially limiting the scope of analysis. We plan to conduct a similar study using the Scopus database to capture a broader range of publications and insights into this important field of study.

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