Deep Learning Meets Bibliometrics: A Survey of Transfer Learning Techniques for Breast Cancer Detection

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***Abstract*—This study aims to provide a comprehensive bibliometric analysis of research on transfer learning in breast cancer detection from 2016 to 2024. It highlights publication trends, influential contributors, collaborations, and keyword patterns. Bibliometric methods are employed to analyze data extracted from the Scopus database. It includes co-occurrence and citation analyses to identify prevalent keywords, highly cited documents, journals, authors, organizations, and countries contributing to this field. The analysis reveals a significant upward trend in publications over the last decade. Key insights include the identification of dominant keywords, influential contributors, and notable collaborations. The results highlight the growing impact of transfer learning techniques in breast cancer detection research, particularly within the domains of medical imaging analysis and predictive analysis. This study offers a systematic overview of the current state of transfer learning in breast cancer detection research, providing valuable insights and guiding future research efforts in this rapidly evolving domain.**

***Keywords*—Transfer learning; breast cancer; medical imaging analysis; predictive analysis**

I. Introduction

The breast cancer remains a significant global health concern. This is the most commonly diagnosed cancer among women and is a leading cause of cancer-related deaths worldwide [1]. Early detection and an accurate prognosis of breast cancer are crucial to improving patient outcomes [2]. There are significant advancements in medical imaging technologies such as mammography, magnetic resonance imaging (MRI), breast ultrasound and thermography. However, multiple challenges exists in manual interpretation of the generated images that leads to variations in diagnosis accuracy among clinicians [3]. Many researchers proposed methodologies based on artificial intelligence (AI) and deep learning (DL) to enable early stage breast cancer detection to mitigate associated mortality rates. However, these approaches encounter various challenges such as limited access to large datasets, data imbalance and overfitting issues. To tackle these obstacles, transfer learning, in conjunction with machine learning have been employed to increase the efficiency and accuracy of breast cancer classification.

The Transfer Learning (TL) has gained attention for its potential to address challenges in medical image analysis, such as limited dataset sizes and class imbalance issues [4]. This involves leveraging pre-trained models on diverse datasets to improve the performance of breast cancer detection algorithms, particularly in scenarios where large, annotated datasets are unavailable [5].

Despite the fact that TL-based techniques enhance breast cancer detection and survival prediction, there is a gap in the literature regarding bibliometric analyses specifically focusing on TL based approaches. Therefore, understanding the current research landscape and identifying future research trajectories in this domain is essential for advancing breast cancer diagnosis and prognosis. In this context, the proposed bibliometric study aims to address this gap by conducting a comprehensive analysis of research trends and developments in transfer learning-based breast cancer detection techniques. The study focuses on publications, covering the period from 2016 to 2024 by employing the data from Scopus database. This study intends to provide valuable insights into the current state and future directions of research by analyzing the publication trends, influential authors, institutions, journals and keyword patterns. Based on this analysis, researchers and practitioners may gain a deeper understanding of the landscape of transfer learning-based approaches for breast cancer detection, facilitating informed decision-making and guiding future research efforts. In order to fulfill the objectives, this study aims to answer the following research questions:

- RQ1. What is the volume of research on breast cancer detection using transfer learning?
- RQ2. What are the collaboration and authorship patterns of breast cancer research using transfer learning?
- RQ3. Which are the active institutions, authors and journals that are producing breast cancer research using transfer learning?
- RQ4. What are the most frequently used keywords and themes of breast cancer research using transfer learning?
- RQ5. What kind of bibliographic coupling of countries, journals and authors exist in breast cancer research using transfer learning?

The structure of this research is organized as follows: The next section presents a comprehensive literature review, providing an overview of previous bibliometric studies relevant to the topic. This is followed by the materials and methods section,

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which details the method employed to conduct this bibliometric study. The results section then reports the statistical and network analysis of the studies selected for this bibliometric analysis. Subsequently, the discussion section interprets the results. The research then addresses the study's limitations and future directions, identifying potential constraints of the current bibliometric study and proposing areas for further investigation. Finally, the conclusion section summarizes the main findings, highlighting the study's contributions and significance of the research.

II. Literature Review

Ahmad et al. [6] have performed bibliometric analysis of breast cancer research in Pakistan up to Feb, 2021 by utilizing the Web of Science database. The study included 1,605 publications authored by 7,774 individuals, with an average of 18.25 citations per publication. Despite international collaborations with 88 countries, the research output doesn't align with the escalating breast cancer cases in Pakistan, indicating the urgency for policy reassessment and increased attention at the national level to combat the disease effectively.

Syed et al. [7] have utilized bibliometric analysis to assess the evolution of Artificial Intelligence (AI) in breast cancer diagnosis and prognosis research from 2000 to 2021. The analysis identified a significant increase in relevant literature, with the USA, China and India leading in productivity. Key authors, affiliations and journals are highlighted, with trends such as transfer learning and deep learning identified. The findings offer insights for policymakers and researchers to guide future collaborations and advancements in AI for breast cancer care [7].

Khairi et al. [8] have employed bibliometric analysis to investigate the development of deep learning for breast cancer image classification from 2014 to 2021, aiming to address the limitations of manual histopathology examination. Utilizing Scopus data, it examined publication trends, international collaborations and emerging research directions through visualization techniques. The research domain, initiated in 2016, exhibited sustained growth, with notable collaboration between the United States and China. This review aimed to guide researchers by identifying emerging areas in medical imaging for breast cancer diagnosis [8].

Zhou et al. [9] have conducted a comprehensive bibliometric analysis of artificial intelligence (AI) applications in histopathological image (HI) analysis from 2001 to 2021, utilizing data from the Web of Science Core Collection. It revealed a rapid increase in publications, with the USA leading in productivity and influence. Keyword and co-citation analyses highlighted breast cancer, prostate cancer and other tumor types as focal points, with classification and nucleus segmentation emerging as primary research directions. The study offered valuable insights for researchers, identifying key cancer types and trends in AI application in HI [9].

Joshi et al. [10] have performed a quantitative bibliometric analysis of research trends in breast cancer detection using machine learning techniques, focusing on histopathological modalities. Data sourced from Scopus database encompass influential authors, research institutes, journals, highly cited articles and keyword trends. The analysis suggested promising avenues for future research in breast cancer care through machine learning or deep learning methodologies [10].

TABLE I. Summary of Bibliometric Studies on Breast Cancer Detection

Study	Year.	Database	Scope of Study	Duration
Ahmad et al. [6]	2021	WOS	Pakistan	Start-2021
Syed et al. [7]	2022	Scopus, WOS	General	2000 to 2021
Khairi et al. [8]	2021	Scopus	Histopathological Images (HI)	2013-2021
Zhou et al. [9]	2022	WOS	HI Analysis	2001-2021
Joshi et al. [10]	2021	Scopus	HI Analysis	2009-2021

The studies outlined in Table I primarily focuses on bibliometric analysis related to breast cancer detection, with a predominant emphasis on histopathological images. Only one study addresses AI-based breast cancer detection techniques indicating a gap in the literature regarding bibliometric analysis specifically targeting transfer learning-based methods. Transfer learning has emerged as a valuable tool in machine learning, offering the potential to boost the effectiveness of breast cancer detection algorithms by leveraging knowledge from one task to enhance performance in another.

III. Materials and Methods

A. Methodology

Many researchers start their research with bibliometric analysis, which entails quantitative and statistical evaluation of data to assess the research performance of publications and discern trends in research publications across institutions, countries, individuals and disciplines [11]. As compared to other methods of reviewing literature, bibliometric offers a systematic, easy-to-understand and reproducible approach. This study employed bibliometric methods, which involve analyzing various scientific research publications such as research articles, books, conference papers and journals to comprehensively examine the landscape of research on the topic of Transfer Learning in Breast Cancer Detection. Through this bibliometric analysis, the aim is to evaluate the evolution of research in AI and transfer learning techniques for breast cancer detection, identify influential authors, institutions and journals in the field, track publication trends over time and uncover patterns of collaboration and citation among researchers and institutions.

B. Source of Data

Commonly used databases such as Scopus, Web of Science, Scimago and Google Scholar are utilized to gather information about publications and their citations. Among these, Scopus, an academic abstracts and indexing database by Elsevier, stands out for its comprehensive coverage, particularly in health-related topics, surpassing other databases like PubMed and Web of Science [12]. Therefore, for this bibliometric analysis the SCOPUS database is employed to compile data on publications related to breast cancer detection using Transfer Learning, along with additional keywords from 2016 to 2024.

C. Search Query and Data Retrieval

A thorough search strategy, as illustrated in Fig. 1, is implemented to retrieve the results.

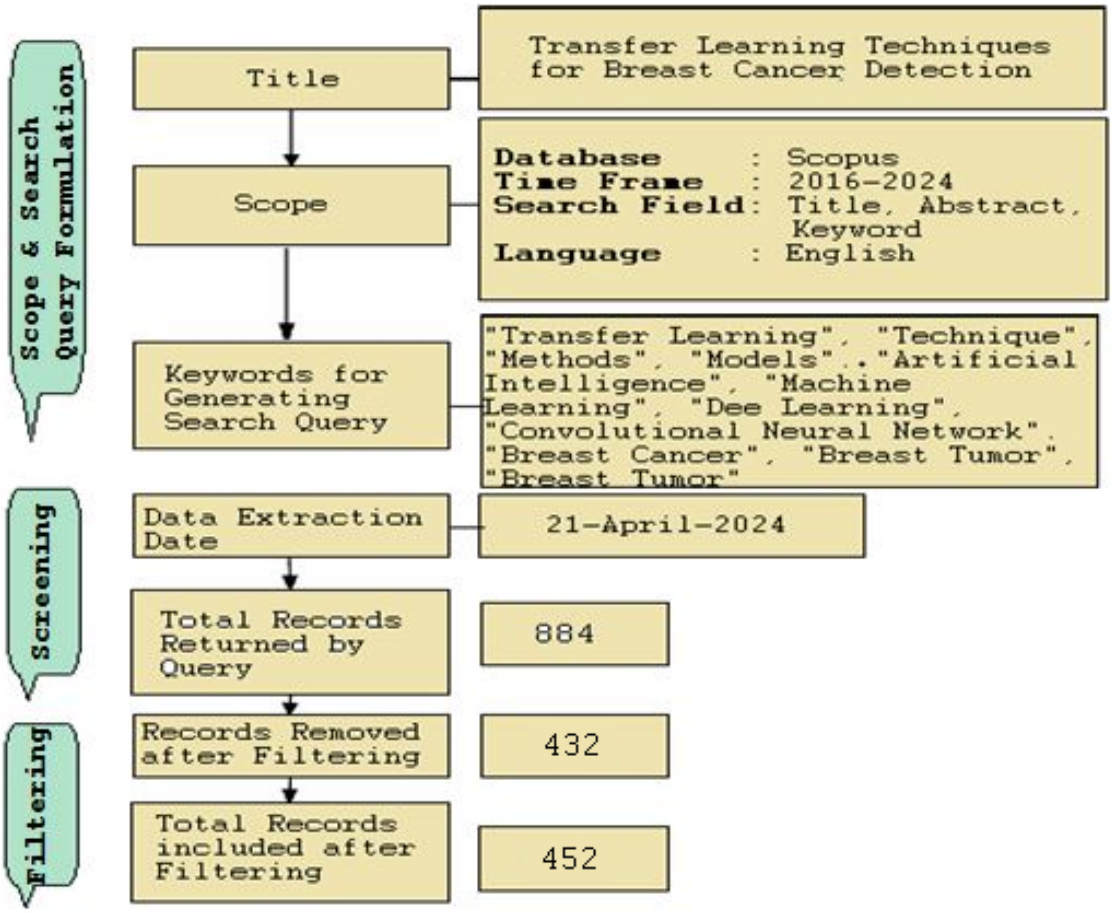

Fig. 1. Search strategy and data filtering.

The literature search is conducted on April 21, 2024. Relevant keywords are identified after consulting pertinent literature and the search query is formulated. These keywords are then combined using Boolean search operators to maximize the retrieval of relevant results. The following search query (Table II) is composed and executed within the SCOPUS database.

TABLE II. QUERY FOR TRANSFER LEARNING TECHNIQUES IN BREAST CANCER DETECTION

TITLE-ABS-KEY (“Transfer Learning”)
AND
TITLE-ABS-KEY (technique* OR method* OR model*)
AND
TITLE-ABS-KEY (“Artificial Intelligence” OR “Machine Learning” OR “Deep Learning” OR “Convolutional Neural Network”)
AND
TITLE-ABS-KEY (“Breast Cancer” OR “Breast Tumor” OR “Breast Carcinoma”)

D. Inclusion and Exclusion Criteria

1) Initial search and query: A search query is conducted on the Scopus database, yielding a total of 884 documents.

2) Screening based on title and abstract: Documents are screened based on their title and abstract, resulting in the retention of 458 articles after filtering.

3) Filtering based on document type: Subsequent filtration is performed to exclude documents that did not meet the specified document types. As a result, 455 records are included for analysis, encompassing journal articles (n = 265), reviews (n = 8), conference papers (n = 175), and book chapters (n = 7), ultimately excluding an additional three papers.

4) Language filtration: A further filtration process is applied to include only articles written in the English language. This resulted in the exclusion of 3 more articles written in Chinese (n=2) and Turkish (n=1) language. After applying these inclusion and exclusion criteria, a total of 452 articles remained for final analysis.

E. Tools Used

The data is processed, analyzed, and visualized using the R-Studio and VOSViewer software.

IV. RESULTS AND DISCUSSION

A. Statistical Analysis

1) Documents by publication years: The analysis of the year-wise trend of publications since last nine years reveals noteworthy insights into the evolution of research in the field. As evident in Table III and shown in Fig. 2, the data presents

a clear upward trend in the yearly publication of transfer learning-based breast cancer detection techniques from 2016 to 2024.

TABLE III. NUMBER OF PUBLISHED ARTICLES BY YEAR

Year	Published Articles	Year	Published Articles	Year	Published Articles
2016	3	2017	9	2018	23
2019	27	2020	39	2021	70
2022	100	2023	133	2024	48

In 2016, only 3 articles published on this topic, indicating a relatively low level of research activity. However, by 2018, the number of publications had more than tripled to 23, signaling a growing interest in transfer learning techniques for breast cancer detection. The trend continued to accelerate in subsequent years, with substantial increases in publication numbers. By 2021, there are 70 articles published, demonstrating a significant surge in research output. This trend reached its peak in 2023, with a staggering 133 articles published, reflecting a flourishing period of research activity in this field. In 2024, up till now 48 articles have been published, indicating a sustained interest in transfer learning-based breast cancer detection techniques.

Overall, the data highlights the increasing prominence of transfer learning-based approaches in breast cancer detection research with a consistent upward trajectory in publication numbers over the specified time period.

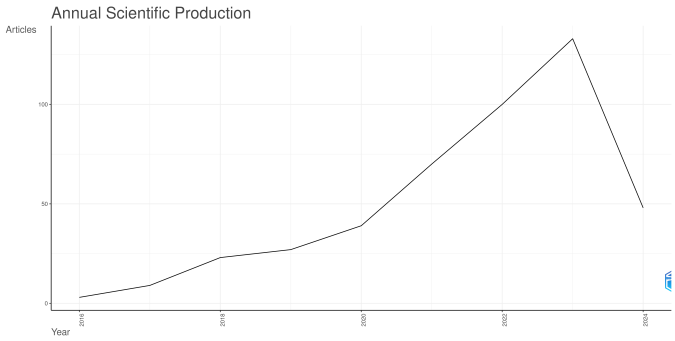

Fig. 2. Yearly publication trends of documents.

2) Documents by average citation per year: The mean total citations per year show a clear declining trend from 2016 to 2024, as shown in Table IV and in Fig. 3. In 2016, the mean total citations per year are 25.52, indicating a relatively high citation rate. However, this number steadily decreased over the subsequent years. By 2024, the mean total citations per year plummeted to just 0.42, suggesting a significant decline in the citation impact of the research publications. This downward trend may reflect a shift in research focus, changes in citation practices, or evolving trends in the academic landscape.

3) Documents by author: The data on the top 10 most relevant authors in breast cancer detection research using transfer learning reveals a diverse pool of contributors. Fig. 4 shows the 10 most relevant authors in this domain. Maryellen L. Giger emerges as the most prolific author with 10 articles to her name, indicating a significant contribution to the field. Mustapha Bouakkaz, Saida Sarra Boudouh, and Se-Woon Choe

TABLE IV. AVERAGE CITATIONS PER YEAR

Year	MeanTCperArt	N	MeanTCperYear	CitableYears
2016	229.67	3	25.52	9
2017	128.33	9	16.04	8
2018	61.87	23	8.84	7
2019	56.19	27	9.37	6
2020	38.97	39	7.79	5
2021	24.30	70	6.08	4
2022	11.88	100	3.96	3
2023	3.73	133	1.86	2
2024	0.42	48	0.42	1

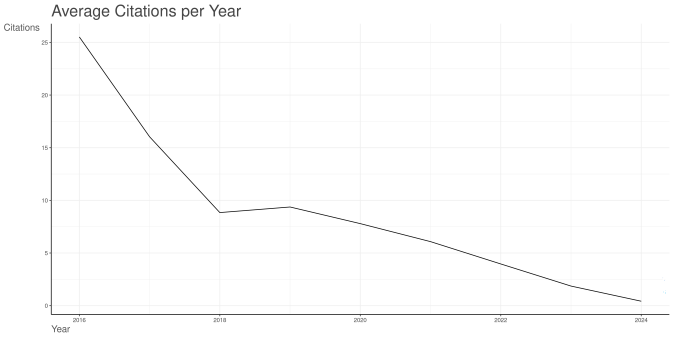

Fig. 3. Average citations per year.

follow closely behind with 7 articles each, underscoring their substantial involvement in research publications. Gelan Ayana and Sannasi Chakravarthy, S.R. are also notable contributors with 6 articles each. The remaining authors, including N. Bharanidharan, Hui Li, My Hachem El Yousfi Alaoui, and Mohamed Bal-Ghaoui, have contributed 5 or 4 articles each, demonstrating their significant engagement in research endeavors related to breast cancer detection using transfer learning techniques.

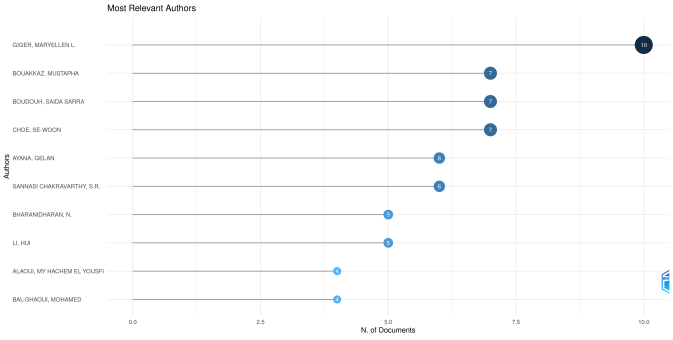

Fig. 4. Documents by relevant authors.

4) Documents by affiliations: The data on the top 10 affiliations involved in research on breast cancer detection using transfer learning reveals a diverse range of institutions contributing to this field. “Princess Nourah bint Abdulrahman University” emerges as the top affiliation with 24 articles, indicating its significant involvement and leadership in research endeavors related to breast cancer detection. Following closely behind is “I.R.C.C.S. Istituto Tumori ‘Giovanni Paolo

II" with 22 articles, highlighting its substantial contribution to the scientific literature in this area. "Harvard Medical School", "Kumoh National Institute of Technology", and "University of Michigan", each have 16 articles, showcasing their active engagement in breast cancer detection research. Similarly, "University of Rome Tor Vergata", "Icahn School of Medicine at Mount Sinai", "King Abdul Aziz University", "University of California", and "COMSATS University Islamabad (CUI)", each contribute significantly with 15, 13, 13, 13, and 12 articles respectively, underscoring their importance as key players in advancing knowledge and innovation in breast cancer detection using transfer learning techniques [see Fig. 5].

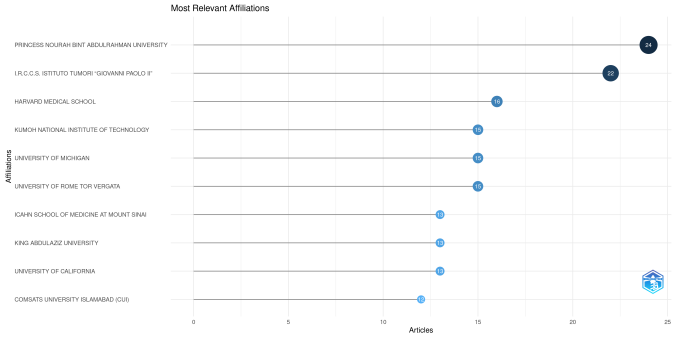

Fig. 5. Documents by affiliations.

5) Documents by sources: The data on the most relevant sources highlights a diverse range of publication venues. "Progress in Biomedical Optics and Imaging - Proceedings of SPIE" emerges as the top source with 18 articles, indicating its significant contribution to the dissemination of research in this field. Following closely behind are "Multimedia Tools and Applications" and "Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)" with 14 and 13 articles, respectively, underscoring their importance as platforms for scholarly communication. "Diagnostics", "Biomedical Signal Processing and Control", "Cancers", and "Computers in Biology and Medicine" , each contribute substantially with 11, 10, 9, and 9 articles, respectively, indicating their relevance in the field. Other notable sources include "IEEE Access", "Communications in Computer and Information Science", and "Lecture Notes in Networks and Systems", each with 9, 8, and 7 articles, respectively, reflecting their role in disseminating research findings on breast cancer detection using transfer learning techniques [see Fig. 6].

6) Documents by countries: The data reveals a varied landscape of research contributions in breast cancer detection using transfer learning techniques across different countries. China and India emerge as the most prolific contributors, with 35 and 90 articles, respectively, showcasing their significant involvement in this field. Other countries, such as Egypt, also demonstrate substantial participation with 11 articles. Interestingly, while some countries like China and India predominantly contribute through single-country publications (SCP), others like Canada and Italy engage in both SCPs and multiple-country publications (MCPs), indicating diverse collaboration patterns. This highlights the global nature of research efforts in breast cancer detection, emphasizing the importance of international cooperation to advance scientific knowledge and

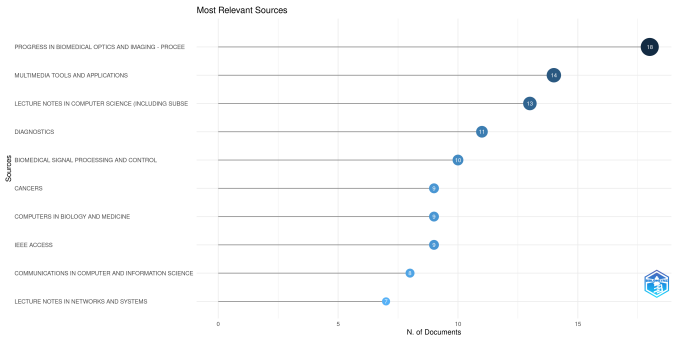

Fig. 6. Documents by sources.

address complex healthcare challenges. The data underscores the need for continued collaboration and knowledge-sharing among researchers worldwide to drive innovation and progress in breast cancer detection methodologies [see Fig. 7].

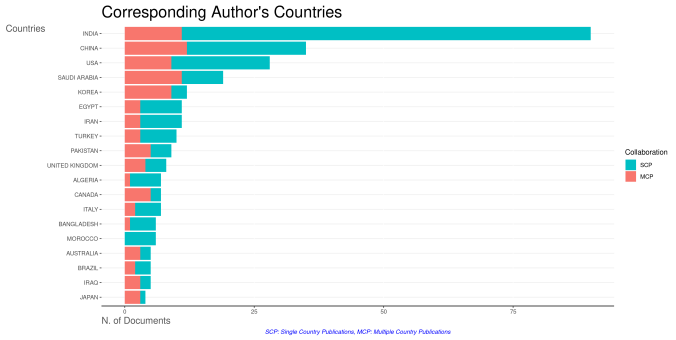

Fig. 7. Documents by countries.

B. Network Analysis

This phase of the study focuses on examining various network metrics, including co-authorship, co-occurrences, citations, bibliographic coupling, and co-citation.

1) Co-authorship analysis: Co-authorship analysis involves examining collaborations among authors, organizations, and countries.

a) Co-authorship analysis with authors: In this analysis, a threshold of at least 2 documents per author is set. Out of 1680 authors, 215 authors met this threshold. The largest connected set comprises 18 out of the 215 authors, as illustrated in Fig. 8.

b) Co-authorship analysis with organizations: The dataset comprises publications affiliated with 1153 organizations. Among these, 48 organizations meet the threshold criteria of having at least 2 documents. However, not all of these 48 entities are interconnected. The largest connected set encompasses 10 items, as illustrated in Fig. 9.

c) Co-authorship analysis with countries: The publications included in this study originate from 73 different countries. Among these, 51 countries meet the threshold requirement of having at least 2 documents. Within these 51 countries, the largest interconnected set comprises 49 items, as depicted in Fig. 10.

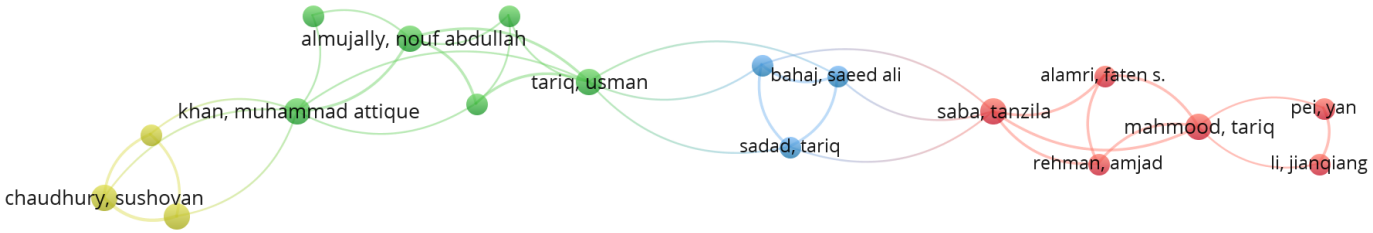

Fig. 8. Co-authorship analysis with authors - network visualization.

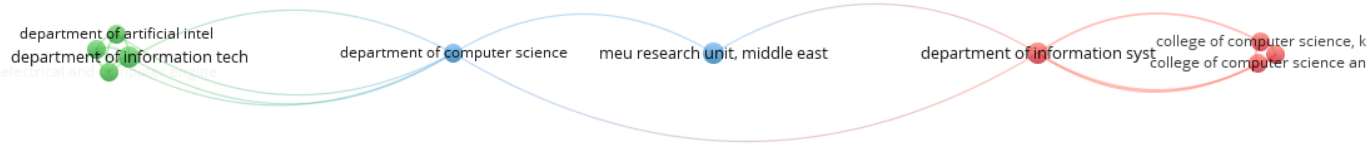

Fig. 9. Co-authorship analysis with organizations - network visualization.

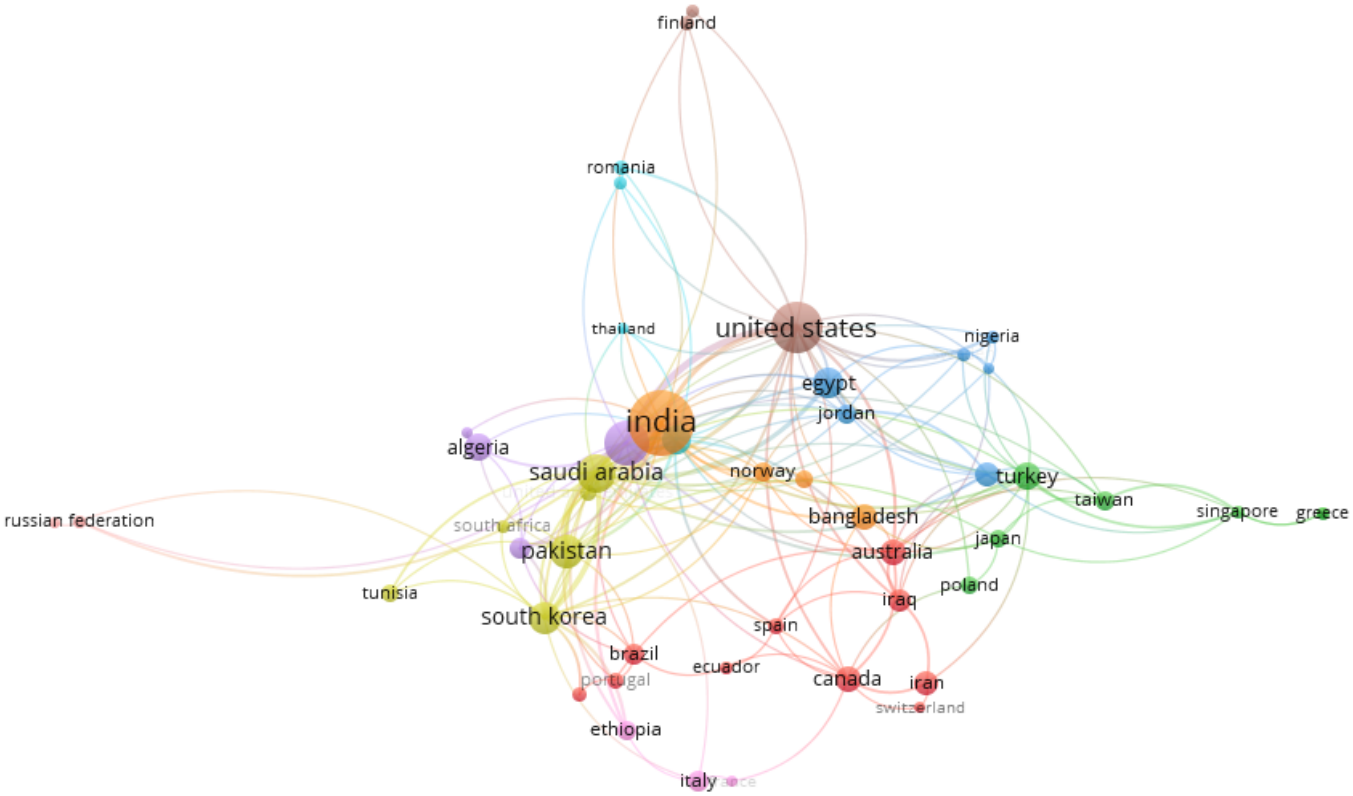

Fig. 10. Co-authorship analysis with countries - network visualization.

2) Co-occurrence analysis: Co-occurrence analysis has been conducted across various categories including all keywords, author keywords, and index keywords.

a) Co-occurrence with all Keywords: Out of the 2396 keywords identified in the selected publications, a total of 483 are analyzed, meeting the minimum occurrence criterion which is set to three. A network visualization is provided in Fig. 11.

b) Co-occurrence with author keywords: Examining the 779 author-assigned keywords, those with at least 3 occurrences are considered. A total of 111 entries met this threshold, as illustrated in Fig. 12.

c) Co-occurrence analysis based on index keywords: Out of the 2017 index keywords identified in the selected publications, 438 keywords met the minimum threshold of 3 occurrences. The network diagram in Fig. 13 reveals insights,

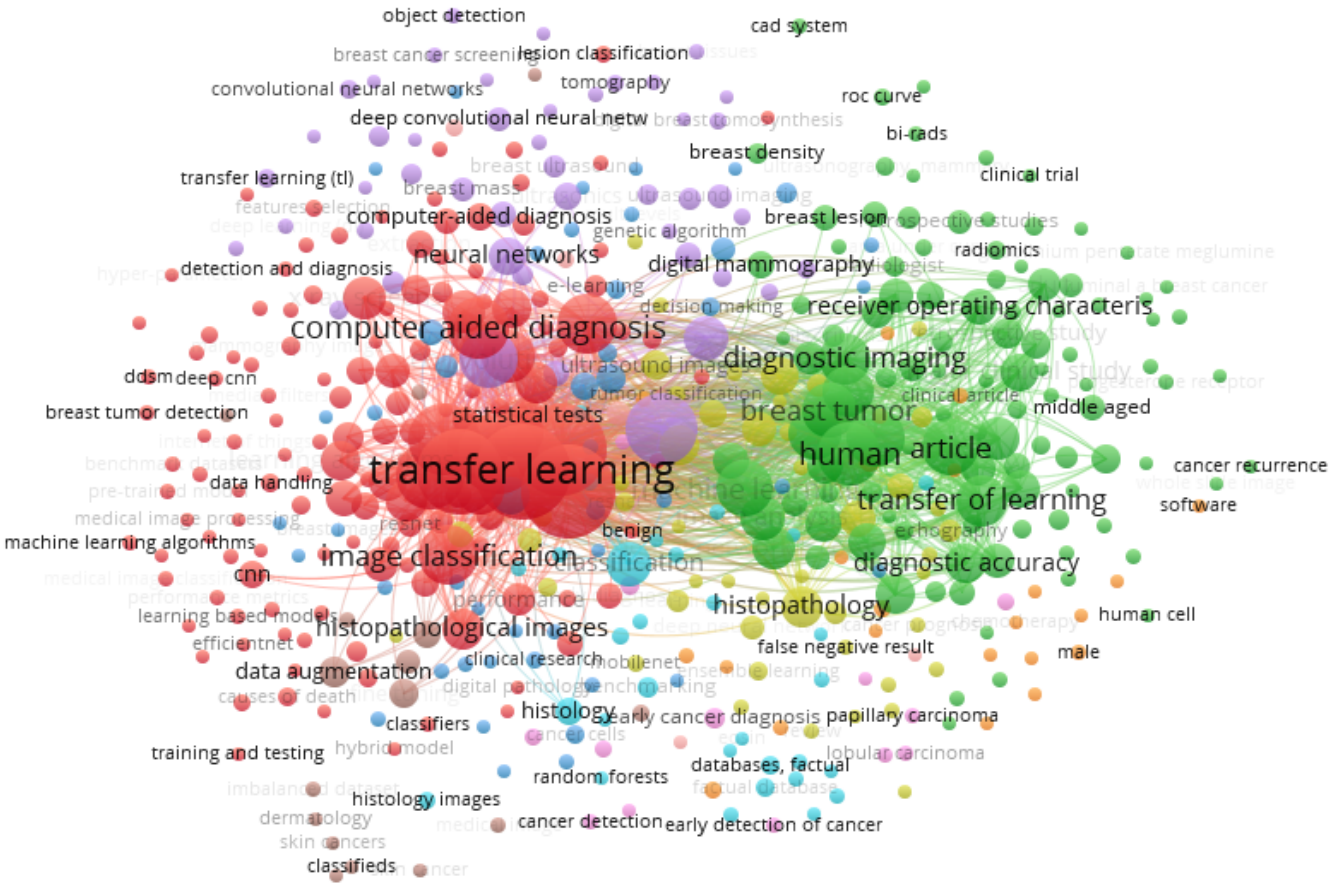

Fig. 11. Co-occurrence with all keywords - network visualization.

such as the keyword “Transfer Learning” having the highest total link strength of 4680, with 280 occurrences. Similarly, the keyword “Deep Learning” has 275 occurrences with a total link strength of 4719.

3) Citation analysis: This citation analysis examines various units of analysis, including documents, sources, authors, organizations, and countries.

a) Document citation analysis: Out of 452 publications, 222 documents meet the threshold of a minimum of 5 citations per document. Notably, Yap holds the top position with 588 citations. Some items in the network are disconnected. A total of 83 items are connected, which can be seen in Fig. 14.

b) Source citation analysis: The documents originate from 258 different sources, out of which 16 meet the threshold criteria of 5. Medical Physics and IEEE Journal of Biomedical and Health Informatics lead the list with 1178 and 678 citations, respectively, as shown in Fig. 15.

c) Author citation analysis: Among the 452 documents, 1680 authors have contributed. Considering a minimum of two documents per author, 215 authors are identified. Notably, Marit et al. has the highest citations (632) with 3 documents. Fig. 16 depicts the visualization of author citation analysis.

d) Organization citation analysis: Contributions from 1153 organizations are observed, with 10 organizations meeting the minimum threshold of 3 documents. The Department of IT/medical IT convergence engineering, Kumoh National Institute of Technology, Gumi, appears with 6 documents and 186 citations, as shown in Fig. 18.

e) Country citation analysis: The analyzed documents originate from 73 countries, with India, United States, and China ranking as the top three with 132, 73, and 51 documents, respectively. Their citation counts are 1496, 3491, and 1069, respectively. Fig. 17 depicts the visualization of country citation analysis.

The findings of this bibliometric analysis highlights a significant upward trajectory in research activities related to transfer learning for breast cancer detection over the past nine years. This growth highlights the increasing recognition and exploration of transfer learning as a viable solution to the challenges inherent in breast cancer detection, particularly those related to data limitations and classification accuracy. The dramatic rise from a mere three publications in 2016 to a peak of 133 in 2023 reflects a growing interest and investment in this area by the scientific community, indicating that transfer learning has become a focal point of innovation in medical imaging and oncology.

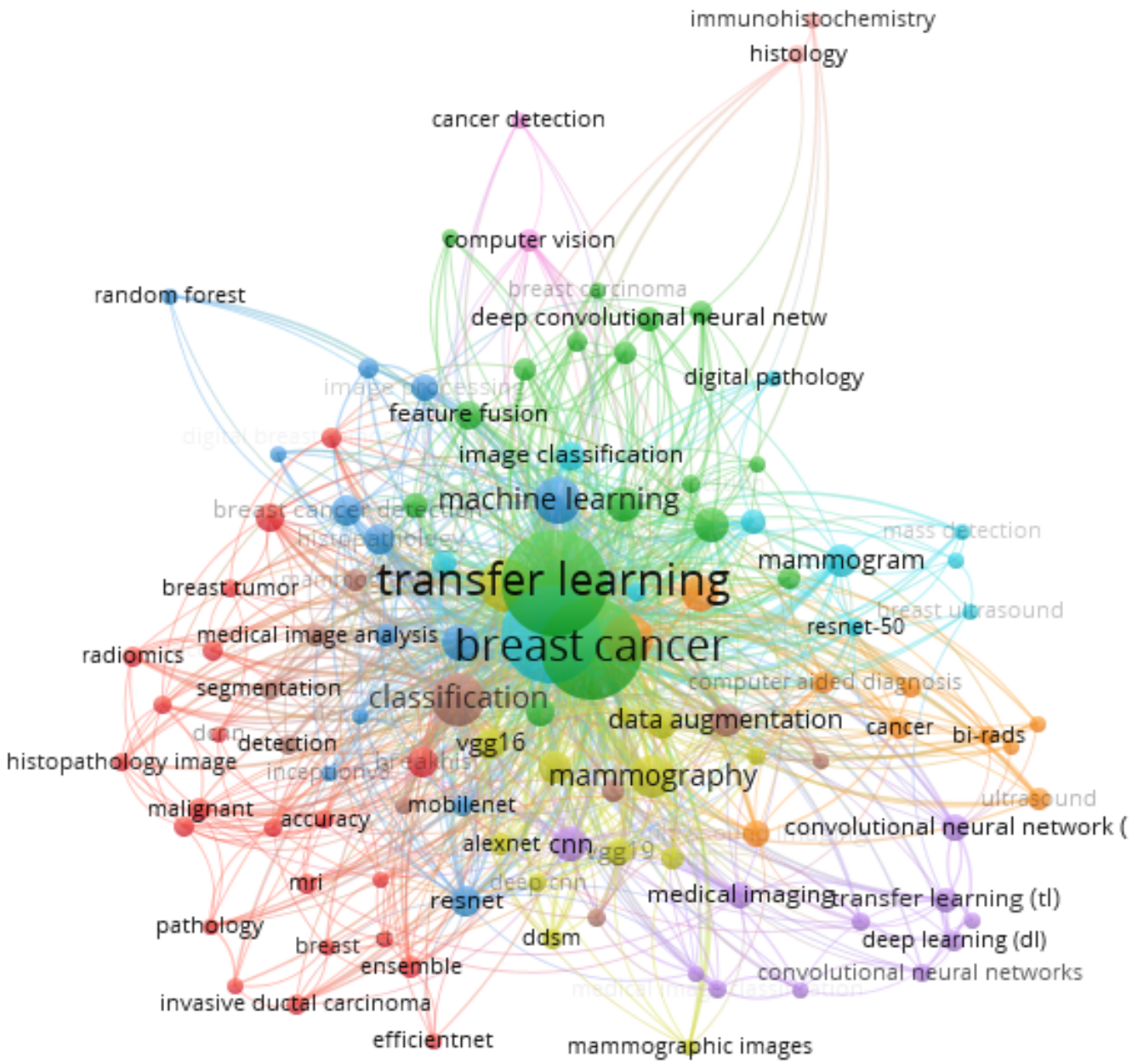

Fig. 12. Co-occurrence with author keywords - network visualization.

Moreover, the analysis identifies key contributors and institutions that are driving this research forward. Notably, Maryellen L. Giger emerged as the most prolific author, suggesting her significant influence and leadership in the field. Similarly, Princess Nourah bint Abdulrahman University is highlighted as a leading institution, demonstrating substantial involvement in advancing breast cancer detection technologies. The co-occurrence analysis of keywords further reveals critical research themes with terms like "Transfer Learning", "Deep Learning", and "Breast Cancer Detection" frequently appearing together. This suggests that these concepts are central to current research efforts and are likely to continue guiding future studies.

Overall, the insights gained from this bibliometric analysis provide a comprehensive overview of the current research landscape and identify potential areas for future exploration. The growing body of literature and the increasing collaboration among researchers and institutions underscore the promising potential of transfer learning techniques in revolutionizing breast cancer detection.

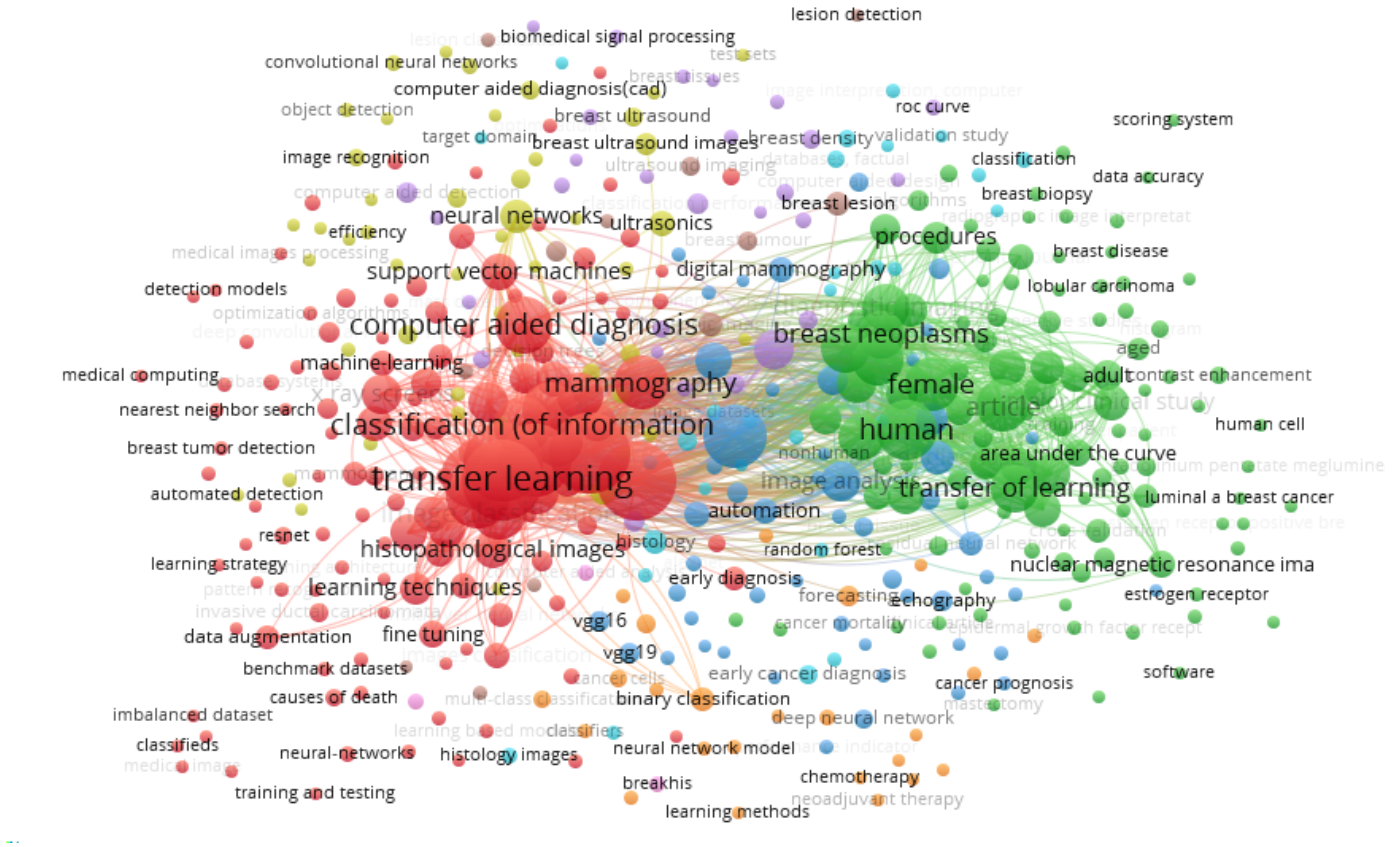

Fig. 13. Co-occurrence based on index keywords - network visualization.

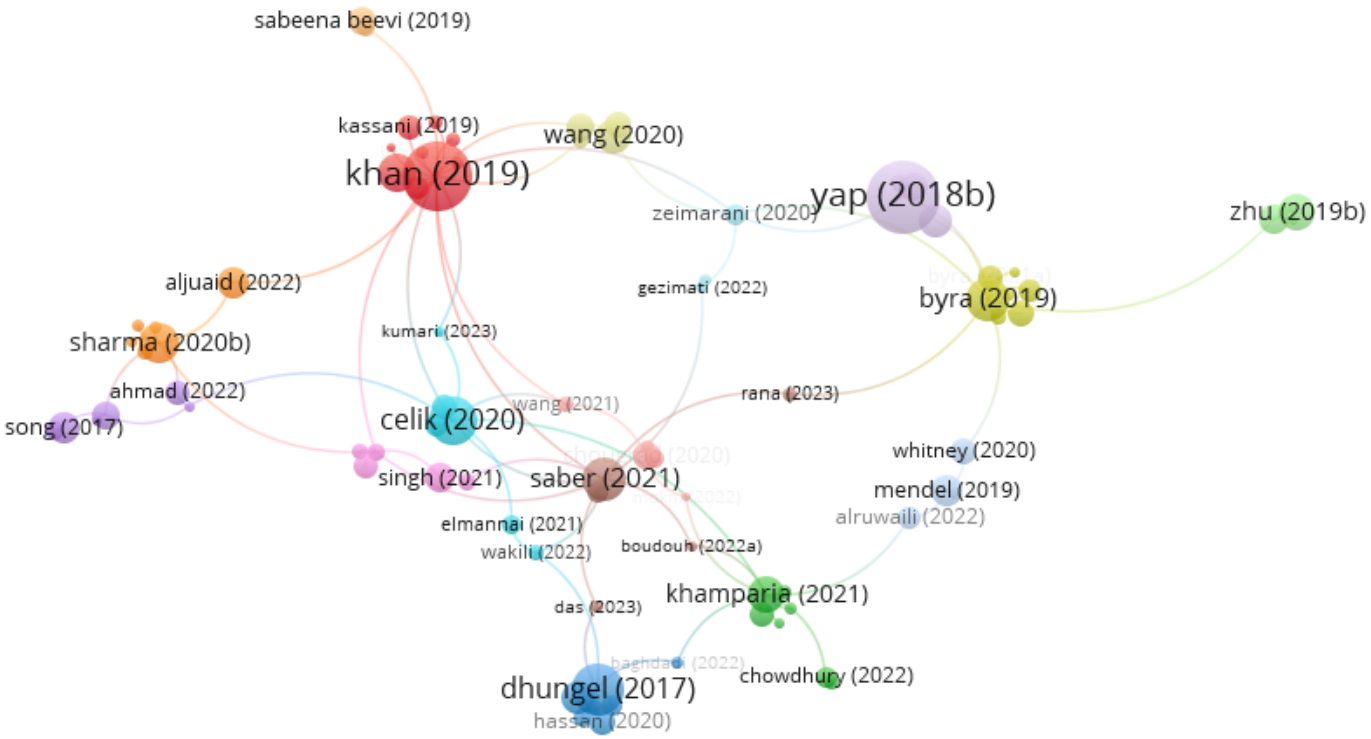

Fig. 14. Document citation analysis – network visualization.

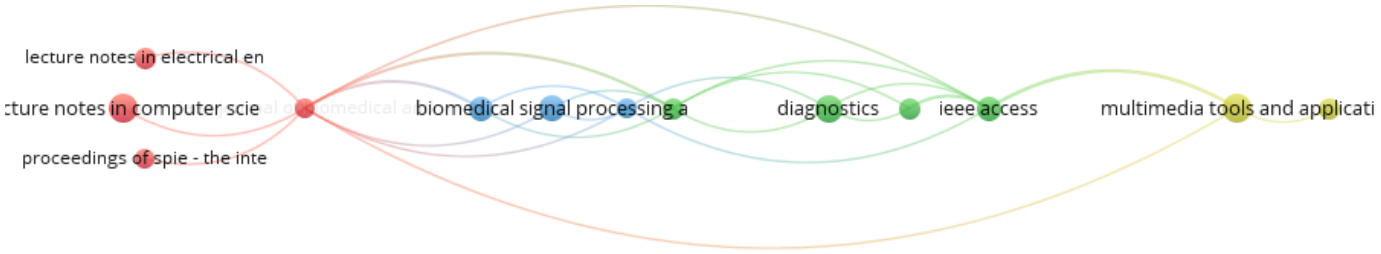

Fig. 15. Source citation analysis – network visualization.

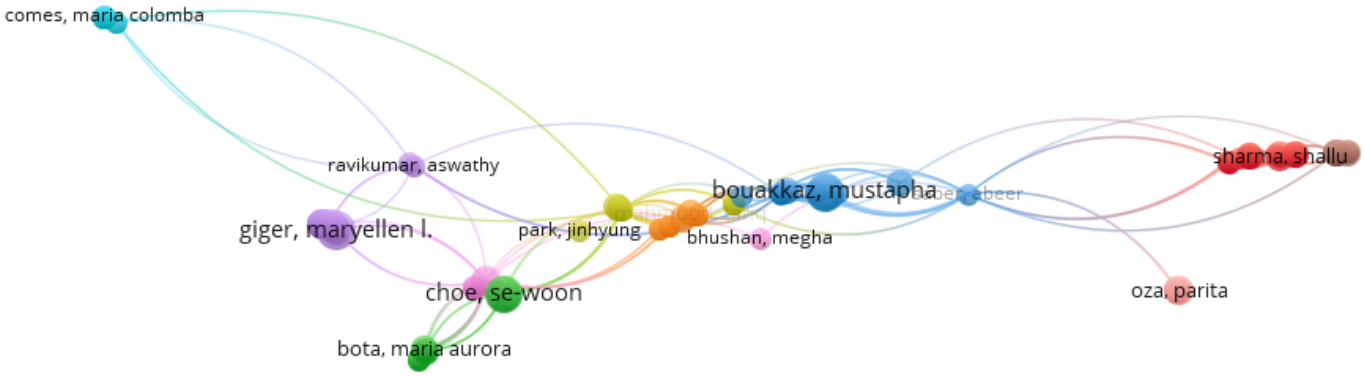

Fig. 16. Author citation analysis – network visualization.

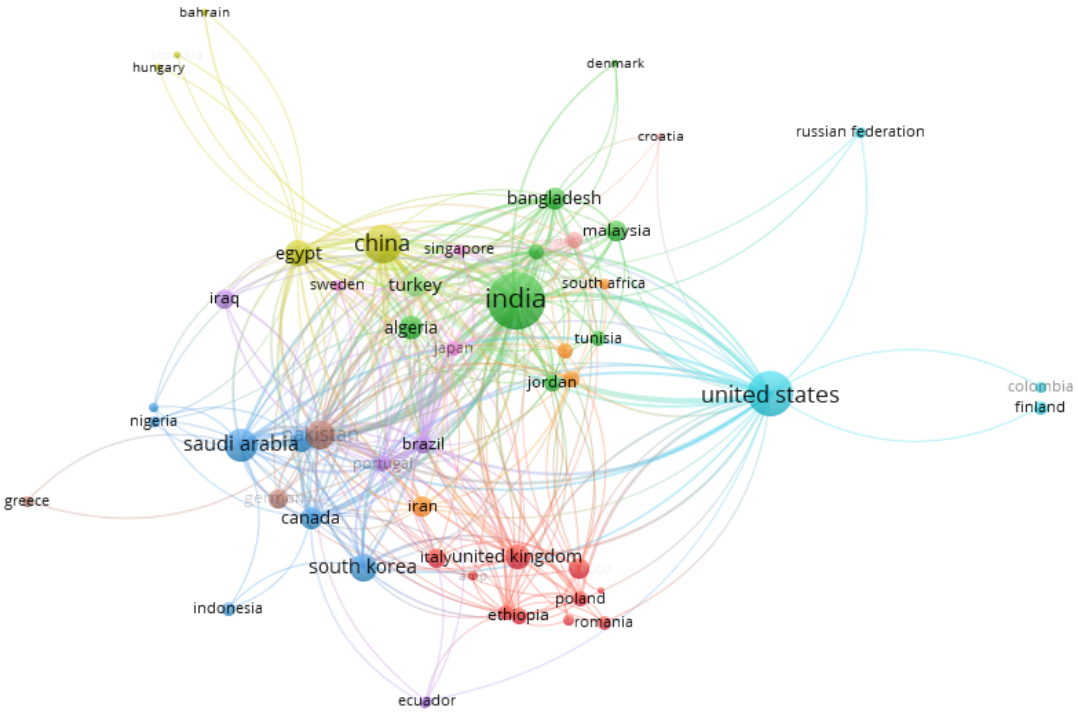

Fig. 17. Country citation analysis – network visualization.

V. Limitations

This study is limited by the exclusive use of the Scopus database for data collection, which may not capture all relevant publications on transfer learning in breast cancer detection. Additionally, the data is retrieved on April 21, 2024, and any documents published after this date are not included in the

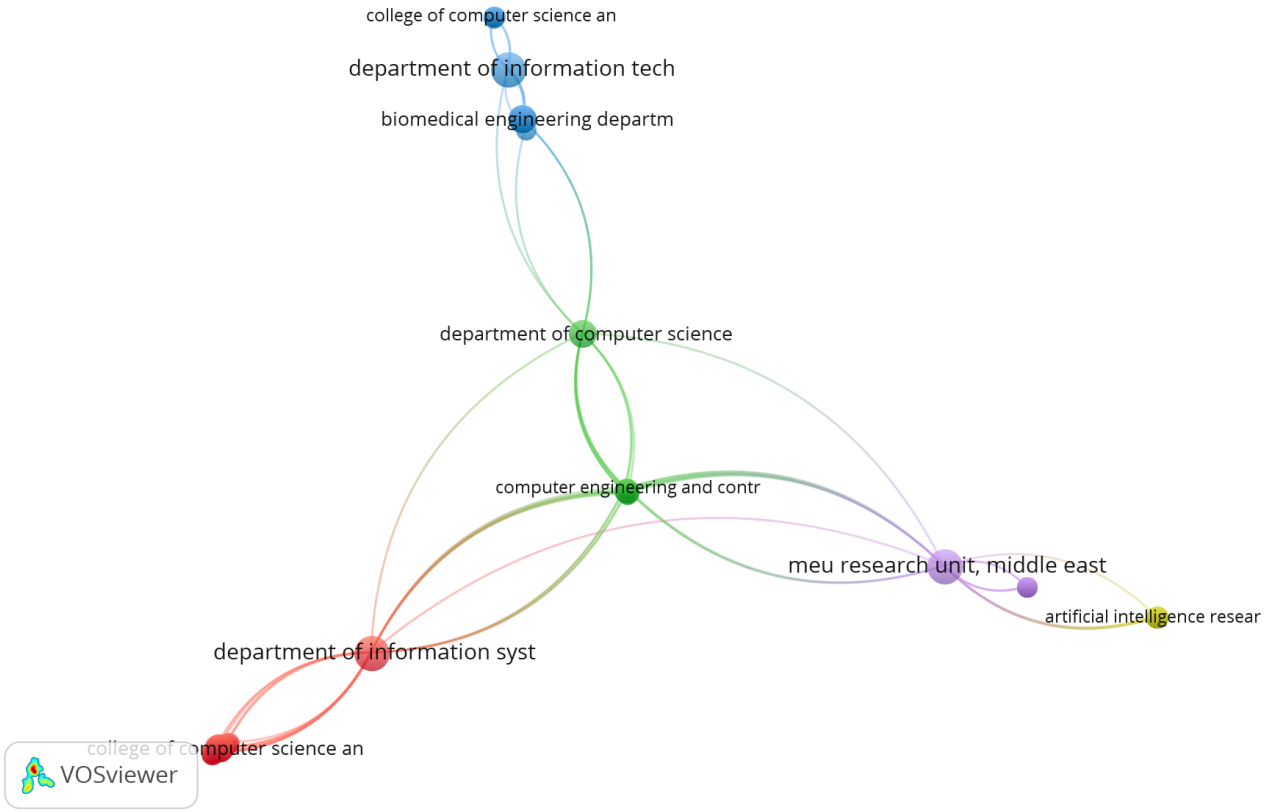

Fig. 18. Organization citation analysis – network visualization.

analysis. These limitations suggest that the findings might not fully represent the entire scope of research in this domain. A more comprehensive approach that includes other databases such as Web of Science, PubMed, and Google Scholar could provide a more holistic view of the research landscape.

VI. Conclusion and Future Directions

This bibliometric analysis reveals a significant upward trend in publications on transfer learning for breast cancer detection from 2016 to 2024, highlighting increasing research interest and advancements in the field. The results indicate that the volume of research on transfer learning for breast cancer detection has been steadily growing. In 2016, only 3 publications were available, but by 2023, this number had reached 133 publications, showing an upward trend in research interest. As of 2024, the results indicate continued activity in the field. The collaboration patterns in this research area reveal a mix of individual and institutional collaborations. Out of 1680 authors, 215 authors have published at least two papers, with the largest connected set comprising 18 authors. Princess Nourah bint Abdulrahman University has emerged as a leading institution, while China and India have shown significant research contributions, both through single-country and multi-country publications.

Future research will consider conducting a systematic review to complement this bibliometric analysis, providing deeper insights into the qualitative aspects of the studies, and identifying gaps in the existing literature. Additionally, comparative studies examining the research output on breast cancer detection using transfer learning across different countries, especially in developing regions, would be beneficial. Expanding the scope to include multiple databases and exploring collaborative patterns in diverse geographical regions could improve understanding of global research trends and foster international collaboration. These steps will help in advancing the field further and potentially lead to breakthroughs in early diagnosis and improved patient outcomes in breast cancer detection.

Data Availability

Data are available on request.

Statements and Declarations

All authors have no conflict of interest with anyone.

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