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Integration of Internet of Things and Blockchain Technologies in Healthcare: A Bibliometric and Network Analysis

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ABSTRACT

This paper has quantitatively analysed the research trends on the integration of the Internet of Things (IoT) and Blockchain Technology (BCT) through bibliometric and network analysis and has also expressed how this integration can be leveraged in healthcare. The research methodology consists of a comprehensive search for scholarly publications on IoT and BCT in healthcare, published during 1999-2021 in Scopus and Web of Science (WoS), leading to 325 articles, followed by bibliometric analysis using Biblioshiny and network analysis using VOSviewer. The bibliometric analysis reveals that there is a surge in research papers since 2020, largely attributed to the outbreak of COVID-19. The research in this area is dominated by India and China, followed by the USA, South Korea, and Australia. The research on the integration of IoT and BCT in healthcare is still evolving. This study adds new avenues of knowledge to the existing literature and gives guidance to future researchers exploring the usage of IoT and BCT to revamp healthcare. This is the first such paper that has done a comprehensive analysis of existing literature in this field by considering papers published in both databases: Scopus and WoS, which could act as a starting point for new researchers.

Keywords: Internet of Things; IoT, Blockchain; Bibliometric Analysis; Healthcare

1. INTRODUCTION

Healthcare across the globe is characterised by age-old practices of patients having to visit a hospital physically for any diagnosis, stay in the hospital throughout the treatment period, followed by multiple follow-up visits, and post-discharge. This adds to the treatment cost as well as strains the already overburdened healthcare facility.[1] Furthermore, health infrastructure across the globe was found to be wanting during the COVID-19 pandemic as the number of patients across all geographies out-numbered the number of healthcare staff; the number of hospital beds was no match to the unprecedented demand; the cost of treatment had blown out of proportion. In this context, health informatics specialists and professionals are keen to comprehend the selection and utilisation of the latest technologies in the healthcare domain. In this area Internet of Things (IoT) can play a crucial part as the capabilities of IoT can be leveraged in both clinical and non-clinical scenarios.

On the clinical front, IoT-enabled wearable gadgets such as smart bands, wireless blood pressure monitoring devices, glucose level measuring instruments, etc, facilitates real-time health monitoring by accessing patient's critical health-related vitals such as temperature, blood pressure, ECG, blood oxygen saturation, etc, generates alerts in case of any abnormalities that can enable doctors to determine the best treatment measures and take prompt action in an emergency remotely. This, in turn would reduce hospital admissions and stay, reducing healthcare costs. Thus, IoT's application in clinical scenarios has empowered medical personnel not only to be more vigilant but also to interact with patients in real-time, thereby, augmenting the performance of Healthcare Services.

On the non-clinical aspect, IoT can be used in asset tracking, ensuring that hospital staffs are adhering to quality standards, and connecting ambulances and other facilities to hospital information systems. These all steps would increase the operational efficiency of the healthcare manifold.

Realising the tremendous potential of IoT in improving the performance of healthcare services, the literature review was done by searching journals with keywords such as "Internet of Things", "IoT", "Healthcare", "Healthcare Services", "Smart Devices" and "wearables", in journal data repositories such as Scopus, Web of Science.

Upon reading articles from the above sources, it was found that healthcare services dealing with patients' sensitive data being captured remotely, have led to data security and privacy concerns and this has been found as

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the primary bottleneck inhibiting IoT adoption. The solution to this inhibitor was found to be Blockchain Technology (BCT) which can provide tamper-free data transactions in the network.[2] The application of BCT in IoT networks provides primarily three major benefits: (i) building trust amongst the stakeholders by ensuring a tamper-free and secure network, (ii) reducing the cost that is incurred owing to intermediaries by removing middleman and (iii) BCT induction, the transaction rate of IoT networks increases manifold as the settlement time is greatly reduced.[3]

It is observed that there are a handful of research papers that have undertaken bibliometric analysis on the integration of IoT and BCT in healthcare such as the article "The rise of blockchain: a bibliometric analysis of blockchain study" and "Blockchain and Internet of Things: A bibliometric study"; however, the afore-mentioned research papers have considered either Scopus or WoS databases to analyse the existing literature and not both. Furthermore, these papers did not focus entirely on the Integration of IoT and BCT in healthcare.

The current study is the first such paper that has tried to comprehensively capture the amount of literature existing on the integration of IoT and BCT in healthcare by examining research papers existing in both the databases: Scopus and WoS and has tried to answer the following research questions with the help of bibliometric and network analysis:

RQ1. What is the primary trend in the research undertaken on the integration of IoT and BCT in healthcare in terms of the number of research publications and author citations?

RQ2. Who are the prominent contributors to the research field in terms of top journals and countries?

RQ3. Which are the most frequently used author keywords in the research domain, their relationships that can give guidance to future researchers?

RQ4. Which countries are top contributors to the research domain and what relationship strength between them?

RQ5. What are the research gaps existing in the literature on IoT and BCT in healthcare which can be potential sources of analysis for future research?

The current reach paper has undertaken a bibliometric analysis of 325 research papers published during 1999-2021 on the integration of IoT and BCT in healthcare, from Scopus and WoS databases, using bibliometric analysis tools such as Biblioshiny and VOSviewer. This paper would help researchers to understand the potential of IoT and BCT in healthcare, and guide them to explore varied use cases through which these innovative solutions can benefit healthcare by connecting with the institutions, and authors who have authored good publications in this research domain.

This research paper has considered papers published in English Language only in databases such as Scopus and WoS databases during 1999-2021. These limitations can be potential avenues for future researches.

2. LITERATURE REVIEW

2.1 Internet of Things

The Internet of Things can be exemplified as a concept where animate and inanimate entities start communicating via the internet, with minimal human intervention but with maximum benefit to humanity. IoT consists of smart gadgets which can grasp palpable parameters and comprehend the same, communicate with other physical entities, and establish logical connections with other inanimate entities based on pre-agreed rules and procedures.[4]

The major benefits a firm is likely to gain from IoT adoption are: more transparency of data and material flow, better traceability of goods flow, better control of inventories and improved integration of business processes contributing to better operational efficiency[5]. This increased visibility consisting of tactical visibility and strategic visibility would augment the operational performance of a firm, manifolds. Tactical visibility refers to information on inventory movements, finance, and other resources, which aids in comprehending the business processes; whereas strategic visibility is related to decisions that are being taken for the entire firm based on insights gained from people's experiences and judgment enabling better decision-making.[6]

2.2 Blockchain Technology

Blockchain is a chain of distributed and decentralised data blocks in which transactions occur on a shared premise without any third-party intervention, such that all transactions are recorded in every block and validated by every block. This in turn ensures unprecedented levels of data transparency and security. Technically this is made possible through a cryptology process called hashing, where each block has a unique hash, and new blocks are added after receiving concurrence from all blocks through a process called consensus[7].

2.3 IoT and Blockchain Technology Integration

Cyber security is one of the greatest impediments on the road to IoT adoption, which comprises user's fear of security risk, both real and perceived. This is contributed by loopholes in the IoT network caused by multiple endpoints, inconsistent protocols, and diversity in standards.[8] Moreover, IoT devices have limited computing, storage, and network capability which they are vulnerable to cyber-attacks. Blockchain is foreseen by industry experts as a disruptive technology that has the potential to play a significant role in securing IoT devices.[9] Research conducted by Kshetri[10] to find out if BCT can strengthen IoT, revealed that the major bottleneck of IoT networks has been the dependence on a centralised cloud. However, with BCT, IoT can leverage the decentralised cloud-based approach thereby overcoming the shortcomings of a centralised cloud where a single point of failure paralyses the entire network. This is made possible through the usage of cryptography which

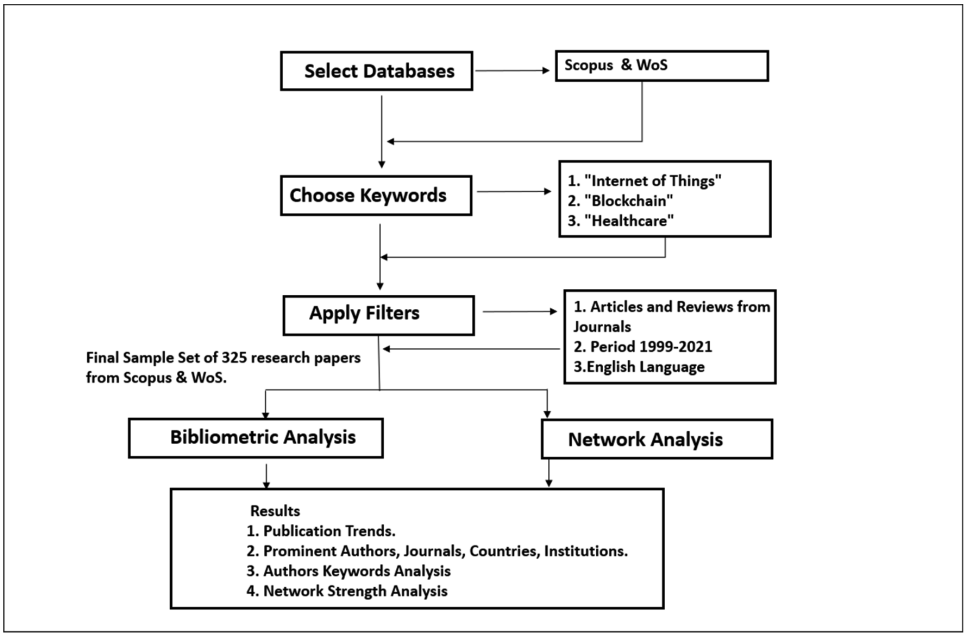

Figure 1. Research methodology.

ensures regulated transactions in blockchain networks and smart contracts which are scripts in a blockchain network ensuring automated transactions based upon the pre-defined rules. For example, the energy sector has leveraged smart contracts in an integrated IoT and BCT network where machines can buy and sell energy in a peer-to-peer network based on preset rules.[11]

The confidentiality of transactions involving smart contracts is ensured using the zero-knowledge-proof (ZKP) method, where the validation of transactions is being made without revealing the identity of the transacting parties and the exact information that is being transacted. In healthcare, IoT-based networks are confronted with problems such as product counterfeits, shortages, and diversion. This can be mitigated by the application of BCT, where all the data is recorded in an uneditable ledger and prevents wrongdoers from manipulating data. This secured BCT network can also be leveraged in pharmaceutical procurement processes, where a private network would give access only to legitimate users and prevent data leaks to hoarders, who might use patients' buying behaviour for commercial gains. Furthermore, BCT can also be used to authenticate medical equipment, vital organ donor information, and blood donors, which if compromised can create havoc in the healthcare outcomes.[12]

Research on IoT and BCT in Healthcare has witnessed a few literature reviews that have been summarised in Table 1.

3. RESEARCH METHODOLOGY

In this paper, a systematic 5 Steps methodology is being employed to scan the existing literature as outlined by Rowley and Slack.[17] Figure 1 depicts the methodology employed for the current bibliometric analysis, which is based on the Prisma Model, successfully used by other researchers as well for systematic literature review.[18]

Step 1: Selecting the relevant database

As the current research is on the integration of new technological solutions such as IoT and BCT, we have considered research papers from Scopus and WoS as these databases have captured all the relevant literature on the research domain. Scopus database managed by Elsevier Publishing is the greatest dynamic and reference store for peer-investigated writing consisting of books, journals, and conference papers. Scopus exhaustively covers all research areas such as medicine, technology, social science, engineering, and management. The WoS comprises impactful publications, having literature in diversified fields such as physical sciences, technology,

Table 1. Literature reviews on IoT and BCT in healthcare during 1999 – 2021

S. No.	Article	First author	Type of review
1	Blockchain for the Internet of Things: A systematic literature review	Conoscenti7	Systematic literature review
2	An exhaustive survey on security and privacy issues in Healthcare 4.0	Hathaliya13	Systematic literature review
3	The rise of "blockchain": a bibliometric analysis of blockchain study	Firdaus14	Bibliometric Analysis
4	Blockchain and Internet of Things: A bibliometric study	Kamran15	Bibliometric Analysis
5	Application of blockchain for internet of things: a bibliometric analysis	Duan16	Bibliometric Analysis

social sciences, and humanities, and provides indexing to around 1900 journals, covering research areas such as telecommunications, computer science, engineering, etc.[19]

Step 2: Identifying the appropriate keywords

For examining the relevant literature on the integration of IoT and BCT in healthcare, the following keywords were used in the query string: "Internet of Things" OR "IoT" AND "Blockchain" AND "Healthcare" OR "medical management" OR "medicare" OR " medical care" OR "primary-care" OR "public-health" OR "health wellness program" OR " health management " OR " family-planning.

The aforementioned query string exhaustively covered all relevant keywords which are relevant for our study.

Step 3: Preliminary results

All research papers published during the period 1999-2021, have been considered in this analysis as the word IoT was coined in 1999 and the research in the current year 2022 is still evolving, hence it has been excluded. The preliminary research using the query string as detailed in Step 2, yielded 612 papers from Scopus and 375 research papers from WoS.

Step 4: Applying filter for refining the initial result

To ensure that only relevant research papers are being considered for our analysis, the result of Step 3 is further refined by applying the following filters:
Only articles and review papers.
Only research papers are published in journals.
Only articles that are published in English.

Applying the above filters to results obtained in Step 3, yielded 266 publications from Scopus and 277 research papers from WoS. A total of 218 research papers from WoS were discarded to remove duplicates as they existed in the Scopus database as well. Thus, a final consolidated set of 325 research papers (266 research papers from Scopus and 59 research papers from WoS) formed the final dataset for carrying out the bibliometric study.

Step 5: Selecting the relevant tools for performing bibliometric and network analysis

The choice of tools is imperative as this governs the ease and accuracy of the analysis, so to comprehensively analyse research literature from the two databases, where the file formats are different, the open-source software Bibliometrix and R-tool is used [20]. It has two components: R Studio which generates a consolidated file with a unique data set and Biblioshiny app which analyses the data set and gives research insights. For network visualisation analysis, another open-source software VOSviewer is being used, for generating connections and relationships between authors and countries.[21]

Table 2. Initial data statistics during 1999–2021

Parameters	Consolidated data figures from Scopus & WoS
Research papers	325
Research sources	154
Author's keywords	887
Period of analysis	1999-2021
Average citation per article	18.17
Authors	1162
Authors of single-authored research papers	10
Authors of multi-authored research papers	1152ww
Average articles /author	0.28
Average authors /article	3.58

4. DATA ANALYSIS

4.1 Initial Data Analysis

A preliminary analysis of 325 research papers that have been identified from Scopus and WoS for the research domain was analysed using Biblioshiny. The initial statistical data is outlined in Table 2.

The 325 research papers from Scopus and WoS databases were housed in a total of 154 different journals for the timeline 1999-2021. A total of 1162 authors were involved in writing 325 articles; however only 10 authors have written the research papers single-handedly, whilst others collaborated for writing the research papers. As a result of this, there was an average of 3.58 authors per research paper. The average citation of 18.17 per research paper depicts that research in this field is still in its nascent stage.

4.2 Yearly Scientific Publication Trend

Figure 2 exhibits the yearly publication trend of research papers on the integration of IoT and BCT in healthcare. From 2017 onwards, the research publications in this domain have seen an upward trend with a steep rise in the number of papers in 2020 and 2021 which can largely be attributed to COVID-19, where researchers across the globe started to explore new technologies which could improve the healthcare infrastructure uniformly across all geographies. A similar trend was observed by Kamran, *et al*.[15] where publications on IoT and BCT showed an upward trend during 2017-2019.

4.3 Citation Analysis

Citation analysis helps one to comprehend the connectivity between different research articles in a particular research domain and gives an estimate of the popularity of a research article. From Figure 3, we

can infer that the number of citations for the research papers in our research domain has been increasing rapidly since 2017 when there were 0 citations; 2021 has witnessed the maximum number of citations. This shows the increasing interest of researchers and academicians in the research field which is similar to the findings by previous researchers in this domain.[15-16]

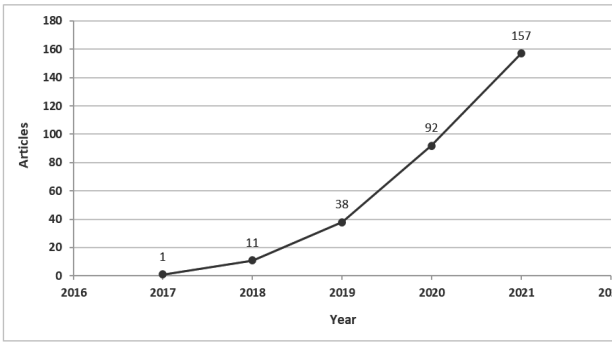

Figure 2. Annual scientific production for 1999-2021.

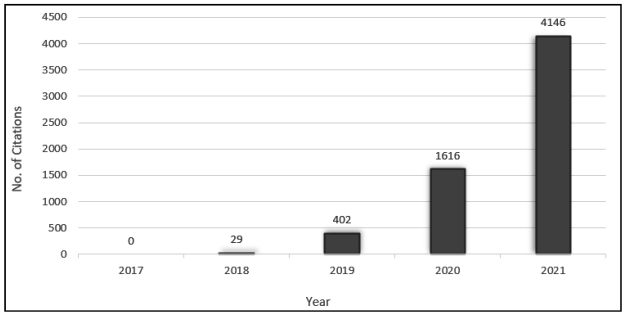

Figure 3. Citation overview for 1999-2021

Table 3. Top publishing journals during 1999-2021

Journal description	Number of articles	Percentage
IEEE Access	37	11.38
Sensors	22	6.77
IEEE Internet Of Things Journal	21	6.46
Electronics	12	3.69
Computer Communications	7	2.15
Journal Of Network And Computer Applications	7	2.15
Transactions On Emerging Telecommunications Technologies	6	1.85
CMC-Computers Materials & Continua	5	1.54
IEEE Communications Surveys And Tutorials	5	1.54
International Journal Of Advanced Computer Science And Applications	5	1.54

4.4 Prominent Journals and Their Performance

The sample set of 325 research papers from Scopus and WoS databases was distributed across 154 journals. Table 3 shows the top 10 journals which have contributed to the research on the integration of IoT and BCT in healthcare, along with a percentage contribution of the total data set. It could be observed that the first 10 journals alone have published around 40 % of the research papers in our research domain. Amongst 154 journals, IEEE Access tops the list having published a maximum of 37 articles, followed by Sensors and IEEE Internet of Things Journal. The bibliometric analysis done on IoT and BCT by Duan and Guo[16] during 2016-2020 showed similar behavior with IEEE Access topping the list, but a slight deviation was observed here as IEEE Internet of Things Journal held the second position, followed by Sensors.

4.5 Country

Table 4 outlines the top 10 countries that are prime contributors of research papers on the integration of IoT and BCT in healthcare, with India topping the list with 176 articles, followed by China having 118 research papers, USA and South Korea. However, the findings by Kamran, *et al*.[15]on research trends in IoT and BCT during 2016 -2018 and Duan and Guo[16] during 2016-2020, found China to be the top contributor followed by the USA and South Korea. This reveals that researchers from India prioritised this research domain during 2020-2021 and currently stand as the prime contributor in the research domain.

Table 4. Top 10 countries in terms of number of publications during 1999-2021

S. No.	Country	Number of articles
1	India	176
2	China	118
3	USA	74
4	South Korea	63
5	Australia	61
6	Saudi Arabia	58
7	UK	44
8	Pakistan	35
9	Canada	24

4.6 Author Keyword Statistics

Table 5 exhibits the top 10 most intermittently used author keywords that have been found in 325 research articles on the integration of IoT and BCT in healthcare; author keywords had been selected as it gives a more realistic picture of the actual theme of the research paper. It can be inferred that words such as “blockchain”, “internet of things”, “iot”, “security” and “healthcare “are the most frequent author keywords that have been

Table 5. Top 10 most frequent author keywords used in research papers during 1999-2021

Word	Frequency
Blockchain	223
Internet of things	103
Security	72
Healthcare	62
IoT	56
Privacy	41
Internet of things (IoT)	33
Medical services	32
Edge computing	22
Smart contract	22

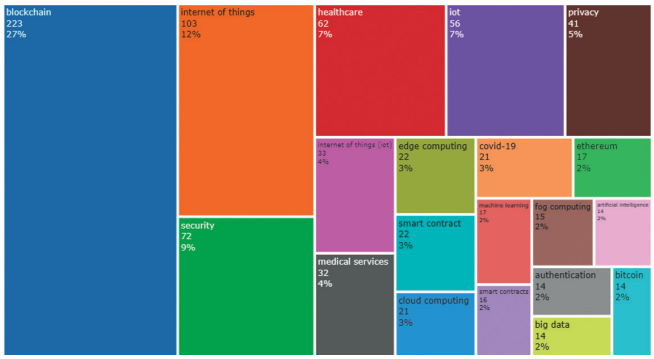

Figure 4. Treemap - top 20 author's keywords for 1999-2021.

scripted in 325 research papers on the research domain which is similar to the findings by other researchers.[15-16]

To analyse author keywords a step further, a word tree map is depicted in Figure 4, which exhibits the top 20 author keywords and their connections. The relationship of BCT and IoT with healthcare, medical services, security, and privacy is evident from the tree map. Other technologies apart from IoT and BCT, which seems to be attracting researchers' attention are edge computing, cloud computing, machine learning, and artificial intelligence, though the frequency of these keywords is low, but can be potential avenues for future research.

4.7 Network Analysis with VOSViewer

VOSviewer is a potential tool for carrying out co-authorship and citation analysis which helps in establishing relationships between research occurring in different countries, different institutions, and by varied authors. VOSviewer cannot do an integrated analysis of 325 research papers from two different databases Scopus and WoS. Owing to different file formats, we have separated the sample data set of 325 articles into two groups: 266 research papers from Scopus and 59 research papers from WoS and done the analysis individually for each data set. Since we have already carried out citation analysis for

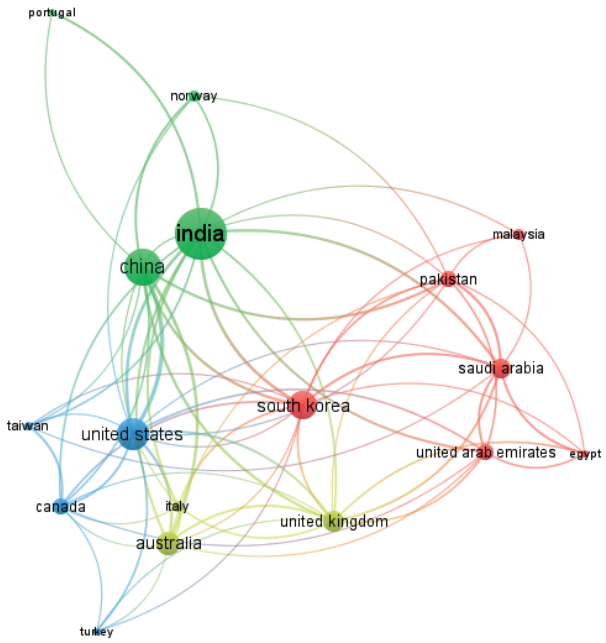

Figure 5. Network analysis on co-authorship between countries during 1999-2021 (Scopus dataset).

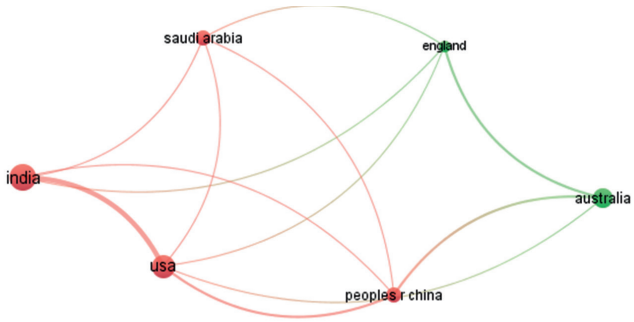

Figure 6. Network analysis on co-authorship between countries during 1999-2021 (WoS dataset).

the combined data set of 325 articles using Biblioshiny, here the analysis of the co-authorship of 325 research articles has been done using VOSviewer.

Co-authorship relations between the countries establish how authors from different parts of the globe are collaborating to publish research papers on a particular research domain. In the VOSviewer analysis, only those countries which have published at least 5 research papers on the integration of IoT and BCT in healthcare are being considered. The results of this analysis based on Scopus and WoS datasets are outlined in Figure 5 and Figure 6 respectively; a total of 20 countries have published 5 or more research papers in the research domain, with India being the frontrunner, followed by China. Authors from India are collaborating with all countries, and have strong relationships with the USA, UK, South Korea, Canada, and Australia, whereas it has no association with Ireland and Turkey; authors from China are having strong connections with all countries, except Malaysia, Saudi Arabia, Ireland, United Arab Emirates, Egypt, Turkey and Iran.

5. CONCLUSION

This bibliometric analysis done on integrated usage of IoT and BCT in healthcare on 325 relevant publications in Scops and WoS databases, has not only extended the findings by previous researchers[15-16] but has also provided new insights. The dearth of research papers in this area reveals that the study is still in its nascent stage and has the potential to evolve. Furthermore, it is found that till 2016, the literature on IoT, and BCT in healthcare had been in silos. The integrated study of IoT and BCT in healthcare has started to garner researchers' attention from 2017 onwards, which is ascertained from the publications and citations trend. The research trend further reveals the number of research papers has soared since 2020, which can be attributed to the onset of the pandemic COVID-19.[22] In this research paper, the top 10 Journals that are prime contributors to the research domain are listed, which can be targeted by future researchers for research insights and publications. Moreover, during 2016- 2020, researchers from China were the prime contributors to the research domain, but from 2021 onwards India is found to be the leading contributor, whereas there are new entrants as well such as Italy among the top 10 contributors. The author's keywords analysis has revealed that apart from IoT and BCT, researchers across the globe are also keen to find other cutting-edge technologies such as machine learning, fog computing, etc. which can revamp the healthcare sector. Also, researchers from across the geographies are collaborating which is ascertained by VOSViewer analysis on co-authorship between countries. This is fuelled by the outbreak of the global pandemic COVID-19, which has put thrust on the need to work collaboratively to counter such menace in the future.

6. SIGNIFICANCE OF THE STUDY

6.1 Managerial Significance

There is plenty of scopes to carry further research in this area as going through the suggested research papers in depth will help the practitioners to comprehend what are the different use cases in which IoT and BCT can prove to be a boon in improving healthcare services, what are the pitfalls which hinder the implementation of IoT and BCT in healthcare. This information will not only help the product developers in improving the offerings but also the product marketers to formalise a potent marketing strategy for creating the urge amongst the masses to adopt IoT and BCT in healthcare.

6.2 Societal Significance

Healthcare is the backbone of any country. It is a sector that cannot be ignored as no one is immune to illness. The global pandemic has changed people's perspective towards healthcare as previously patients' healthcare was a physical activity done as patients had to physically visit the hospitals whereas the concept of remote patient monitoring and remote ailment diagnosis seemed to be fiction, but in today's time all these concepts have proved to be a reality. In this paper, an attempt is made to explain the potential IoT and BCT have in improving healthcare, the limited amount of research that is done in this area, thereby attracting the attention of other researchers to explore untouched topics in the research domain.

7. LIMITATIONS AND SCOPE FOR FUTURE RESEARCH

This research has considered papers published in Scopus and WoS databases during 1999-2021, thus, it is imperative that future researchers extended this study in 2022 as well to see if the publications and citations in the research domain continue to exhibit an ascending curve. The research in this area is dominated by researchers from China and India, so it allows researchers from other parts of the globe as well to test the suggested application models in their geography and share useful insights, which would not only benefit others but also bridge the gap in the publications, which is currently concentrated to few countries. This research paper has investigated the amount of literature existing on the integrated study of IoT and BCT in healthcare. However, there are other sectors such as defense, retail, supply chain, and banking where one can leverage the benefits of IoT and BCT. Future research can be done in the aforementioned sectors. Apart from IoT and BCT, other technologies such as edge computing, cloud computing, machine learning, and artificial intelligence can be potential avenues for future research.

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