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NARRATIVE/SYSTEMATIC REVIEW/META-ANALYSIS

Tracing the Blockchain Challenges in Healthcare: A Topic Modeling and Bibliometric Analysis

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Abstract

The application of blockchain technology to healthcare offers promise in providing solutions to some key challenges related to data sharing, privacy, security, and access control. However, several barriers prevent the widespread adoption of blockchain and prompted research efforts. This study aims to conduct a bibliometric analysis of 196 documents indexed in the Scopus database to examine their structure, impact, contributors, and journals. The bibliometric analysis provides information on the publication and citation structure, as well as the most productive authors, universities, countries, journals, and most cited studies. In addition, it identifies the most prevalent keywords and their co-occurrence patterns on blockchain challenges in healthcare. A topic modeling approach, using Latent Dirichlet Allocation (LDA), is also employed to reveal the latent topical structure of this literature. As a result of these findings, the research landscape in this area has been quantitatively analyzed, identifying six critical challenges regarding the use of blockchain in healthcare: data privacy/security, integration with smart devices, interoperability, scalability, governance, and cost.

Plain Language Summary

Despite the potential of blockchain technology to improve healthcare, its widespread adoption remains limited. This study examines the research conducted on blockchain challenges in healthcare. A bibliometric analysis of 196 studies was performed to clarify the current state of this research area. In addition, a topic modeling technique was used to identify the major challenges: data privacy/security, integration with smart devices, interoperability, scalability, governance, and cost. This analysis demonstrates that data privacy/security and integration with smart devices are the predominant challenges regarding their topic size. These findings provide a comprehensive overview of the obstacles blockchain faces in healthcare and highlight areas for future research.

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In the last century, technological advancements in the healthcare sector have revolutionized the industry significantly. Following the advancements and increasing uses of the internet, online communication systems are becoming a priority for different users,[1] resulting in generating a growing amount of personal health data. Accordingly, the healthcare industry faces a significant challenge that requires the proper management and secure retrieval of massive amounts of data to address this concern. However, health data are mostly inaccessible, non-standardized across systems, and challenging to understand, use, and share.[2] More specifically, as patient data are scattered throughout the value chain of the healthcare industry, and the sharing of information is subject to multiple levels of permission control, vital data are not always accessible when needed. To address this challenge, blockchain technology has received considerable attention for its potential application to healthcare.

Blockchain technology provides an exceptionally transparent and secure system for exchanging information with minimal risk of leakage or modifications to the security system. In the blockchain, multiple copies of information are

shared among multiple nodes on a blockchain network.[3] As a result, such distributed systems that rely on many nodes to perform different roles on the network can be assured of their integrity, security, consistency, and reliability.

Despite the benefits witnessed or studied by the research community in the blockchain revolution for healthcare challenges, this technology still faces significant concerns regarding its adoption by the entire global healthcare industry.[4] Given that blockchain technology presents challenges to the healthcare industry, this study traces and analyzes these challenges by employing bibliometric analysis to provide an overview of the field and a text analytics method based on topic modeling to identify specific challenges.

The objectives of this study are twofold:

1. Quantify and analyze research outputs, impact, and collaboration patterns in the field of blockchain challenges in healthcare.
2. Identify key contributors, influential publications, and leading journals in this domain.

To uncover the dominant themes and challenges discussed in the literature using topic modeling techniques, this article is organized as follows: Section 2 presents the related works conducted on the targeted topic. Section 3 discusses the methodologies used in this study. Section 4 presents the findings of both bibliometric analysis and topic detection. Section 5 provides the discussion and conclusions.

As a novel technological development, blockchain technology has prompted considerable interest among researchers, resulting in the publication of several studies examining its innovative potential and diverse applications in the healthcare sector. Despite blockchain's transformative potential in the health domain, it is also confronted with challenges that are prompting extensive research to address these challenges from different viewpoints.[5] As a result, several systematic reviews have been conducted over the past few years to synthesize and summarize the findings from various studies that addressed the applications and challenges of blockchain in healthcare.

Reviews providing a comprehensive analysis indicate that blockchain technology can not only help enhance the security, privacy, data sharing, and access control of health records but also faces challenges due to scalability, interoperability, storage, and costs (Table 1). Among these, more specific reviews,[5] the focus is on identifying and proposing potential solutions for specific challenge categories such as scalability.

Methodology

The methodological framework employed in this study is illustrated in Figure 1. Detailed explanations of data acquisition, preparation, and analysis using bibliometric and topic modeling tools are provided in the following subsections.

Data Acquisition

With a focus on blockchain challenges in healthcare, this study employed a rigorous data collection process from Elsevier's Scopus repository, which covers academic literature extensively. One of the main advantages of Scopus is its ability to organize bibliographic information into categories, codify the retrieved material, and automatically analyze the information. To find the publications, different combinations of keywords of blockchain, challenges, and healthcare were used to ensure that relevant studies are covered as widely as possible. The search, conducted in February 2024, was based solely on the article titles and keywords, utilizing logical "OR" operators for synonymous phrases related to challenges, healthcare, and different forms of blockchain, all connected by three "AND" conditions:

> ("blockchain" OR "block-chain") AND ("healthcare" OR "medical" OR "health") AND ("challenge" OR "obstacle" OR "issue" OR "barrier")

A total of 196 articles were retrieved from the search. These publications, written in English, included articles, reviews, and conference papers, all published between 2017 and 2023. For analysis, details related to the collected documents were exported to a CSV (Comma Separated Values) Excel file.

Bibliometric Analysis

In this study, a bibliometric approach was applied to the analysis of the most important and common indicators. Based on the methodology outlined by Goodell and colleagues,[13] we conducted a comprehensive bibliometric analysis to examine the publication and citation structure, identify the most productive authors, universities, and countries, highlight studies with the highest citation counts, determine the most productive journals, and perform keyword occurrence and co-occurrence analyses. Additionally, the co-occurrence analysis was visualized using VOSviewer, which features an easy-to-use interface and provides an overview of author and index keywords and their co-occurrence. In addition, this software was employed to create a network diagram of the co-authorship relationships among countries to illustrate the extent of their collaborations in producing scholarly publications.

Topic Modeling: Data Preparation and Analysis

For topic analysis, the collected data must be preprocessed in the first step through a set of procedures to provide a

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Table 1. A summary of literature reviews on blockchain in healthcare.

Study	Objective	Methods	Source	Years covered/ articles (N)	Key findings
AbuHalimeh & Ali[6]	Conduct a comprehensive review to identify challenges associated with data quality when using blockchain technology in healthcare.	SLR	Scopus, ACM, Emerald, Science Direct, Web of Science, IEEE	2016–22 (49)	• Blockchain in healthcare poses significant challenges around data quality, classified technological, adoption, and operational factors.
Singh et al.[7]	Examine blockchain technology and its application in healthcare, including the challenges, comparisons, and possible solutions.	Review	Scopus, IEEE Xplore, ScienceDirect, ACM Digital Library, and SpringerLink	N/A (84)	• Security, privacy, interoperability, and data sharing are challenges facing current healthcare systems; blockchain can address these issues. • Scalability, privacy, governance, standards, ownership, and costs are challenges in adoption of blockchain for healthcare.
Taherdoost[8]	Review research on blockchain privacy and security in healthcare, focusing on practical applications and challenges.	SLR	Scopus	2017–22 (65)	• Blockchain in healthcare is growing and can be used to control access to medical records, share data, and enhance privacy. • Blockchain adoption faces several challenges, including scalability and interoperability.
Kumar et al.[9]	Examine healthcare blockchain applications powered by AI and their challenges.	SLR and Meta-Analyses (PRISMA)	IEEE Xplore, PubMed, ScienceDirect, Google Scholar, Web of Science, DOAJ, ResearchGate	2012–22 (100)	• Medical records, including health data, can be securely stored and shared using blockchain technology. • Blockchain and AI in healthcare have some open challenges (e.g., privacy, bandwidth, regulations, and trust).
Sharma et al.[10]	A comprehensive overview of blockchain-based applications across various domains to identify challenges and directions for future research.	SLR	Google Scholar	2015–19 (161)	• Blockchain is most commonly used in IoT, cloud storage, and healthcare. • Application challenges associated with blockchains include storage, scalability, privacy, and security.
Agrawal et al.[1]	Review 10 blockchain applications and tools, addressing scalability, immutability, robustness, network latency, audibility, and traceability issues.	SLR	IEEE Access, IEEE Transactions, ACM Computing Surveys, Computers & Security, Future Generation Computer Systems	2017–22 (>150)	• Blockchain-based applications are identified: academics, aviation, banking, car sharing, e-voting, healthcare, IoT, IPR, and supply chain. • Scalability, latency, storage overhead, security vulnerabilities, lack of privacy, high energy consumption, interoperability concerns, usability concerns, and regulatory uncertainty are presented as challenges and open issues with blockchain technology.

continued

Table 1. (Continued) A summary of literature reviews on blockchain in healthcare.

Study	Objective	Methods	Source	Years covered/ articles (N)	Key findings
Ratta et al.[11]	Analyze applications of blockchain-IoT integration in healthcare, identifying challenges and proposed solutions.	SLR	IEEE, Elsevier, Springer	2016–21 (30)	• Blockchain can mitigate vulnerabilities of IoT in healthcare by providing decentralization, transparency, and security. • Challenges faced by healthcare blockchain-IoT solutions include interoperability, scalability, storage, standardization, and convincing clinicians and patients to share information.
Khatri et al.[12]	Conduct a comprehensive analysis of challenges and trends in implementing blockchain solutions in the healthcare industry.	SLR	IEEE Xplore, Science Direct, Springer Link, ACM Digital Library, PubMed	2015–20 (50)	• Focus on areas such as data sharing, EHRs, access control, and clinical trials is a growing trend in blockchain healthcare research. • The main challenges to using blockchain in healthcare include security, privacy, scalability, interoperability, speed, lack of expertise, and high costs of healthcare infrastructure.
Mazlan et al.[5]	To undertake a systematic review of scalability challenges faced by blockchain-based healthcare applications and potential solutions	SLR	IEEE, ACM, PubMed	- (41)	• Major challenges to scalability were identified: block size, high volume of data, number of transactions, and protocol limitations. • 16 solutions are proposed and categorized under three categories: storage optimization (3 solutions) and blockchain redesign (13 solutions).

ACM: Association for Computing Machinery; AI: artificial intelligence; IEEE: Institute of Electrical and Electronics Engineers; DOAJ: Directory of Open Access Journals; IPR: Intellectual Property Rights; IoT: Internet of Things; N/A: not available; SLR: systematic literature review.

cleaned corpus. The study utilized titles, abstracts, and keywords from the stored 196 articles in the CSV file. For this purpose, all textual data in the dataset were converted to lowercase, a process known as lowercase conversion, which is essential to avoid duplicate representations of the same word due to capitalization variations. This results in the consistency and uniformity of the corpus. Afterward, special characters and punctuation marks, making noise with the topic modeling process, were removed from the text. To further refine the dataset and emphasize terms that are more relevant and informative, the common stopwords "the," "and," and "in" were excluded from the dataset. By taking this step, the topic modeling process can be rationalized in terms of computational overhead.

Additionally, stemming and lemmatization techniques were applied to normalize the text data. The stemming process transforms words into their root forms, while lemmatization transforms words into their base forms. By converging variations of the same word, both techniques increased the quality of the dataset and improved the representation of the corpus.

Topic Detection: Latent Dirichlet Allocation

For topic detection, Latent Dirichlet Allocation (LDA), one of the most widely used algorithms for topic modeling,[14] was used to identify dominant topics. The LDA relies on the assumption that each document in the corpus contains several different topics[15] in various proportions, each of which represents a probability distribution over a fixed set of words. Based on this assumption, the LDA algorithm makes a latent topical structure of the corpus from the co-occurrence patterns of words across documents.[16]

To implement the LDA-based topic modeling in this study, the preprocessed textual corpus, obtained through the preprocessing steps, was transformed into a Document-Term Matrix (DTM), serving as the input for the LDA algorithm. Through this transformation, a numerical format of the corpus could be created, enabling LDA to identify latent topics and their word distributions efficiently. The most important challenge topic modeling faces is selecting the optimum number of topics for a corpus.[17] Accordingly, the Coherence score was used in this study as a metric to identify the optimal number

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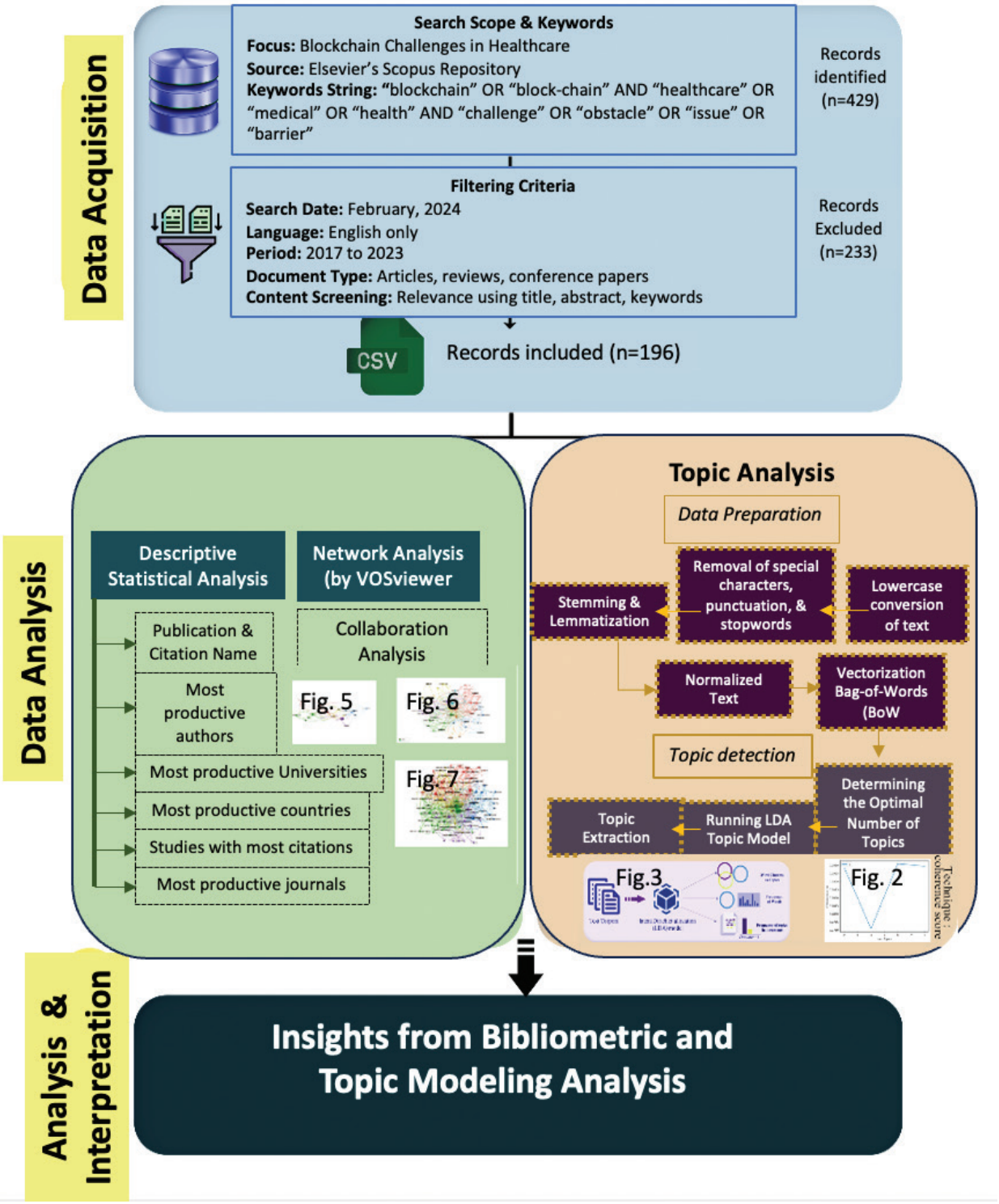

Fig. 1. Research framework for bibliometric and topic modeling analysis. See Figures 2, 3, 5, 6, and 7 for detailed scatter plots and illustration shown in this figure.

of topics. In coherence computation, words constituting a topic are checked for consistency. Higher coherence scores indicate higher quality of topics,[18] providing better interpretability of the topics. The optimal number of topics was six, as determined by the coherence score (Figure 2 and Table 2), indicating the elbow of the curve in coherence and adding topics beyond six did not significantly improve coherence.

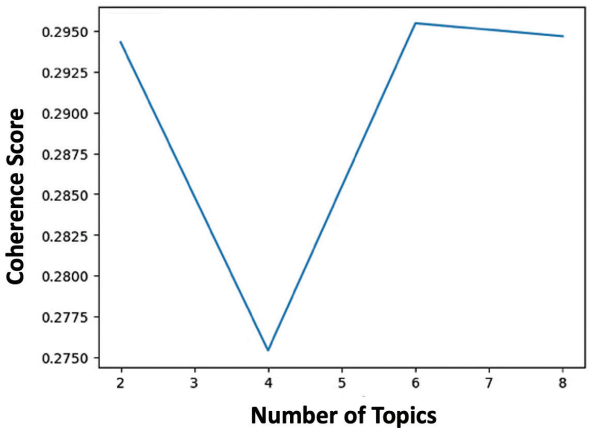

Fig. 2. Coherence score for Latent Dirichlet Allocation. See Figure 1 for greater context.

Table 2. Coherence score by the number of topics.

Topics (*n*)	Coherence score
2	0.2943
4	0.2754
6	0.2955
8	0.2947

Figure 3 illustrates the structure of LDA topic modeling using Dirichlet distributions for topic and word distributions. This model includes three levels: the corpus level, the document level, and the word level.[19] At the corpus level, $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are the global parameters, representing the distribution of topics across documents and the word distributions for each topic, respectively. The $\boldsymbol{\theta}$ parameter, a document-level variable, indicates the topic proportions in a particular document. Finally, the variables **z** and **w** correspond to the word level, where z specifies the topic assigned to a particular word, and w represents a word associated with a particular topic.

Results

Publication and Citation Structure

Table 3 presents information on the number of papers published in the realm of healthcare, with a focus on blockchain challenges and the general citation structures that appeared in these articles. This information is also depicted in Figure 1, showing the trends in publication counts and the number of citations for this topic since 2017. Starting with a single publication in 2017, there was steady growth during the early years, with more than doubling the previous year's output. The publications of 2021 achieved 48 and revealed a significant jump. The upward trend in production continued through 2022 and 2023.

As shown, the number of publications conducted to study the challenges faced by blockchain in healthcare is growing noticeably. There is also evidence that the vast majority of highly cited papers were published during the period from 2019 to 2021. Specifically, Table 3 and Figure 4 reveal a steady increase for the first 2 years, followed by a remarkable increase to 1,695 citations in 2019. After this peak, a slight decrease was marked by a rapid decline in subsequent years. Specifically, about 4.5% of the articles acquired more than 150 citations, 3.5% more than 100, 7.14% more than 20, 14.79% more than 10, 9.69% more than 5, and almost 24% received more than one citation.

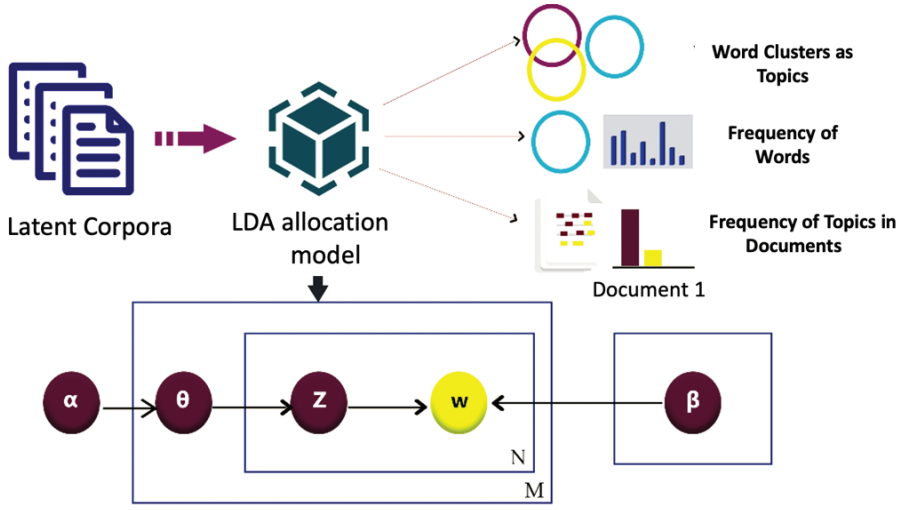

Fig. 3. Graphical representation of the Latent Dirichlet Allocation (LDA) model. See Figure 1 for greater context. $\boldsymbol{\alpha}$: Dirichlet hyperparameter for topic proportions; $\boldsymbol{\theta}$: topic proportions per document; **Z**: topic assignment per word; **W**: observed word; $\boldsymbol{\beta}$: topic-word distributions; **M**: document numbers; **N**: the word numbers in a particular document.

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Table 3. General citation structure of studies addressing blockchain challenges in healthcare.

Year	>150	>100	>50	>20	>10	>5	>1	Total studies	Total citations
2017	1	0	0	0	0	0	0	1	247
2018	0	1	3	1	0	0	1	6	364
2019	4	1	1	1	3	1	2	13	1,695
2020	2	1	4	3	5	1	3	21	1,236
2021	2	2	6	7	8	6	12	48	1,352
2022	0	2	0	6	5	7	18	46	571
2023	0	0	0	4	8	4	11	57	336

The data were retrieved in February 2024 based on Scopus; the numerical values >150, >100, >50, >20, >10, >5, and >1 denote the number of citations each study has received.

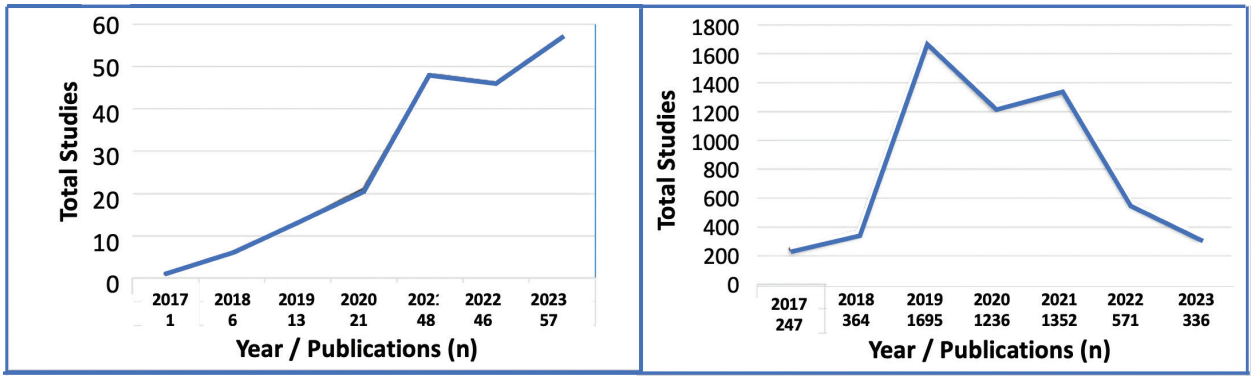

Fig. 4. Trends in publications and in citations addressing research into blockchain challenges in healthcare.

Most Productive Authors

A list of the 10 most productive authors who studied blockchain challenges in healthcare is presented in Table 4. This table shows how many studies have been published on this topic by the highly productive authors, how many citations their studies received, and their scholarly influence and productivity in the field. In addition to these metrics, an evaluation of each author's contribution within the targeted subject was conducted, taking into account both the number of articles produced to the total number of publications in the field and the number of citations among the total number of publications reviewed.

Jayaraman and Salah at Khalifa University in the United Arab Emirates demonstrate notable research outputs with a high number of citations, showing impactful contributions, with an average of 14.63% production over total studies. The highest number of citations, as shown in Table 4, is attributed to seven studies authored by researchers Kumar from the Thapar Institute of Engineering and Technology in India and Choo from the University of Texas at San Antonio in the United States. It reflects the significant influence of these studies on other research and their substantial contribution to the field. Moreover, the greatest h-index belongs to Bhushan from the Ohio State University in the United States, showcasing his high-quality studies.

Most Productive Universities

Table 5 presents a list of top 10 universities with the highest number of papers published on blockchain challenges in healthcare. Alongside the total number of productions and received citations, these universities are compared in terms of country, QS World University Rankings, and the number of publications reaching citation thresholds of 50, 100, and 150. As depicted, the University of Petroleum and Energy Studies in India and Khalifa University of Science and Technology in the United Arab Emirates stand out with the highest number of publications. With the same number of publications, Khalifa University of Science and Technology has received a total of 266 citations, which is notable in comparison to the publications of the University of Petroleum and Energy Studies.

The more citations publications receive, the more significant their contributions to advancing knowledge, indicating they are valued highly in this field. Accordingly, the University of Texas at San Antonio and the Thapar Institute of Engineering & Technology occupy the top two positions as the most influential universities, with 843 and 702 citations, respectively, followed by the Nirma University Institute of Technology with 440 citations. In addition to the related information about the publications in the addressed area by each university,

Table 4. The most productive authors of the study of blockchain challenges in healthcare.

Rank	Author	Institution	TP	TC	TP/total studies (%)	TC/total citations (%)	H	>5	>20	>50	>100
1	Jayaraman, R.	Khalifa University, UAE	6	254	14.63	8.7	43	2	0	2	1
2	Salah, K.	Khalifa University, UAE	6	254	14.63	8.7	66	2	0	2	1
3	Ellahham, S.	Cleveland Clinic, Abu Dhabi, UAE	5	121	12.20	4.2	32	2	0	2	0
4	Kumar, N.	Thapar Institute of Engineering and Technology, India	4	702	9.76	24.2	119	1	1	0	2
5	Tanwar, S.	Nirma University, India	4	436	9.76	15.0	72	2	0	0	1
6	Yaqoob, I.	Charles Sturt University, Australia	4	193	9.76	6.7	49	1	0	1	1
7	Bhushan, B.	The Ohio State University, United States	3	40	7.32	1.4	144	3	0	0	0
8	Choo, KKR.	University of Texas at San Antonio, United States	3	806	7.32	27.8	94	0	0	1	2
9	Kumar, A.	University of Petroleum and Energy Studies, India	3	39	7.32	1.3	45	3	0	0	0
10	Mantas, G.	University of Greenwich, UK	3	55	7.32	1.9	23	2	1	0	0

Data were retrieved in February 2024 based on Scopus: H: h-index; TC: total citations; TC/total citations (%): the percentage of total citations each author has received relative to the total citations; TP: total publications; TP/total studies (%): the percentage of total publications by each author relative to the total publications. The numerical values >150, >100, >50, >20, >10, >5, and >1 denote the number of citations each study has received.

Table 5. Top productive universities for blockchain challenges in healthcare.

Rank	Institute, country	TP	TC	TC/total studies (%)	TC/total citations (%)	QS	>5	>20	>50	>100
1	University of Petroleum and Energy Studies, India	7	44	14.89	1.43	901–950	3	0	0	0
2	Khalifa University of Science and Technology, UAE	7	266	14.89	8.67	230	3	0	2	1
3	Thapar Institute of Engineering & Technology, India	5	702	10.64	22.88	951–1,000	1	1	0	2
4	Nirma University, Institute of Technology, India	5	440	10.64	14.34	N/A	4	0	0	1
5	Cleveland Clinic Abu Dhabi, UAE	5	121	10.64	3.94	N/A	1	0	2	0
6	The University of Texas at San Antonio, United States	4	843	8.51	27.48	1,001–1,200	1	0	1	2
7	Vellore Institute of Technology, India	4	50	8.51	1.63	851–900	5	0	0	0
8	Universiti Putra Malaysia, Malaysia	4	278	8.51	9.06	158	0	1	0	2
9	Federation University Australia, Australia	3	247	6.38	8.05	791–800	0	1	1	1
10	Charles Darwin University, Australia	3	77	6.38	2.51	601–610	2	0	1	0

The data were retrieved in February 2024 based on Scopus: QS: Quacquarelli Symonds World University Rankings; TC: total citations; TC/total citations (%): the percentage of total citations each author has received relative to the total citations; TP: total publications; TP/total studies (%): the percentage of total publications by each author relative to the total publications. The numerical values >5, >20, >50, >100 denote the number of citations each study has received.

the current world ranking of these universities, according to Quacquarelli Symonds (QS), is obtained from the QS World Universities Ranking website and presented. As shown, the top universities and institutes focusing on advancing blockchain technology in healthcare follow a wide range of QS World University Rankings, demonstrating the varied levels of impact and expertise. In this regard, Universiti Putra Malaysia and Khalifa University of Science and Technology show a stronger global presence than the other institutions in Table 5, with QS World University Rankings of 158 and 230, respectively.

Most Productive Countries

Table 6 compares the academic contributions of different countries based on research output and impact metrics.

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Table 6. Countries with the most publications on blockchain challenges in healthcare.

Rank	Name	TP	TC	TP/total studies (%)	TC/total citations (%)	>5	>20	>50	>100
1	India	87	1,387	39.19	19.63	24	3	2	3
2	United States	28	1,839	12.61	26.03	7	3	8	5
3	Pakistan	18	651	8.11	9.22	7	3	1	2
4	United Kingdom	16	454	7.21	6.43	2	4	2	1
5	Malaysia	15	421	6.76	5.96	3	2	1	2
6	Saudi Arabia	11	520	4.95	7.36	5	1	0	2
7	South Korea	10	178	4.50	2.52	4	2	1	0
8	Australia	9	382	4.05	5.41	4	1	2	1
9	China	9	931	4.05	13.18	2	4	1	2
10	United Arab Emirates	9	301	4.05	4.26	1	2	2	1

The data were retrieved in February 2024 based on Scopus; TC: total citations; TC/total citations (%): the percentage of total citations each author has received relative to the total citations; TP: total publications; TP/total studies (%): the percentage of total publications by each author relative to the total publications; the numerical values >5, >20, >50, >100 denote the number of citations each study has received.

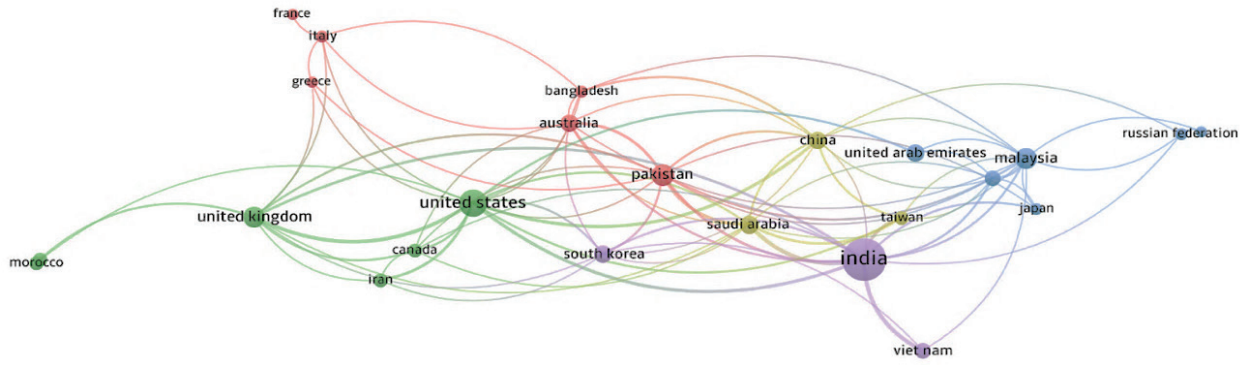

Fig. 5. Collaboration among researchers from different countries. See Figure 1 for greater context.

There are several metrics for comparing the listed countries, including the total number of papers, the total number of citations, their publication contribution ratio relative to total studies, and their citation contribution ratio relative to total citations. Furthermore, it shows how highly cited research is distributed within each country according to the number of publications with citation counts exceeding the specified thresholds (>5, >20, >50, and >100).

According to the data, India is the leading contributor in both the number of publications and citations, indicating significant research impact and output. Despite fewer total publication numbers, the United States received the most citations on its publications compared to India, suggesting a higher degree of impact. Following the United States and India, China and Pakistan hold the third and fourth positions, respectively, in terms of the number of citations for publications in the specified field.

As presented in Table 6, the most influential studies received more than 50 and 100 citations and were conducted by researchers from the United States and India. In particular, the United States stands out by contributing 13 articles that received more than 50 or 100 citations, with 8 of the 13 articles receiving more than 50 citations and five articles receiving more than 100 citations. Comparatively, five studies published by Indian researchers received more than 50 and 100 citations, including two with more than 50 citations and three with more than 100. Clearly, the United States leads the way when it comes to influential studies, followed by India.

On the other hand, Figure 5 shows the collaborations made between researchers from different countries for the studies in the addressed field. Regarding the information given in Table 6, the majority of publications in the focused area are from India and the United States, followed by Pakistan and the United Kingdom. Accordingly, the more studies published by each country, the larger the nodes representing them. Moreover, the edges indicate collaborative research efforts between countries, and the thicker the edges, the more intense the collaboration. Furthermore, the countries within the same clusters are differentiated by varying colors, indicating a higher frequency of regional or thematic collaborations among them.

Table 7. Studies with the most received citations.

Rank	Title	Authors	Publisher	Year	Document type*	TC (N)	TC/total citations (%)
1	Blockchain in healthcare applications: Research challenges and opportunities	McGhin, T, et al.	Academic Press	2019	Review	517	17.99
2	A survey of blockchain from the perspectives of applications, challenges, and opportunities	Monrat, AA, et al.	Institute of Electrical and Electronics Engineers Inc.	2019	Review	516	17.98
3	Blockchain for 5G-enabled IoT for industrial automation: A systematic review, solutions, and challenges	Mistry I, et al.	Academic Press	2020	Article	416	14.50
4	Applications of blockchain technology in medicine and healthcare: Challenges and future perspectives	Siyal AA, et al.	MDPI AG	2019	Article	279	9.73
5	Blockchain solutions for big data challenges: A literature review	Karafiloski E. & Mishev A.	Institute of Electrical and Electronics Engineers Inc.	2017	Conference paper	247	8.61
6	Applications of Blockchain in Ensuring the Security and Privacy of Electronic Health Record Systems: A survey	Shi S, et al.	Elsevier Ltd.	2020	Review	233	8.12
7	A survey on the adoption of blockchain in IoT: Challenges and solutions	Uddin, MA. et al.	Zhejiang University	2021	Review	171	5.95
8	'Fit-for-purpose?'—Challenges and opportunities for applications of blockchain technology in the future of healthcare	Mackey TK, et al.	BioMed Central Ltd.	2019	Article	170	5.93
9	Geospatial blockchain: Promises, challenges, and scenarios in health and healthcare	Kamel Boulos MN, et al.	BioMed Central Ltd.	2018	Editorial	167	5.82
10	Application of Blockchain and Internet of Things in Healthcare and Medical Sector: Applications, Challenges, and Future Perspectives	Ratta P. et al.	Hindawi Limited	2021	Review	159	5.54

The data were retrieved in February 2024 based on Scopus; TC: Total Citation; TC/Total Citations (%): the percentage of total citations each author has received relative to the total citations.

*Document type as categorized by Scopus.

Studies With the Most Citations

Table 7 lists a selection of scholarly publications with the highest number of citations investigating the challenges of blockchain technology in healthcare. Observing this table, the most important, influential, and popular contributions to healthcare challenges with blockchain can be identified.

The total number of citations received by each paper was the criterion for ranking the publications, which were then listed in descending order. As illustrated, the article by McGhin and colleagues[19] in 2019 by Academic Press is the most cited and contributes almost 18% to the total. In addition to discussing the applications and benefits of blockchain in healthcare, this article reviews the key challenges that remain in its deployment. As a result, five main challenges were identified and reported: scalability, mining incentives, blockchain-specific attacks, and key management/key leakage. The other most cited study was conducted by Monrat and colleagues[20] and published by the Institute of Electrical and Electronics Engineers Inc. The authors conducted a comparative study to investigate the blockchain challenges that arise when implementing it in healthcare. They report five challenges, including scalability, privacy, interoperability, energy consumption, and regulatory issues. Notably, both of the most cited articles are review types, as presented in Table 7. Furthermore, the table reveals that half of the top 10 most cited studies (5 out of 10) are also review articles.

Most Productive Journals

Table 8 illustrates an overview of the performance metrics for 10 top journals that are posing the greatest productivity rate in the studied field. The indicators of the total number of published papers, total citations, H-index, impact factor, and 5-year impact factor are provided to indicate the influence and visibility a journal has in the academic world. Regarding the number of publications considered in the criteria for ranking the journals in Table 8, the *Journal of Network and Computer Applications and Sensors*, both with noteworthy impact factors and h-indices, has the highest number of notable publications. Similarly, the journals *Sensors* and *Lecture Notes in Networks and Systems*

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Table 8. The most productive journals on blockchain intelligence in healthcare.

Rank	Name	TP	TC	TP/total studies (%)	TC/total citations (%)	H	IF	5Y-IF	>5	>20	>50	>100
1	*Journal of Network and Computer Applications*	6	754	14.63	62.4	129	8.7	7.3	1	1	3	1
2	*Sensors*	6	83	14.63	6.9	219	3.9	4.1	1	2	0	0
3	*Lecture Notes in Networks and Systems*	6	7	14.63	0.6	27	0.54	N/A	0	0	0	0
4	*IEEE Access*	4	65	9.76	5.4	204	4.82	4.676	1	1	1	0
5	*IEEE Internet of Things Journal*	4	139	9.76	11.5	149	11.61	12.64	2	1	1	0
6	*Advances in Intelligent Systems and Computing*	4	27	9.76	2.2	58	0.21	0.63	2	0	0	0
7	*Lecture Notes in Business Information Processing*	3	74	7.32	6.1	56	1.05	0.87	1	0	1	0
8	*Intelligent Systems Reference Library*	3	25	7.32	2.1	35	0.85	0.66	3	0	0	0
9	*EAI Springer Innovations in Communication and Computing*	3	3	7.32	0.2	19	0.78	0.89	0	0	0	0
10	*IEEE Journal of Biomedical and Health Informatics*	2	35	4.88	2.9	146	8.33	7.38	1	1	0	0

The data were retrieved in February 2024 based on Scopus: H: h-index; IF: impact factor; TC: total citations; TC/total citations (%): the percentage of total citations each author has received relative to the total citations; TP: total publications; TP/total studies (%): the percentage of total publications by each author relative to the total publications. The numerical values >5, >20, >50, >100 denote the number of citations each study has received.

have published the same number of articles as the *Journal of Network and Computer Applications*. However, they differ significantly in terms of citations and impact factors, indicating that publications in the *Journal of Network and Computer Applications* have a greater influence compared to the other two journals in the specified field. Following the *Journal of Network and Computer Applications* in this field, the *EEE Internet of Things* (IoTs) received the most citations for its total publications in this field, as shown in Table 8. To assess the journals that publish the highest quality research, we provide the h-indices for each journal. Among the journals recognized for their high research quality are *Sensors*, *IEEE Access*, and the *IEEE IoTs Journal*, with h-indices of 219, 204, and 149, each demonstrating exceptional scholarly impact.

Moreover, the impact factor and 5-year impact factor are annual metrics measured by Thomson Reuters Journal Citation Reports. Specifically, the impact factor is calculated regarding the total number of citations received in a specified year for the last 2-year published articles, divided by the total number of those articles. The calculation method for the 5-year Impact Factor is similar. Still, it accounts for citations received over the past 5 years and is divided by the number of articles published during that time. These indicators provide researchers with insights into the influence and citation impact of each journal within its field. With an impact factor and 5-Year Journal impact factor of 11.61 and 12.64, respectively, the *Journal of IEEE Internet of Things* stands out among the other journals.

Keyword Occurrence and Co-Occurrence Analyses

Using the VOSviewer version 1.6.19 software, this section illustrates the results of the keyword occurrence and co-occurrence analysis. To achieve this, it was decided to consider index and author keywords separately for this analysis. These two types of keywords differ in their sources of origin: author keywords are provided by the author(s), whereas index keywords are generated by indexing services such as Scopus.[21] The co-occurrence analysis revealed a smaller number of author keywords, with 473 compared to 990 index keywords determined by Scopus.

Table 9 presents two lists of the top 20 keywords, provided separately for each keyword type, showcasing the most frequently selected terms in the collected publications. As shown at the top of the author keyword list, "security" and "privacy" are the top priorities, with 43 and 27 mentions, respectively, after blockchain and healthcare, which are the primary terms in this area. In addition, these keywords with substantial link strengths highlight their importance and priorities. However, the order of the most frequently repeated keywords in the index list differs due to the varying terms employed by Scopus for broader concepts. Specifically, the concept of "security" is reflected through different terms such as "Network security" and "Security challenges," which collectively appear 52 times.

Consequently, "security" could also be ranked at the top, followed by the main terms. In addition, the combined total of occurrences for "data privacy" and "privacy" that convey the same concept reaches 29,

Table 9. Top 20 authors and index keywords from the studied publications.

Rank	Author keyword	Occurrences	Total link strength	Rank	Index keyword	Occurrences	Total link strength
1	Blockchain	138	342	1	Blockchain	136	1,006
2	Healthcare	87	342	2	Healthcare	95	738
3	Security	43	146	3	Internet of things	46	382
4	Privacy	27	93	4	Distributed ledger	22	218
5	Internet of things	20	65	5	Digital storage	22	194
6	IoT	16	52	6	Healthcare industry	22	163
7	Smart contract	11	38	7	Security	21	206
8	Cloud computing	9	35	8	Healthcare systems	21	204
9	Machine learning	8	32	9	Network security	19	196
10	Supply chain	8	32	10	Smart contracts	12	85
11	Bitcoin	8	29	11	Electronic health record	16	158
12	Artificial intelligence	8	28	12	Data privacy	15	159
13	Crypto-currency	8	28	13	Healthcare sectors	15	125
14	Interoperability	8	19	14	Privacy	14	160
15	Ethereum	7	23	15	Information management	14	128
16	Consensus	7	20	16	Human	13	126
17	Distributed ledger	7	19	17	Interoperability	12	103
18	Big data	6	26	18	Healthcare application	12	94
19	Crypto-graphy	6	22	19	Security challenges	12	89
20	Fog computing	6	21	20	Access control	11	123

The data were retrieved in February 2024 based on Scopus; Rank is based on the total number of occurrences.

ranking after "security." To visualize keyword occurrences in networks, a threshold of four occurrences of the keywords was determined for both types of keywords. See Figures 6 and 7. As shown in the presented networks, a node represents each keyword, and the size of the node is correlated with the number of times the keyword is repeated across the studied publications. Moreover, clusters of keywords that frequently occur together are displayed in different colors. This resulted in the development of five clusters for index keywords and seven clusters for author keywords, with each cluster comprising a set of related keywords that represent specific research themes.

Dominant Topics Using LDA

In this section, the results of topic modeling of blockchain challenges in healthcare are reported. The dominant topics in this study are organized into six clusters, showing the best coherence scores and the optimal number of topics. The topics that were extracted from the representative keywords using the LDA algorithm were then labeled and shown in Table 10.

Cluster 1: Data Privacy and Security

This cluster, showing the most significant contribution among all six clusters, primarily discusses the concerns of privacy and security as major challenges that arise when implementing blockchain technology in healthcare systems. While blockchain technology provides data transparency and improves data management due to its decentralized nature, it faces limitations related to certain attacks or security issues. This topic suggests addressing these crucial issues for the successful adoption of blockchain in healthcare.[22]

Cluster 2: Integration With IoT and Smart Devices

The predominant theme in this cluster revolves around integrating blockchain technology with the IoT and smart devices within healthcare systems. By leveraging the connectivity of various smart devices, which enables secure and real-time data sharing, several key challenges arise from this integration. This cluster highlights secure data transfer between IoT devices and blockchain networks as a major challenge. It also addresses the issue of resource constraints in many IoT devices, which leads to the need for standardized protocols to ensure seamless data exchange (see reference[23]).

Cluster 3: Interoperability

These cluster studies reveal that interoperability and data standards are considered obstacles to blockchain adoption in healthcare (see reference[23]). Organizations with varying priorities and regulations complicate the management of decentralized identity, permissions, and smart contracts. Interoperability challenges in healthcare require coordinated efforts among stakeholders to develop systems based on open standards and a unified digital framework.

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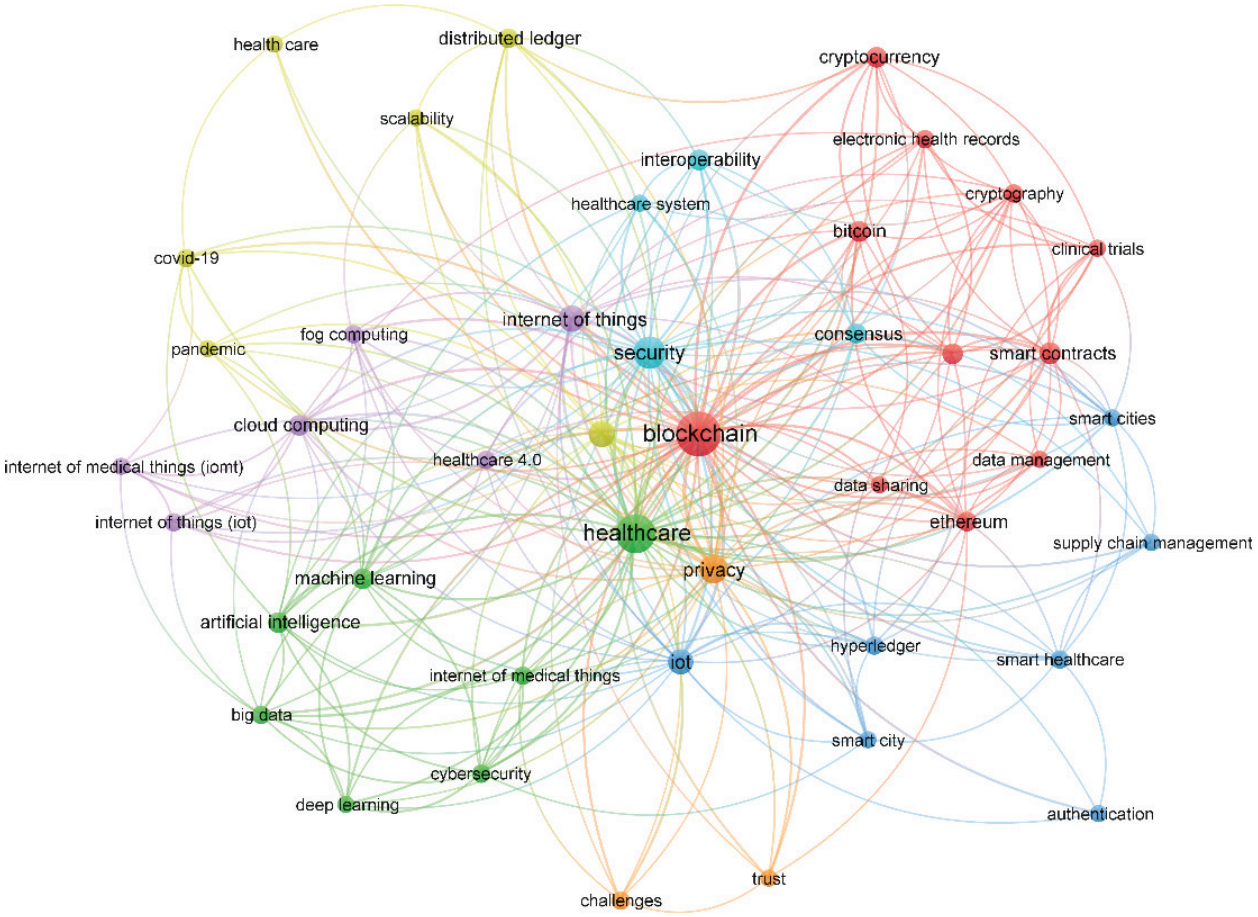

Fig. 6. Co-occurrence network of author keywords with a threshold of 4, displaying 44 out of 473 keywords that met the threshold. See Figure 1 for greater context.

Cluster 4: Scalability

This cluster is mainly dedicated to scalability challenges. As the health sector generates a growing volume of data, transactions, and participants, blockchain networks face various scalability challenges. These challenges include block size limitations and an increasing number of network nodes.[5,24] Although blockchain architectures have been redesigned and storage optimized, scalability issues persist, preventing widespread adoption. Integration of healthcare with emerging technologies like IoT and cloud computing can accelerate data generation, leading to intensifying the scalability challenges faced by blockchain.

Cluster 5: Governance

The healthcare industry can benefit from blockchain solutions by creating collaboration with patients, providers, payers, device manufacturers, and health systems. Blockchain adoption requires new governance and coordination between stakeholders in the healthcare sector. Therefore, governance challenges have emerged that are being addressed by the studies in this cluster (see reference[25]). The challenges that come along with governance include managing large networks of entities, setting policies regarding the sharing of data, resolving disputes, and aligning incentives.

Cluster 6: Cost

The cluster also delves into another challenge coming from using blockchain technology in healthcare, which is the initial investment for implementing the technology. Although it is believed that blockchain technology will result in reducing costs in the long term through improving efficiency, supply chain operations, and administrative overhead, "high cost involved" is repeatedly cited across the documents as an impediment to the project's success (see reference[26]).

Discussion and Conclusion

This study has conducted a bibliometric analysis and topic modeling of academic publications, addressing blockchain challenges in the healthcare industry. First, the general structure of the research's publication and citation was provided to indicate how the research has evolved since 2017. Findings demonstrate growing attention to this research area, with a notable increasing number of publications in 2021–2023.

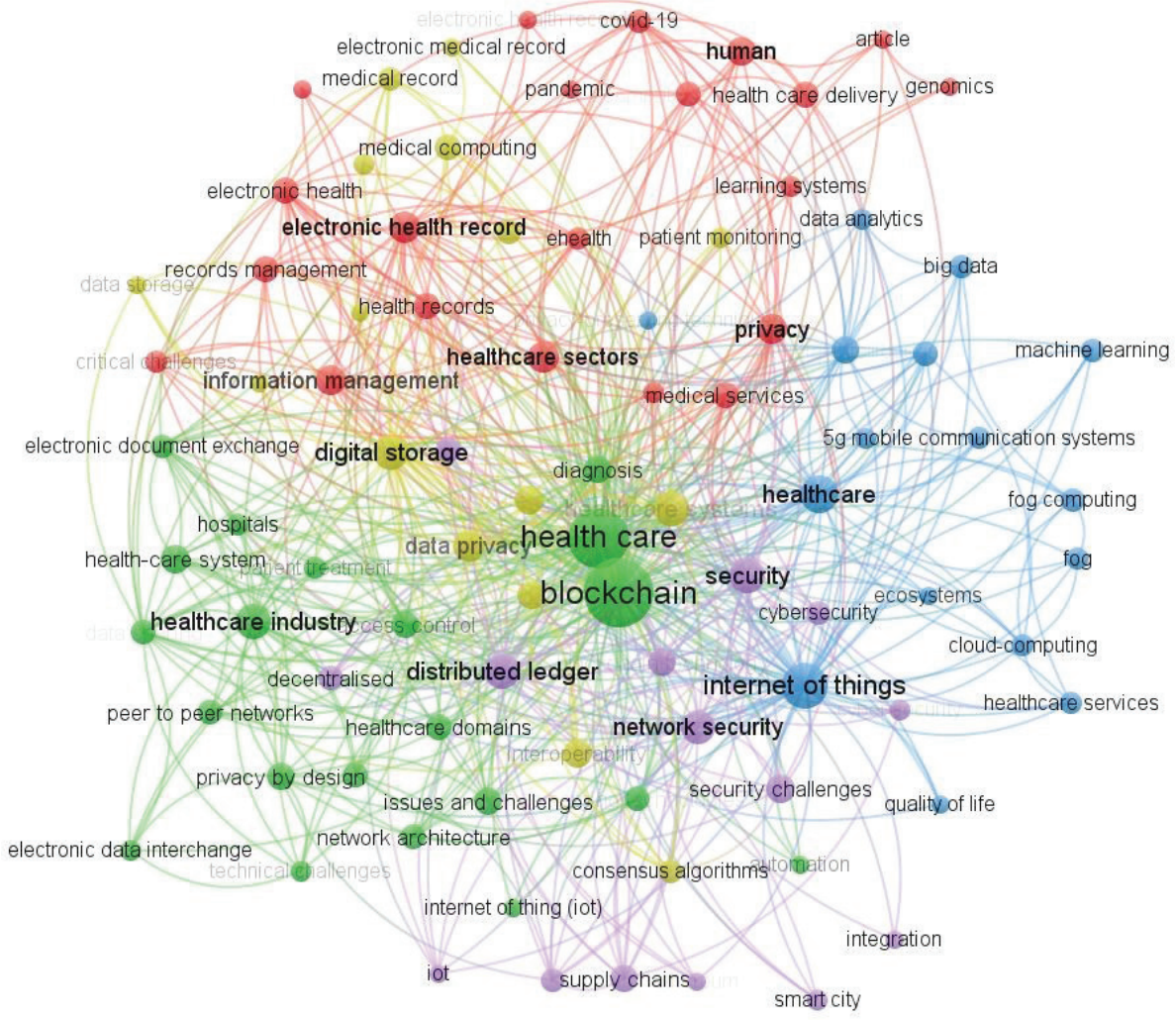

Fig. 7. Co-occurrence network of index keywords with a threshold of 4, displaying 89 out of 990 keywords that met the threshold. See Figure 1 for greater context.

Table 10. The dominant topics on blockchain challenges in healthcare.

Topic no.	Topic name	Keywords*	Topic size (%)
1	Data privacy and security	healthcare, blockchain, security, technology, data, system, health, challenge, solution, patient, manage, privacy, service, use, application	38.78
2	Integration with IoT and smart devices	healthcare, blockchain, system, data, IoT, technology, smart, challenge, network, issue, service, device, medical, information, integration	28.06
3	Interoperability	blockchain, technology, healthcare, application, industry, challenge, system, health, potential, record, data, domain, process, develop, digit	14.80
4	Scalability	blockchain, healthcare, big data, technology, challenge, application, industry, IoT, platform, service, develop, evaluation, data, model, patient	7.65
5	Governance	blockchain, data, healthcare, security, challenge, manage, patient, governance, safety, technology, decentralized, convergence, process, adopt, design	5.61
6	Cost	blockchain, healthcare, technology, data, cost, challenge, security, efficiency, manage, issue, medical, system, server, feature, smart contract	5.10

*The words in each list are ordered based on their weights. Higher weighting indicates greater importance or relevance to the topic. The topics were selected based on these weighted terms determining their significance within each topic.

IoT: Internet of things.

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Table 11. Top authors, universities, countries, and journals focusing on blockchain challenges in healthcare.

	Total publications	Total citations
Authors	• Jayaraman, R.	• Choo, KKR.
	• Salah, K.	• Kumar, N.
	• Ellahham, S.	• Tanwar, S.
Universities	• University of Petroleum and Energy Studies	• The University of Texas at San Antonio
	• Khalifa University of Science and Technology	• Thapar Institute of Engineering & Technology
Countries	• India	• United States
	• United States	• India
	• Pakistan	• China
Journals	• *Journal of Network and Computer Applications*	• *Journal of Network and Computer Applications*
	• *Sensors*	• *IEEE Internet of Things Journal*
	• *Lecture Notes in Networks and Systems*	• *Sensors*

The data were retrieved in February 2024 based on Scopus.

The publications followed a sinusoidal pattern with a peak, experiencing accelerating citation rates and subsequent decline. Afterward, the most productive authors, universities, countries, and journals were identified based on bibliometric indicators and presented. In addition, the studies receiving the most citations for their influential contributions were reported. Table 11 provides a summary of the bibliometric analysis based on Total Publications and Total Citations.

Also, McGhin and colleagues[19] and Monrat and colleagues[20] are recognized as highly cited studies, reflecting their significance in this field. Moreover, both author and index keywords were utilized for keyword occurrence and co-occurrence analyses, revealing that security, data privacy, and interoperability are among the hottest themes in the research.

Topic modeling exposes six predominant challenge themes persistent in the literature: data privacy/security, integration with IoT and smart devices, interoperability, scalability, governance, and costs. The findings align closely with previous studies, such as Singh and colleagues,[7] which reported scalability, privacy, governance, standards, ownership, and costs as the main challenges. While the previous review studies, such as by Ratta and colleagues,[11] examined the challenges that arise when integrating blockchain networks with IOT devices, this study highlights it as a more prominent challenge area, reflecting the growing convergence of blockchain with IoT in healthcare applications. The findings of this research will assist researchers in pinpointing the open issues that require additional investigation as the industry strives to capitalize on the promise of blockchain technology.

This study has several limitations that need to be addressed in future work. First, this study focused on the publications indexed in Scopus, missing relevant works from the other databases. Second, although LDA topic modeling gives valuable insights from the latent structure, more advanced topic modeling techniques can be employed to gain a deeper understanding of the literature.

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Conflicts of Interest

No conflicts of interest.

Contributors

Dr. Mehraeen contributed significantly to the study's development through conceptualization and supervision. Additionally, he played a key role in reviewing and editing the manuscript to enhance the quality and clarity of the final work.

Ms. Mahmoudi contributed to the design and execution of the study. She played a major role in data collection and analysis, ensuring the accuracy and relevance of the findings. She also took responsibility for writing the manuscript, interpreting the results, and structuring the paper.

Data Availability Statement (DAS), Data Sharing, Reproducibility, and Data Repositories.

The data supporting the findings of this study were obtained from the Scopus database.

Application of AI-Generated Text or Related Technology

ChatGPT was used to improve the manuscript grammatically whenever needed.

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