



# Healthcare 5.0 as an emerging research domain: A comprehensive bibliometric analysis and science mapping study

Güler Koştı

Department of Scientific Research Projects, Afyonkarahisar Health Sciences University, Afyonkarahisar, Turkey

## ABSTRACT

Healthcare 5.0 constitutes a paradigmatic transformation in medical systems, yet its intellectual topology remains insufficiently examined. Through a systematic literature review encompassing Industry 5.0 and Healthcare 5.0 frameworks, this investigation presents a comprehensive bibliometric analysis of Healthcare 5.0's evolutionary trajectory, analyzing 112 Scopus-indexed publications spanning 2020-2024. Employing VOSviewer and Biblioshiny analytical platforms, we conducted performance analysis, scientific production analysis, and science mapping to elucidate the field's structural composition. Network analysis revealed three predominant research clusters: technological infrastructure, security solutions, and clinical applications. Thematic mapping identified blockchain technology and artificial intelligence (AI) as pivotal innovations, while lexical analysis delineated five distinct clusters: health technologies and operational systems, blockchain-enabled digital transformation, industrial sustainability frameworks, security-privacy protocols, and advanced AI applications. The security-privacy cluster exhibited robust interconnectivity across all domains, underscoring its fundamental significance within Healthcare 5.0. The expeditious integration of emergent technologies, including metaverse applications and quantum cryptography, indicates the domain's dynamic evolution. Obtained findings empirically document Healthcare 5.0's accelerating transition from a technology-centric to a human-centric paradigm while emphasizing the strategic imperatives of blockchain and AI investments for healthcare organizations pursuing digital transformation initiatives.

## ARTICLE HISTORY

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## KEYWORDS

Healthcare 5.0; industry 5.0; bibliometric analysis; blockchain; federated learning

## 1. Introduction

Technological developments and innovations constitute the fundamental dynamics of social transformation. Industrial revolutions, which are the most comprehensive reflection of this transformation process, have profoundly affected social structure and institutions beyond the changes in production systems [1]. From a historical perspective, this four-phase process is currently evolving towards its fifth stage, Industry 5.0. Industry 5.0 represents a novel paradigm that places human-machine collaboration at its core, fundamentally grounded in sustainable development and ethical principles [2]. The preceding four industrial revolutions were fundamentally shaped by technological advancements. Industry 1.0 focused on mechanization through water and steam power, Industry 2.0 encompassed electrification, mass production, and division of labor, Industry 3.0 embodied information technologies and automation, while Industry 4.0 centered on the integration of digital technologies, predominantly cyber-physical systems and the Internet of Things (IoT). Industry 5.0 has been conceptualized as a next-generation industrial approach that aims to transform industrial production into a sustainable, highly adaptive, society-centric, and competitive framework, while simultaneously striving to minimize environmental impacts within ecosystem boundaries [3]. The observation that Industry 4.0 prioritized digitalization and Artificial Intelligence (AI) technologies to enhance production efficiency and flexibility, while relegating social justice and sustainability principles to secondary consideration, constitutes the foundational basis for Industry 5.0's emergence. This new paradigm optimizes human-technology synergy by prioritizing the mutual benefit of both the industrial ecosystem and workforce, positioning technology not as a substitute for human labor but as a complementary

component [4]. While Industry 5.0 is similar to Industry 4.0 in terms of technological infrastructure, it differs in that it prioritizes more human-centered technologies and aims to optimize the symbiotic relationship between people and technology for the mutual benefit of industrial processes and workers. In this context, technology is not positioned as a substitute for human labor, but as a complementary element [3]. In essence, whereas Industry 4.0, akin to its industrial revolution predecessors, adopts a technology-centric approach, Industry 5.0 establishes a value-based paradigm. These two industrial transformation processes are inherently complementary, with Industry 5.0 emphasizing societal imperatives, value creation, and social responsibility as core objectives while necessitating Industry 4.0's technological infrastructure and solutions for their realization [5].

The accelerating advancement of digital technologies coupled with the increasing complexity of healthcare services necessitates a comprehensive transformation within the healthcare sector [6]. The evolutionary development of healthcare has also followed a parallel course with the industrial revolutions, evolving from Health 1.0 based on empirical knowledge to Health 2.0 based on technology and mass production, from Health 3.0 shaped by computer-based systems to Health 4.0 characterized by smart medicine applications [7]. Today, Health 5.0, which is the result of the reflection of Industry 5.0 developments in the field of health, is basically developing with the integration of explainable AI systems, secure blockchain technologies and federated learning techniques [8, 9]. The adaptation of these technologies to healthcare services and the increasing significance of the human-centric approach enhance early disease detection, optimize treatment processes, and improve patient monitoring effectiveness, representing a patient-centered and personalized approach beyond traditional healthcare services. In particular, medical IoT and metaverse-supported tele-surgery applications significantly elevate the accessibility and quality of healthcare services [10]. The development of Healthcare 5.0 is also in line with sustainable development goals. This new paradigm not only emphasizes technological innovation, but also social and environmental sustainability. In particular, issues such as energy efficiency, sustainability, security and patient privacy are among the key focal points of Healthcare 5.0 [11].

In the comprehensive literature review, although there are various bibliometric analyses on Industry 5.0 in the scientific literature [12–15], no bibliometric study on Healthcare 5.0 has yet been found.

The aim of the study is to examine the intellectual structure, development trends and research orientations of Healthcare 5.0 through bibliometric analysis and to reveal its conceptual relationship networks and periodic development. In this context, the transition process from Health 4.0 to Healthcare 5.0 has been addressed with a retrospective and evolutionary perspective in an exploratory research format. The results of the study are intended to contribute to future sectoral and academic research. The main question of the research is ‘What are the trends of academic studies on Healthcare 5.0 and how is this conceptual development taking shape?’.

Based on the comprehensive analyses conducted, the significant contributions to the literature and primary objectives of this study are presented below.

1. Being the first comprehensive bibliometric analysis that systematically reveals the intellectual structure and development dynamics of Healthcare 5.0,
2. Identifying potential areas and research gaps to guide future work towards Healthcare 5.0,
3. Analyze the conceptual development of Healthcare 5.0 research and research trends from a multidimensional perspective,
4. Provide strategic insights to practitioners and policy makers on the development dynamics of Healthcare 5.0,
5. Contribute to shaping implementation strategies in the digital transformation of healthcare services,
6. It illuminates the scientific communication structure of the field through detailed mapping and multi-dimensional analysis of international cooperation networks.

The organizational structure of the study is structured as follows: In the second chapter, the evolutionary process from Industry 1.0–5.0 and from Health 1.0–5.0 is analyzed in a comprehensive theoretical framework. In the third chapter, the methodological framework of the research and the data collection protocol are systematically discussed. In the fourth chapter, the findings from the bibliometric analysis are presented under the headings of performance analysis, network analysis and scientific mapping. In the fifth chapter,

the research findings are discussed in the light of the existing literature, and in the final chapter, the theoretical and practical implications of the study and recommendations for future research are presented.

## 2. Theoretical background

### 2.1. The evolutionary process of transition from Industry 1.0 to Industry 5.0

Industrial revolutions represent a broad transformation from production systems to social structure. Industry 1.0 (1780-1870), also known as the ‘Age of Steam’, was shaped by the invention of the steam engine by James Watt. This period enabled Europe to establish economic superiority over other regions by shifting production from piecework to mass production and from the workshop to the factory [16]. While this period was characterized by changes in energy regimes and mass media, developments were mostly trial-and-error.

Industry 2.0 (1870-1914), referred to as the ‘Technology Revolution’, is the product of the Enlightenment period, when scientific methods flourished. The most important developments of the period were the transition to mechanization in weaving and the transition from steam power to petroleum-based internal combustion engines [17]. This process brought about significant developments in the oil, automotive and electricity sectors. With the development of electrical energy, production processes have become more organized, production lines have become semi-automated and control has been provided to employees [18].

Industry 3.0, referred to as the ‘Age of Digital Revolution’, lasted from the aftermath of the Second World War until the 2000s. The foundations of Internet technology were laid with the ARPAnet project launched in 1957 [19]. This period is characterized by five fundamental components: electric transportation vehicles, renewable energy, smart buildings, global energy-sharing networks, and hydrogen storage technologies [20].

Industry 4.0, the so-called ‘Age of Smart Manufacturing’, represents the integration of cyber-physical systems and IoT [21]. The institutional foundations of the concept were established at the Hannover Fair in 2011 through the initiatives of the German Government [22] and developed within the framework of the ‘High Technology Strategy 2020’ [23]. The three distinguishing features of this new paradigm are the exponential pace of technological developments, the comprehensive transformation created by digitalization, and systemic change across all sectors [24]. Industry 4.0 includes various technological components such as big data analytics, cloud computing, IoT, augmented/virtual reality, 3D printers, cyber security, AI, smart robots and cyber-physical systems [25]. This integration is achieved through the coordination of digital systems and information technologies [26], transforming all processes from production to supply chain. Figure 1 briefly illustrates the distinct technological and organizational characteristics of each Industrial stage in the chronological development of industrial revolutions.

The contemporary concept of Industry 5.0 was initially discussed in two virtual workshops organized by European research and technology organizations on July 2 and 9, 2020 [3]. On the tenth anniversary of the

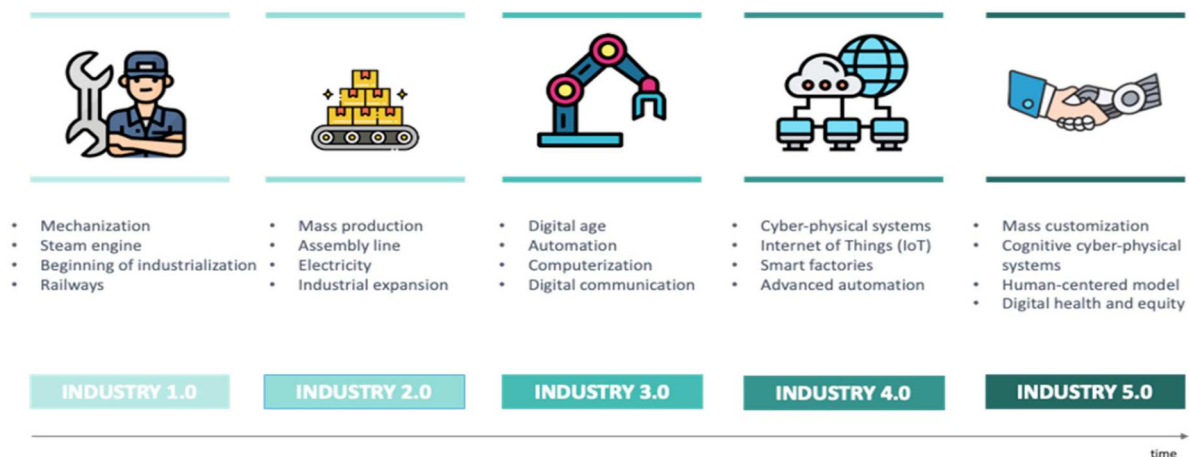


Figure 1. Evolution of industrial revolutions: from industry 1.0 to industry 5.0 [27].

introduction of Industry 4.0, the European Commission announced Industry 5.0. Industry 5.0 goes beyond the technology-driven approach of Industry 4.0 and represents a new paradigm that is human-centered, sustainable and based on ethical values. It emphasizes that Industry 5.0 is not an alternative to Industry 4.0, but a logical evolution of it. Therefore, Industry 4.0 is considered to be technology-oriented while Industry 5.0 is considered to be value-oriented [5]. This new paradigm aims to achieve social goals beyond employment and growth through an innovative, flexible and community-centered industrial vision that respects the limits of the planet and places the well-being of industrial workers at the heart of the production process, minimizing negative environmental impacts [2]. The main features of Industry 5.0 are built on three basic principles, as shown in Figure 2 below [28]:

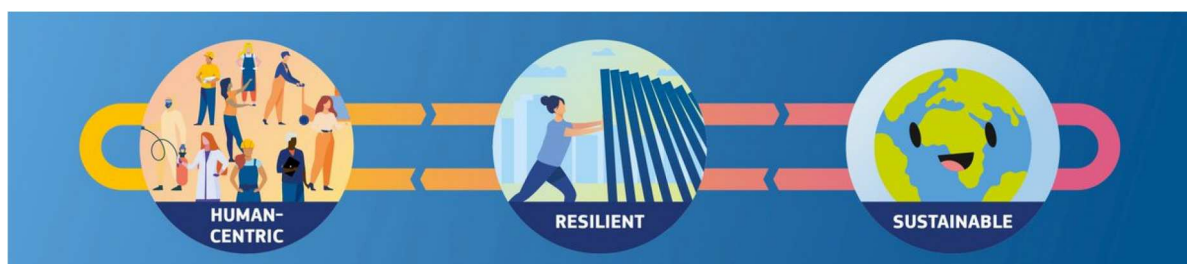
As seen in Figure 2, Industry 5.0, unlike previous industrial revolutions, adopts a human-centered approach in production processes and aims to ensure that human workers work in harmony with advanced technologies such as robotic systems and AI by emphasizing their cognitive and creative abilities [29]. This human-centered production approach allows individuals to focus on their creative abilities and problem-solving skills, aims to increase workers' safety and job satisfaction by transferring routine or hazardous work to machines, and envisages technology taking on a supportive and empowering role for workers [2]. This combination supports a vision of sustainable and inclusive manufacturing that optimally integrates both technological and human elements, and provides a more humane framework for future business models and working environments [30].

Sustainability is a principle adopted to minimize the environmental impact of industrial production and ensure efficient use of resources. This approach aims to create an environmentally friendly production ecosystem based on renewable energy sources and circular economy principles to increase environmental sustainability. Thus, it contributes to the protection of natural resources and prevention of waste by optimizing resource use [31]. [28], emphasizes that the principle of sustainability aims to ensure the long-term sustainability of industrial systems through the reduction of environmental impacts and optimization of resource efficiency. This sustainability-oriented approach represents a growing awareness of the need to strike a balance between economic development and environmental protection, as well as the development of a more ethical and responsible production process [32]. Furthermore, Industry 5.0 aims to create more resilient and adaptable production ecosystems, taking into account the needs and expectations of both current and future generations. Overall, Industry 5.0's emphasis on sustainability reflects a growing awareness of the need to strike a balance between economic growth, environmental protection and social responsibility, and a desire to develop a more sustainable and equitable vision of future business models [29].

Resilience is a principle that refers to the ability of production systems to adapt to unexpected changes and crises. This approach aims to maintain the continuity and efficiency of production processes and improve the ability of production systems to respond quickly to changing market conditions, technological developments and global crises by incorporating flexible production systems design and effective risk management strategies [28].

In terms of technological infrastructure, the key technologies supporting Industry 5.0 are categorized as follows [33]:

1. Individualized human-machine interaction technologies that connect and combine the strengths of humans and machines,



**Figure 2.** Three fundamental principles of industry 5.0 [3, 5].

2. Bio-inspired technologies and smart materials that allow recyclable embedded sensors and materials with advanced properties,
3. Digital Twins and simulation to model entire systems,
4. Data transmission, storage and analysis technologies that can handle data and system interoperability,
5. AI technologies that detect causality in complex, dynamic systems, leading to actionable intelligence,
6. Energy efficiency, renewable energy, storage and autonomy technologies.

This technological infrastructure is designed to support social and ecological values, ensuring that technological transformation is shaped according to social needs [34]. As a result, the most prominent feature of the paradigm is the symbiotic relationship established between human and technology. All these systems aim for a sustainable and resilient industrial transformation centered on human values and social needs [3].

## **2.2. The evolutionary process of transition from Health 1.0 to Healthcare 5.0**

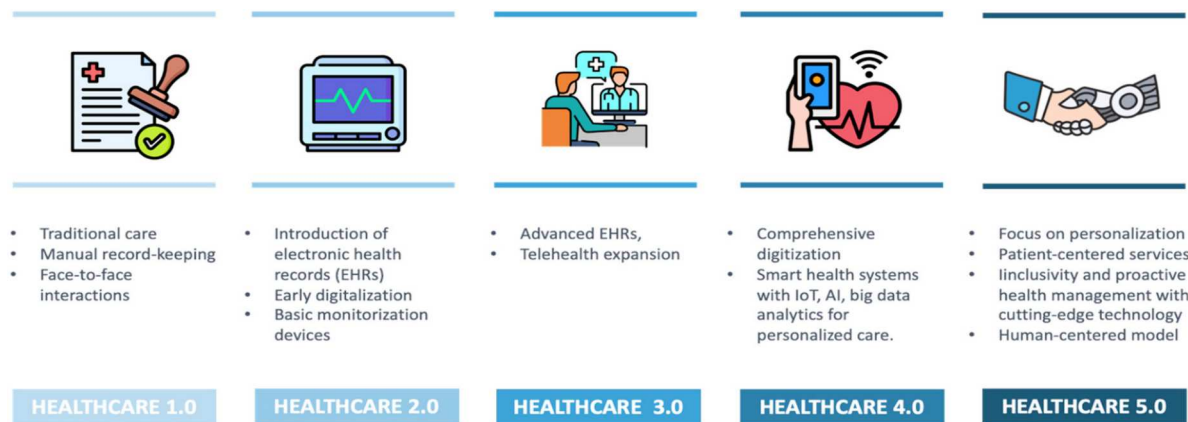
The systematic development of health services took place in five main phases in parallel with industrial advances. Health 1.0 (1830-1870) began when the British Government recognized that epidemics were caused by contaminated drinking water [7]. In this period, the emergence of health problems was attributed to two main reasons: supernatural powers and the failure of the organs in the body to function properly. While religious and magical methods were used in the treatment of diseases, experimental methods were also used. Health has been recognized as a fundamental human right and the provision of health services to all has been one of the main functions of the state [35]. There have also been significant advances in epidemiology and laboratory science, with improvements in food and water safety, antibiotics and vaccines.

Health 2.0, which represents the era of modern medicine, was shaped by the discovery of the germ theory, and rapid developments in biology, physiology, anatomy and pathology formed the foundations of modern medicine [36]. During this period, the identification of the causative agents of tuberculosis and cholera, and the development of tetanus, diphtheria and polio vaccines provided important breakthroughs in medical science. The integration of industrial mass production technologies into the field of health made significant contributions to the production of antibiotics, especially for large pharmaceutical companies such as Hoffmann-La Roche [37]. Treatment of diseases and preventive measures were based on scientific research, and diagnosis and treatment processes were carried out by specialists trained in the field of health with advanced technological tools. According to [7], during this period, basic sciences and clinical education gained equal importance in medical education, and hospitals transformed into large specialized institutions where more professionals served and doctors could treat more complex cases.

Health 3.0 represents the integration of digital technologies into healthcare. The process, which started with computer-based patient record systems in the 1960s, developed with smaller computers with fast computing and large data storage capacity with the development of microprocessors in the 1980s, and these developments contributed to the formation of electronic health systems in the 2000s [38]. [39], state that this period offers a modern approach that emphasizes environmental and political actions that directly affect the social determinants of health. In this period, the development of imaging techniques, minimally invasive surgical tools, laser technology and surgical robots made the diagnosis and treatment of diseases practical, and previously impossible operations and organ transplants were successfully performed [40].

Health 4.0 represents the comprehensive integration of digital transformation. Health 4.0 aims to reduce complications and improve clinical processes by developing smart systems that deliver the right information at the right time, in the right place [41]. Schiavoni et al. [42], state that the main goal of this era is to provide personalized care by remote monitoring of patients' physiological parameters, such as biomedical parameters, in real time. [43], emphasize that Health 4.0 technologies offer promising solutions for elderly care and remote patient monitoring applications, especially for physical impairments caused by aging or accidents. [44], emphasize that personalized medicine, genomics, gene modification and nanotechnology are important areas developing with Health 4.0. According to [45], Health 4.0, powered by Electronic Health Record systems, AI and real-time data from wearable devices, is making healthcare more predictive and personalized.

As can be seen in Figure 3, which shows the historical development process of health services, health services have transformed from analog systems to a digital and human-centered structure.



**Figure 3.** The evolution of healthcare systems: from healthcare 1.0 to healthcare 5.0 [27].

The evolutionary development of healthcare services has been shaped by the objectives of improving patient outcomes, enhancing service efficiency, and elevating the quality of care [46]. Healthcare 5.0, the most current stage of this evolutionary process, aims to provide a holistic approach to the health and well-being of individuals by using advanced technologies with a patient-centered and personalized care approach, while providing a care service tailored to the unique needs of each patient and increasing the sustainability of healthcare services [29].

The human-centered approach, which is the core philosophy of Industry 5.0, directly overlaps with the nature of the healthcare sector. Multidimensional data interactions in healthcare services increase the operational complexity of healthcare organizations. The Healthcare 5.0 paradigm goes beyond traditional treatment-oriented approaches and focuses on the proactive participation of individuals to make knowledge-based decisions in health management and a holistic understanding of health. This approach aims to sustainably improve the overall health and well-being of individuals in addition to the treatment of diseases [47]. The integration of Industry 5.0 into the healthcare sector is expected to lead to fundamental changes in areas such as personalized medicine practices, improving patient outcomes, automation of routine tasks, telemedicine services and preventive care approaches. This integration has the potential to raise standards of care, cost optimization and efficiency gains. In particular, personalized medicine stands out as one of the most important advantages offered by Industry 5.0 to the healthcare sector. This approach makes it possible to develop customized treatment protocols based on patients' genetic makeup, lifestyle and individual needs [48]. The integration of advanced technologies into healthcare enables healthcare professionals to develop individualized treatment plans with AI, data analytics and IoT Technologies [49].

Another important innovation brought by Healthcare 5.0 is the automation of administrative and routine tasks, allowing healthcare professionals to focus more on complex cases and critical tasks. This technological transformation contributes to increased service efficiency, optimized costs and improved patient outcomes [29].

The technological infrastructure of Healthcare 5.0 is based on the holistic integration of advanced systems that work integrated with each other. While this integration represents a comprehensive transformation in the delivery of healthcare services, there have been numerous studies on the IoT, AI, Big Data analysis and blockchain technologies that form the basis of the technological revolution in healthcare systems. Saraswat et al. [50], examined the opportunities and challenges of explainable AI systems for Healthcare 5.0, particularly highlighting its potential in clinical decision support systems. Security and blockchain technology are other prominent topics in the Healthcare 5.0 literature, and Rehman et al. [51] propose a secure Healthcare 5.0 system that integrates blockchain technology and federated learning techniques. Similarly, Bhavin et al. [8] aim to improve the security of Healthcare 5.0 applications by developing a hybrid scheme based on blockchain and quantum blind signature. Tele-medicine and remote surgery applications are also widely covered in the literature. [52] examined the integration of metaverse-enabled telesurgery with blockchain and explainable AI, demonstrating the potential of these technologies in surgical applications. In the field of advanced AI applications, [53] developed a weighted federated deep extreme machine

learning model for lung cancer prediction, demonstrating the potential of this technology in clinical applications. The IoMT dimension of Healthcare 5.0 is also one of the important research areas. [11] presented a new framework on security and energy optimization for medical IoT, while [54] investigated IoMT-based disease prediction systems powered by transfer learning. [55] examined Healthcare 5.0 from the perspective of consumer-oriented IoT-based fog/cloud computing and examined the user-oriented dimension of the system. [56] emphasizes that this transformation in Healthcare 5.0 is especially evident in federated systems supported by AI and deep learning systems. As articulated by [57], these systems enable the establishment of a secure and distributed healthcare ecosystem. Furthermore, this literature analysis reveals Healthcare 5.0's multidimensional and interdisciplinary structure, emphasizing the significance of fundamental aspects such as security, efficiency, accessibility, and sustainability.

As a result, Healthcare 5.0 has the potential to change healthcare delivery, improve patient outcomes and become part of Industry 5.0 by considering a more patient-centered, personalized and preventive healthcare approach [58]. Healthcare 5.0's personalized medicine can provide more effective treatments and better patient outcomes by tailoring medical treatments based on a patient's specific genetic makeup and medical history. With wearable sensors and AI algorithms, Healthcare 5.0 can offer more advanced diagnostic tools, enabling earlier detection and better management of diseases. Healthcare 5.0 has the potential to facilitate patient-centered care wherein individuals assume more proactive roles in their health management.

In essence, the inherently human-centric architecture of healthcare services, coupled with Industry 5.0's vision of synthesizing technological advancement with human capabilities, establishes an optimal framework for the evolution of the Healthcare 5.0 paradigm. Although Industry 5.0 and Health 5.0 are based on common philosophical foundations, they contain similarities and differences in terms of their application areas and operational contexts. Both paradigms are shaped around three fundamental principles – human-centeredness, sustainability, and resilience – in addition to the technological capabilities offered by previous technology-centric approaches. However, these concepts differ in terms of technological infrastructure, regulatory and ethical frameworks, and performance metrics. In terms of technological infrastructure, Industry 5.0 focuses on production robots and automation systems, while Health 5.0 prioritizes medical devices and patient monitoring systems. Regarding regulatory and ethical frameworks, Industry 5.0 is guided by industrial standards and occupational safety regulations, while Health 5.0 is shaped by health-focused regulations such as patient privacy, medical ethics, and clinical approval processes. In terms of performance metrics, Industry 5.0 measures success through production efficiency, employee satisfaction, and environmental impact reduction, while Health 5.0 evaluates effectiveness through patient outcomes, care quality indicators, and treatment accessibility.

### 3. Research design and methodology

Although the bibliometrics method emerged in the 1900s, it became conceptually widespread in the 1970s. This method, which has become an important tool in the evaluation of scientific knowledge, was defined by Pritchard [59] as 'the application of statistical and mathematical methods to books and other communication media'.

Bibliometric analysis enables the examination of primary level analyses of scientific publications or documents such as the number of authors, citations, journals, and subjects, and secondary level analyses, including the creation of matrices using this information, through statistics and quantitative analysis [60]. In addition, bibliometric research is based on analyzing certain characteristics of the content of documents or publications and obtaining various findings on scientific communication [61].

In bibliometric studies, the most productive researchers on any subject are identified and the dimensions of the relationships between them are also analyzed. Since bibliometric studies clearly reveal the effectiveness of scientific publications, they enable the researcher to have an idea about the state of use of the literature or publication in question [62]. Koehler [63] classified bibliometric analysis approaches into four fundamental categories: citation analysis studies, co-citation analyses, institutional, national and individual productivity analyses, and analyses of scientific outputs (patents, articles, books, etc.). This classification systematically demonstrates the scope and focal points of bibliometric research and provides researchers with a clear framework for structuring their studies.

### 3.1. Data collection strategy

Database selection is critical for the methodological reliability of the research [64]. Since the study is an exploratory study, it is first necessary to decide on the database from which the data will be collected. Because there are many academic databases with various scopes and data sets in many different fields. The scope of these databases can vary from national publications of countries to the compilation of publications specific to certain disciplines. Therefore, as a result of the literature review, databases such as Web of Science, Scopus, Pubmed and Google Scholar, which contain many scientific publications, were examined. Studies have indicated that both Scopus and WoS databases are frequently utilized due to their comprehensive coverage and accessibility to well-structured datasets suitable for analysis [12, 13, 15].

In this study, Scopus, which is a comprehensive database in terms of both content and metadata, was preferred. Four main criteria were effective in choosing Scopus [14, 15, 65]: (1) it is one of the largest peer-reviewed databases covering multidisciplinary research publications, (2) it provides easy access to reputable journals in economics, business, health and engineering, (3) it has advanced search features and allows for the export of bibliographic data, (4) it contains more articles relevant to the research topic compared to Web of Science.

The fact that Scopus has a wider scope of resources than Web of Science is especially important for an emerging research area such as Healthcare 5.0 [66]. [67] assert that 'broader coverage is beneficial for mapping smaller research fields.' This is because the first publications on new concepts can often be published outside the core journals of a field. This is because the first publications on new concepts can often be published outside the core journals of a field. Although Web of Science has a longer historical coverage than Scopus, this factor was not considered in the study due to Healthcare 5.0's relatively brief history. In addition, Scopus' broad coverage of health sciences and publications at the intersection of technology and health enabled a comprehensive examination of Healthcare 5.0.

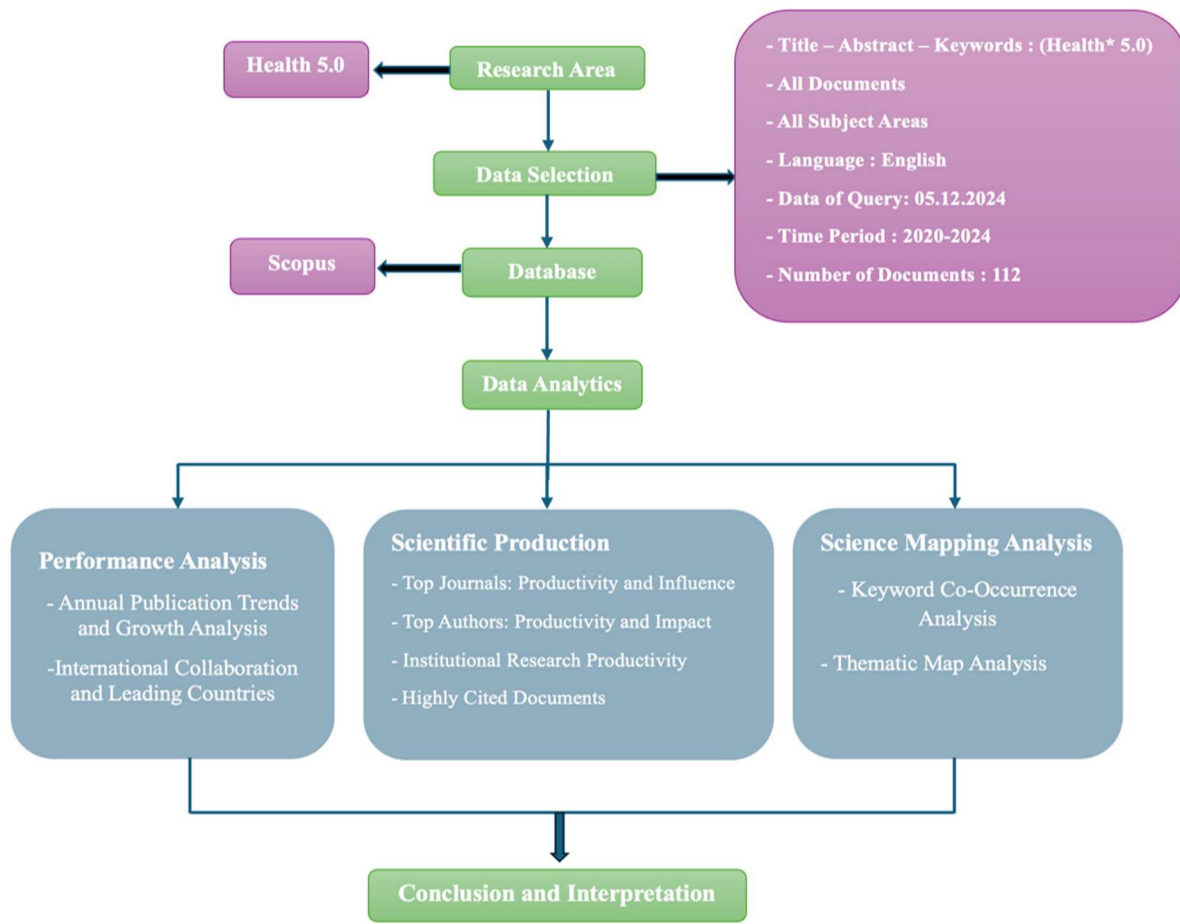
### 3.2. Database selection and search protocol

For the clarity of the research scope, only 'Health\* 5.0' was used as the search term. All documents in which this term was mentioned in the 'Abstract, Article title, Keywords' were included in the scope of the research. This selection was made due to Healthcare 5.0 being an emerging concept and the ambiguity of potential synonymous terms. It was anticipated that a broader search strategy would risk deviating from the focal point of the research. Given the currently limited number of publications on Healthcare 5.0, an inclusive approach was adopted, incorporating all research domains and source types into the evaluation.

The timeframe of the research was determined by taking into account the simultaneous development process of Healthcare 5.0 and Industry 5.0. In this context, two virtual workshops organized by the European Commission on July 2-9, 2020, where the conceptual framework of Industry 5.0 was formally shaped, were taken as reference points [3]. This founding workshop, attended by research institutions, technology organizations and funding agencies across Europe, represents the institutional inception of Industry 5.0 and thus provides a logical starting point for the examination of its specific reflection in the field of health, Healthcare 5.0. The research period was established as 2020-2024. To emphasize the cross-sectional nature of the research, it is specifically noted that the data collection process was conducted on December 5, 2024. Figure 4 shows the research design and the data collection process used.

The methodological framework and data analysis process of the study are systematically depicted in Figure 4. The research process encompasses four principal phases: (1) Data collection and selection, (2) Database selection, (3) Data analysis, and (4) Interpretation of findings. In the initial phase, publications within the Healthcare 5.0 domain were systematically screened in accordance with predetermined criteria (2020-2024 period, English-language publications, all document types and subject domains). In the second stage, Scopus database was preferred for a comprehensive and reliable analysis. The third stage, data analysis, was carried out in three processes: Performance Analysis, Scientific Analysis and Science Mapping. In the last stage, the findings obtained from all these analyses were integrated and the results obtained were evaluated.

The various considerations and choices are summarized in Figure 4. As can be seen, the following search query was used: TITLE-ABS-KEY ('Health\* 5.0') AND PUBYEAR > 2019 AND PUBYEAR < 2025 AND



**Figure 4.** Research design and data collection process.

(LIMIT-TO (LANGUAGE, 'English')). In other words, the search was for documents with the term 'Health\* 5.0' in the article title, abstract or keywords between 2020 and 2024. English publications were preferred as the language criterion and the types of academic publications were included in the analysis. Within this methodological framework, the primary objective of the research is to analyze the intellectual structure of Healthcare 5.0 from the perspective of conceptual relationship networks and to systematically demonstrate its chronological development.

VOSviewer software version 1.6.20 and the bibliometrix library were utilized for the visualization and mapping of bibliometric data. Developed by Nees Jan Van Eck, VOSviewer is a Java-based program that enables relational analysis and visualization of bibliometric data. Bibliometrix is an open-source bibliometric analysis package operating in the R environment. Developed by Massimo Aria and Corrado Cuccurullo, this package provides a user-friendly structure through its web-based interface, Biblioshiny. Both visualization tools were adopted in this research owing to their compatibility with prominent bibliometric databases such as Scopus and Web of Science, comprehensive analytical capabilities, open-source availability, and intuitive user interface.

### 3.3. Data processing and analysis framework

Following data acquisition, the process proceeds to the data organization phase. The majority of these errors stem from insufficient organization of analyzed elements or errors originating from the data source. These errors are minimized through data organization, including the elimination of data duplications, correction of incorrect entries, and standardization of differently written terms [68]. Consequently, to ensure data accuracy, the acquired data necessitates preprocessing and revision prior to conducting bibliometric analyses [18].

**Table 1.** Summary of bibliographic information (Source: Bibliometrix using data from Scopus).

DESCRIPTION	RESULTS
MAIN INFORMATION ABOUT DATA	
Timespan	2020:2024
Sources (Journals, Books, Etc)	87
Documents	112
Annual Growth Rate %	77,83
Document Average Age	1,04
Average Citations Per Doc	12,62
References	5033
DOCUMENT CONTENTS	
Keywords Plus (Id)	798
Author's Keywords (De)	311
AUTHORS	
Authors	381
Authors Of Single-Authored Docs	8
AUTHORS COLLABORATION	
Single-Authored Docs	8
Co-Authors Per Doc	3,99
International Co-Authorships %	40,18
DOCUMENT TYPES	
Article	44
Book	2
Book Chapter	24
Conference Paper	33
Conference Review	2
Editorial	1
Note	1
Review	5

### 3.4. Methodological limitations

This study inherently encompasses certain limitations due to the nature of bibliometric analysis methodology. Primarily, the research solely comprises publications indexed in the Scopus database. This circumstance results in the exclusion of publications available in other databases or those not indexed in academic databases. Secondly, the search strategy was limited to the term 'Health\* 5.0,' potentially excluding studies that express the concept using different terminology. Thirdly, only English-language publications were included, with publications in other languages being excluded from the scope. Fourth, owing to the cross-sectional nature of the research, studies published subsequent to December 5, 2024, were not incorporated into the analysis. Table 1 presents fundamental statistics pertaining to the employed methodology.

## 4. Results

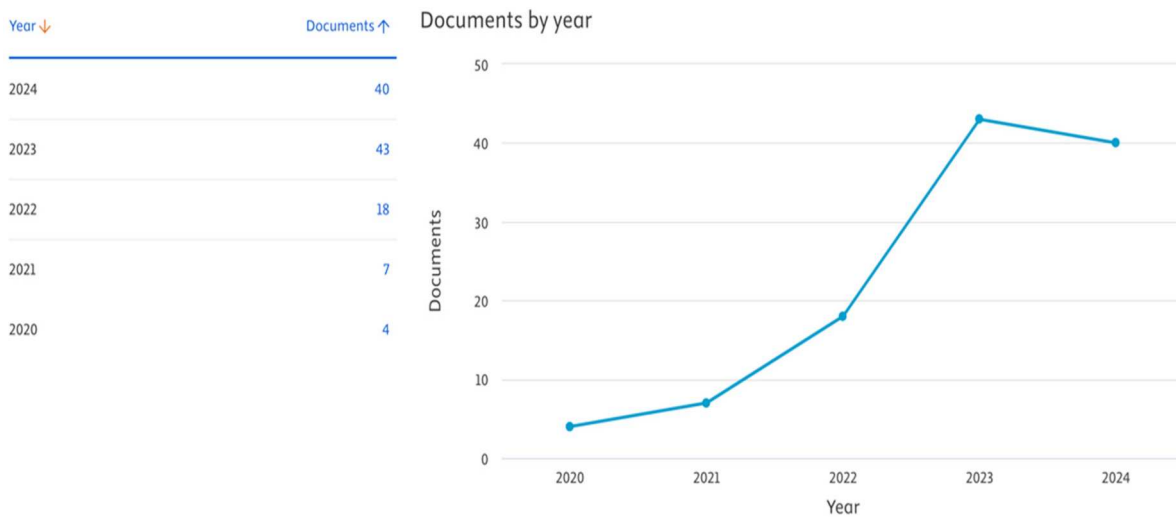
Three main bibliometric approaches were used to systematically analyze the scientific structure of the Healthcare 5.0 field. First, within the scope of performance analysis, annual publication trends, growth analysis and international collaboration structures were examined. Second, under the scientific production analysis, the most influential journals, authors, institutions and highly cited studies were evaluated. Finally, within the framework of scientific mapping analysis, keyword co-occurrence networks and thematic map analysis were conducted to reveal the conceptual structure and research trends of the field. The findings obtained through this three-dimensional analysis approach are presented in detail under the following headings.

### 4.1. Performance analysis

#### 4.1.1. Annual publication trends and growth analysis

The results of the annual analysis showing the publication trends in the field of Healthcare 5.0 are presented in Figure 5.

According to the data obtained from the Scopus database, a total of 112 scientific publications were identified between 2020-2024. Scientific production in the field of Healthcare 5.0 has shown a remarkable



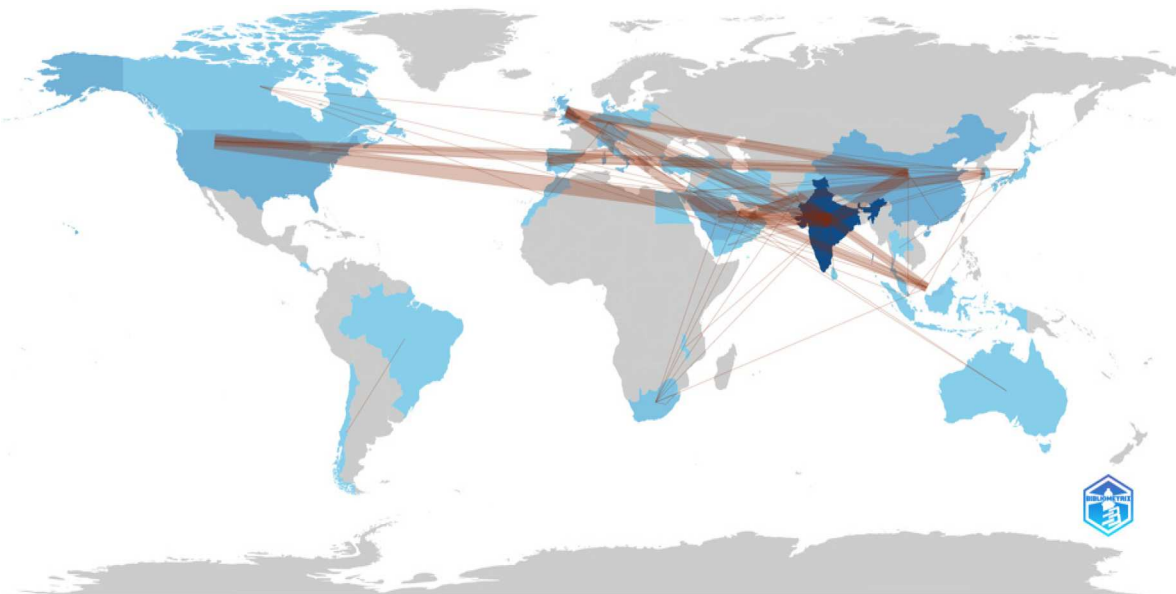
**Figure 5.** Annual publication trends and growth analysis.

increase, especially since 2022. The lowest number of publications was recorded in 2020 ( $n = 4$ ), while the highest number of publications was recorded in 2023 ( $n = 43$ ). Especially in the period 2022-2023, the peak was reached with an increase of 138.8% in the number of publications. Two distinct periods can be observed in this development process: The initial period between 2020–2021 and the rapid growth period between 2022-2024.

#### 4.1.2. International collaboration and leading countries

The results of the analysis of international cooperation networks in the field of Healthcare 5.0 are presented in Figure 6. On the map, the blue colored areas represent the cooperating countries and the lines represent the cooperation links. The thickness of the lines indicates the intensity of cooperation.

As seen Figure 6, the map demonstrates a broad geographical distribution of international research collaborations, with India exhibiting the most intensive collaborative network (indicated by dark blue). Following India, the United States and the United Kingdom demonstrate strong collaborative linkages. Among European countries, an intensive collaboration network has been observed particularly between the United



**Figure 6.** Map of scientific cooperation between countries (Source: Bibliometrix using data from Scopus).

Kingdom, Germany, and Italy. Southern hemisphere countries such as Australia and South Africa have also been incorporated into the research network, albeit with comparatively lower collaboration intensity. In the Asia-Pacific region, there exists a distinct collaboration network among China, South Korea, and Japan. The data derived from the mapping indicates that Healthcare 5.0 research is conducted on a global scale, yet collaboration networks are concentrated in specific regions. The analysis results demonstrating countries' scientific productivity and collaboration metrics in the Healthcare 5.0 domain are presented in [Table 2](#).

The results of the analysis in [Table 2](#) show that these countries play a central role in the international collaboration network in the field. Accordingly, India is the most productive and most cited country in the field with 50 documents and 678 citations. Although the number of publications ( $n = 5$ ) of South Africa was relatively low, it was found to have the second highest number of citations with 373 citations. Similarly, the United Arab Emirates achieved the third highest impact level with 251 citations from 6 documents. When examining Total Link Strength values, South Africa (43), India (31), and the United States (18) emerge as the countries with the highest collaborative connection strength.

## 4.2. Scientific production

### 4.2.1. Top journals: Productivity and influence

The results of the analysis showing the productivity and impact levels of journals in the field of Healthcare 5.0 are presented in [Table 3](#).

According to the analysis results in [Table 3](#), Federated Learning and AI for Healthcare 5.0 is the most productive journal with 10 publications. This journal is followed by IEEE Access with 5 publications and IEEE Internet of Things Journal and Lecture Notes in Networks and Systems with 3 publications each, while other journals contribute with 2 publications.

### 4.2.2. Top authors: Productivity and impact

Temporal analysis of the scientific productivity and citation impact of researchers in the field of Healthcare 5.0 is presented in [Figure 7](#) and [Table 4](#).

**Table 2.** The 10 countries that have documented the most on healthcare 5.0 work (Source: VOSviewer using data from Scopus).

Country	Documents	Citations	Total Link Strength
<i>India</i>	50	678	31
<i>China</i>	12	175	6
<i>United States</i>	11	116	18
<i>Saudi Arabia</i>	10	130	4
<i>Portugal</i>	8	37	9
<i>United Kingdom</i>	8	33	3
<i>Italy</i>	7	17	6
<i>United Arab Emirates</i>	6	251	3
<i>South Africa</i>	5	373	43
<i>Germany</i>	5	134	1

**Table 3.** Top ten most productive journals publishing on healthcare 5.0 (Source: Bibliometrix using data from Scopus, Publication Year (PY), Number of Publications (NP), Total Citations (TC)).

Source	NP	h_index	TC	g_index	m_index	PY_start
Federated Learning and AI for Healthcare 5.0	10	2	10	2	1	2023
IEEE Access	5	4	273	5	1.33	2022
IEEE Internet of Things Journal	3	1	4	2	1	2024
Lecture Notes in Networks And Systems	3	1	4	2	0.5	2023
IEEE Transactions on Industrial Informatics	2	2	143	2	0.66	2022
Computers in Biology and Medicine	2	1	114	2	0.33	2022
Expert Systems	2	1	3	1	0.5	2023
IFIP Advances in Information and Communication Technology	2	1	1	1	0.5	2023
Proceedings of the 2022 International Conference On Computer, Information and Telecommunication Systems, Cits 2022	2	1	47	2	0.33	2022
Smart Innovation, Systems And Technologies	2	1	4	2	0.5	2023

When the number of publications (the size of the blue dots) and the total number of citations per year (the length of the line) of the authors are analyzed in Figure 7, different levels of productivity and impact are observed. Tanwar Sudeep, Bhattacharya Prosanta and Gupta Rajesh are the prominent researchers in the productivity analysis of the authors. In terms of productivity, it was found that the majority of the authors were active in the period 2022-2023.

According to the analysis results obtained from Table 4, Tanwar Sudeep (Nirma University) is the most influential researcher in the field with 473 citations, 7 h-index and 9 g-index values. Bhattacharya Prosanta (Amity University) ranks second with 234 citations, 3 h-index and 5 g-index. Gupta Rajesh (University of California) ranks third with 189 citations, 5 h-index and 6 g-index.

In terms of total number of publications (NP), Tanwar Sudeep stands out as the most productive researcher with 9 publications. When the institutional distribution of researchers is analyzed, it is seen that Nirma University in India is represented with three researchers, followed by the University of Johannesburg in South Africa with two researchers.

#### 4.2.3. Institutional research productivity

The results of the analysis showing the research productivity of institutions in the field of Healthcare 5.0 are presented in Figure 8.

Within the information in Figure 8, 'Nirma University' stands out as the most productive institution with 21 publications in the research productivity of institutions in the field of Healthcare 5.0. This is followed by 'Imam Abdulrahman Bin Faisal University' with 12 publications and 'University College London' with 11

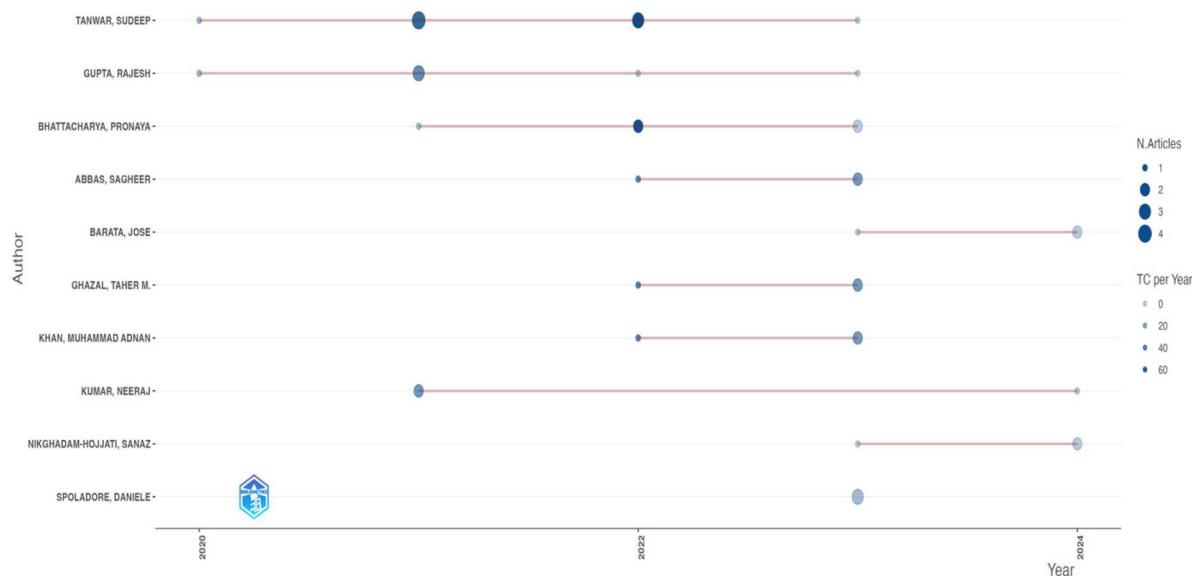
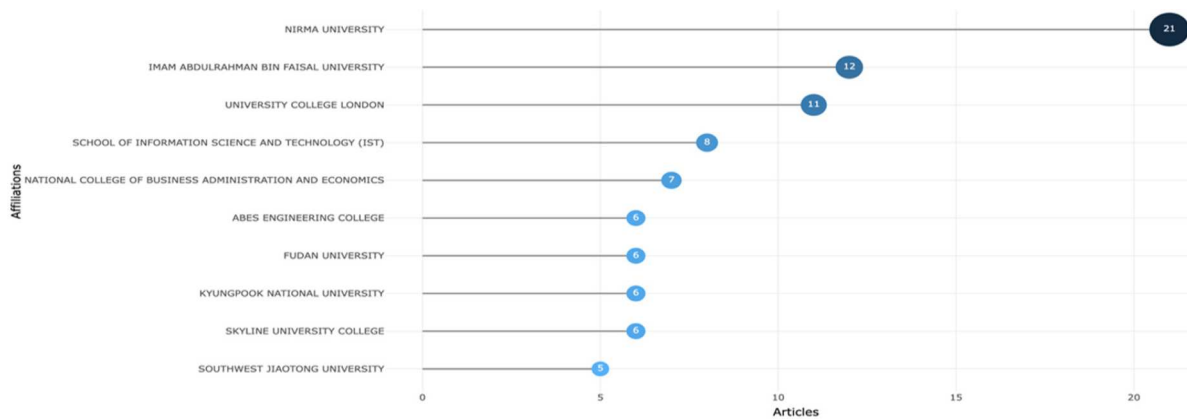


Figure 7. Author productivity over time (Source: Bibliometrix using data from Scopus).

Table 4. Most cited authors and metrics (Source: Bibliometrix using data from Scopus).

Author	Current Affiliation	Country	TC	H	G	M	NP	Year
Tanwar, Sudeep	Nirma University	India	473	7	9	1.4	9	2020
Bhattacharya, Pronaya	Amity University	India	234	3	5	0.75	5	2021
Gupta, Rajesh	University of California	USA	189	5	6	1	6	2020
Abbas, Sagheer	Prince Mohammad bin Fahd University	Saudi Arabia	167	3	3	1	3	2022
Ghazal, Taher M.	Applied Science University	Saudi Arabia	167	3	3	1	3	2022
Khan, Muhammad Adnan	Gachon University	South Korea	167	3	3	1	3	2022
Bokoro, Pitshou N.	University of Johannesburg	South Africa	156	1	1	0.33	1	2022
Prasad, Vivek Kumar	Nirma University	India	156	1	2	0.33	2	2022
Saraswat, Deepti	Nirma University	India	156	1	1	0.33	1	2022
Sharma, Gulshan	University of Johannesburg	South Africa	156	1	1	0.33	1	2022



**Figure 8.** Top 10 most prolific organizations on healthcare 5.0 2020–2024 (Source: Bibliometrix using data from Scopus).

publications. ‘School of Information Science and Technology (IST)’ ranks fourth with 8 publications, while ‘National College of Business Administration and Economics’ ranks fifth with 7 publications. ‘ABES Engineering College’, Fudan University, ‘Kyungpook National University’ and ‘Skyline University College’ share the same productivity level with 6 publications each. ‘Southwest Jiaotong University’ completes the list with 5 publications.

#### 4.2.4. Highly cited documents

The results of the analysis of the most cited studies in the field of Healthcare 5.0 are presented in Table 5. Table 5 includes the imprint information, title and summary content of each study. These studies address the conceptual framework, technological components and application areas of Healthcare 5.0 from different perspectives.

### 4.3. Science mapping analysis

#### 4.3.1. Keyword co-occurrence analysis

Co-word analysis is an effective bibliometric method used to reveal conceptual relationships and research patterns in scientific publications. [72], this analysis technique reveals networks of relationships between concepts by examining the frequency with which keywords co-occur in a publication. This method both measures the strength of the connections between concepts and visualizes a holistic network structure of the relevant research area. The results of the co-occurrence network analysis of keywords in the field of Healthcare 5.0 are presented in Figure 9. The findings of the analysis reveal a network structure consisting of five main clusters with 152 elements, 458 links and 514 total link strengths.

When the inter-cluster connections are analyzed, it is seen that especially ‘healthcare 5.0’ and ‘blockchain’ nodes are in intense interaction with other clusters. In the first cluster (blue), a structure centered on ‘healthcare 5.0’ is observed and includes concepts such as 5G technology, health 4.0, health operators, cyber security awareness, data breaches and aging. This cluster focuses specifically on the operational aspects of health technologies. The second cluster (red) centers on ‘blockchain’ technology and covers concepts such as AI, machine learning, federated learning, digital health and IoT. This cluster represents the key technological components of digital transformation. The third cluster (green) is centered around ‘industry 5.0’ and includes the concepts of digital manufacturing, sustainability and manufacturing 5.0. This cluster emphasizes industrial transformation processes. The fourth cluster (purple) focuses on ‘security’ and ‘privacy’ concepts, encompasses terms related to smart contracts and security protocols, and concentrates on security and privacy issues. The fifth cluster (yellow) centers on ‘deep learning,’ amalgamating concepts of explainable AI, telesurgery, and smart healthcare services, thus representing advanced AI implementations.

The network map in which the concepts are handled in a temporal context and the terms frequently used according to time are visualized with colors is shown in Figure 10. The network map showing the temporal

**Table 5.** Analysis of the most cited studies in healthcare 5.0 (2020–2024).

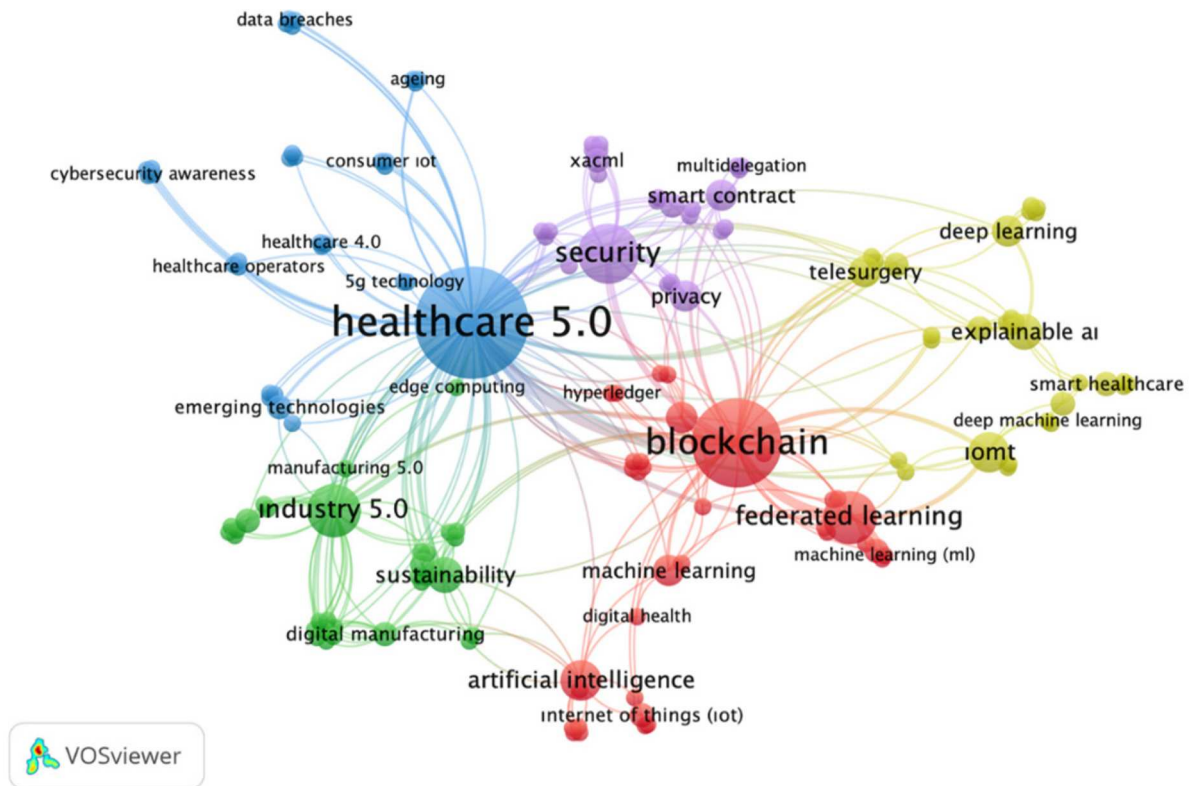
Paper (First Author, Journal, Year)	Article Title	Summary of the Study
Saraswat D., IEEE Access, 2022 [50]	Explainable AI for Healthcare 5.0: Opportunities and Challenges,	The study aims to examine the requirements and operational processes of explainable AI (EXAI) applications in Healthcare 5.0. The research methodology combines a systematic literature review and case study approach. An EXAI-based architecture has been proposed for computerized tomography image classification and segmentation, and an integrated case study incorporating federated learning for electrocardiogram (ECG) monitoring has been conducted. The key findings of the study show that EXAI brings transparency to predictive analysis in healthcare and builds trust in clinical decision-making processes. The empirical results from the case study reveal that the proposed EXAI approach offers an effective solution for various clinical applications in healthcare organizations. The research also documented challenges faced in the realization of Healthcare 5.0, such as operational procedures, verifiability of predictive models and lack of ethical framework.
Mbunge E., Global Health Journal, 2021 [69]	Sensors and healthcare 5.0: transformative shift in virtual care through emerging digital health technologies	It aims to examine the transformative role of sensor technologies in virtual healthcare in the context of Healthcare 5.0 and identify opportunities and challenges in this area. The research analyzed the development and applications of digital health technologies during the COVID-19 period through a systematic literature review methodology. The primary findings of the study demonstrate that the transition from paper-based processes to digital technologies in healthcare systems proved critically important, particularly during the pandemic period. Research findings demonstrate that Healthcare 5.0 is orchestrating a fundamental paradigm shift in multiple domains: intelligent disease surveillance, virtual care delivery, advanced health management systems, and precision medicine. However, it has been identified that factors such as organizational challenges, technological and infrastructural barriers, lack of legal framework, insufficient funding, and religious and cultural barriers affect the successful implementation of Healthcare 5.0.
Rehman, A., Computers in Biology and Medicine, 2022 [51]	A secure healthcare 5.0 system based on blockchain technology entangled with federated learning technique	It aims to develop a secure healthcare monitoring system that integrates blockchain technology and federated learning techniques in Healthcare 5.0. Methodologically, using blockchain technology and Intrusion Detection System (IDS), a system is designed that performs patient tracking and disease prediction with medical sensors. The system combines a federated learning approach with blockchain technology to ensure security and privacy in Internet of Medical Things (IoMT) networks. The main findings show that the proposed system achieves 93.22% accuracy in disease prediction. The RTS-DELM based secure healthcare 5.0 system achieved 96.18% accuracy in intrusion detection. As a result, the proposed system provided an effective optimization in healthcare monitoring and performed well in terms of both disease prediction and safety with high accuracy rates.
Bhavin M., Journal of Information Security and Applications, 2021 [8]	Blockchain and quantum blind signature-based hybrid scheme for healthcare 5.0 applications	It aims to improve the security of electronic health records (EHR) in the healthcare ecosystem. Within the scope of the research, existing EHR security architectures were analyzed and Quantum Computing was applied to traditional encryption systems. Methodologically, the study focuses on developing a role-based architecture using quantum blind signatures on the Hyperledger Fabric blockchain infrastructure. The main findings of the research revealed that the proposed system outperforms existing systems in terms of resource consumption, throughput and network traffic parameters. As a result of the study, it was determined that the hybrid structure using blockchain-based and quantum blind signature offers an effective solution for data security and privacy protection in EHR systems.
Zhang J., IEEE Transactions on Industrial Informatics, 2022 [70]	An Efficient Blockchain-Based Hierarchical Data Sharing for Healthcare Internet of Things.	It aims to develop a blockchain-based hierarchical data sharing framework (BHDSF) for the Healthcare Internet of Things (H-IoT) in the Healthcare 5.0 ecosystem. The study uses blockchain technology to secure personal health records (PHRs) against untrusted cloud systems and malicious auditors. The BHDSF framework is designed to provide hierarchical key distribution and fine-grained access control over encrypted PHRs. Methodologically, experimental tests were performed on a real-world dataset. The results show that BHDSF is effective in PHR integrity checking, metadata verification and batch authentication of source records from H-IoT devices. As a result, it is found that the BHDSF framework

*(Continued)*

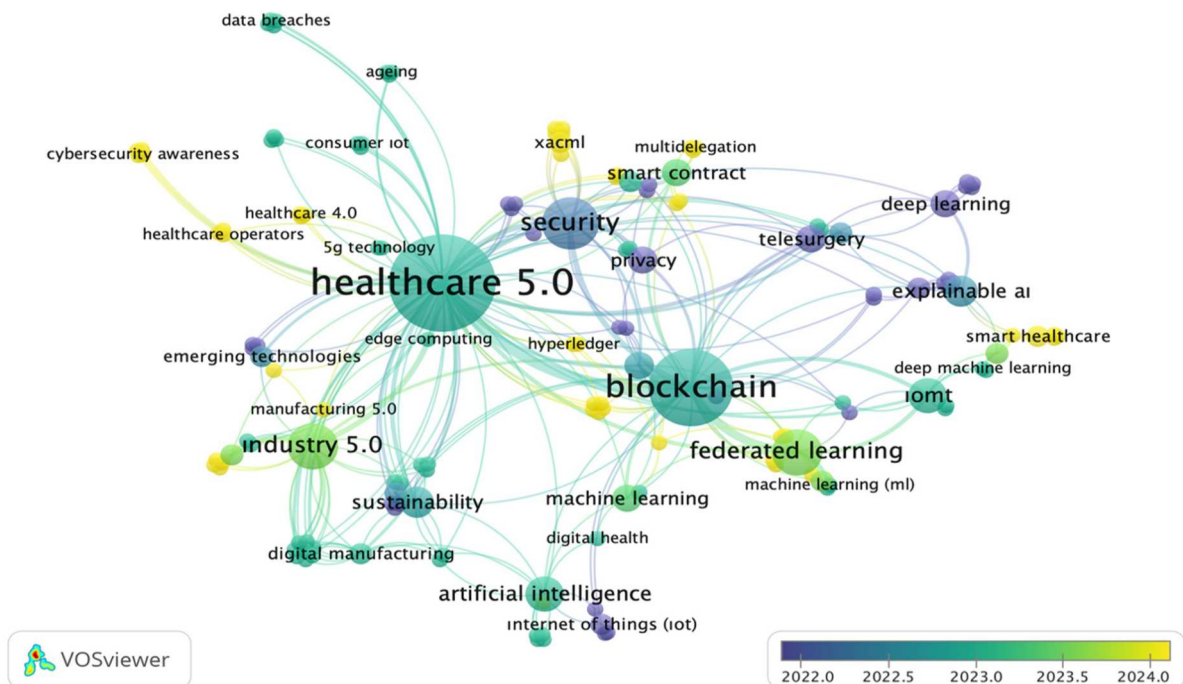


Table 5. Continued.

Paper (First Author, Journal, Year)	Article Title	Summary of the Study
<b>Gomathi L., 7th International Conference on Trends in Electronics and Informatics, 2023 [29]</b>	Industry 5.0 for Healthcare 5.0: Opportunities, Challenges and Future Research Possibilities	provides low-consumption key distribution and key leakage resistance, and offers a more comprehensive approach in terms of security and efficiency compared to existing solutions. It aims to examine the current status, opportunities, challenges and future research opportunities of Healthcare 5.0, the application of Industry 5.0 in the health sector. The research methodology is based on a literature review and includes a systematic analysis of studies on Industry 5.0 and Healthcare 5.0. The main findings of the study are summarized under four main headings: (1) the potential of Healthcare 5.0 in personalized medicine, advanced diagnostics and telemedicine, (2) the applications of AI, blockchain, big data analytics and robotics in healthcare, (3) the integration of patient-centered care approaches with technology, and (4) the role of human-machine collaboration in healthcare. The research results reveal that key challenges such as data security, privacy, ethical and legal issues, training of healthcare professionals, and cost-effectiveness need to be addressed for successful outcomes of Healthcare 5.0.
Taimoor N., IEEE Access, 2022 [71]	Reliable and Resilient AI and IoT-Based Personalised Healthcare Services: A Survey.	It has conducted a comprehensive literature review aiming to examine personalized healthcare shaped by technological developments such as IoT and 5G. The methodology of the study is based on the analysis of AI/machine learning based and non-AI based systems using a three-tier architecture approach. The key findings of the research revealed that existing personalized health services are specific to particular settings and fail to holistically assess interrelated health conditions. Different security threats were identified at each layer of the IoT architecture and AI-based and non-AI-based solutions were identified to address these threats. As a result of the study, a new methodology for reliable, flexible and personalized healthcare services is proposed to overcome the identified shortcomings and the contribution of this methodology to the development of Healthcare 5.0 technology is stated.
<b>Bhattacharya P., Proceedings of the 2022 International Conference on Computer, Information and Telecommunication Systems, CITS, 2022 [52]</b>	Metaverse assisted Telesurgery in Healthcare 5.0: An Interplay of Blockchain and Explainable AI	It aims to examine the integration of blockchain and explainable AI technologies in metaverse-enabled telesurgery systems in the context of Healthcare 5.0. As a methodological approach, a telesurgery scheme involving the interaction between patients, virtual hospitals and doctors was designed and analyzed through an experimental use case. The main findings of the study revealed that blockchain technology ensures transparency and immutability in transactions stored on the metaverse, while explainable AI provides reliable and interpretable diagnoses in clinical decision support processes. As a result of the research, it was determined that the proposed blockchain and explainable AI integration offers a more effective solution for patient data security and clinical decision support processes compared to traditional telesurgery systems.
Natarajan R., Infrastructures, 2023 [11]	A Novel Framework on Security and Energy Enhancement Based on Internet of Medical Things for Healthcare 5.0	It aims to improve the security and energy efficiency of IoMT platforms in the context of Healthcare 5.0. In this research, an elliptic curve cryptography-based energy efficient routing protocol (ECC-EERP) is developed to secure sensitive health data transmitted over wireless sensor networks. Methodologically, the encryption and decryption of web traffic has been performed using the ECC-EERP method using public and private key pairs. The findings of the study are evaluated in terms of security, encryption efficiency, energy efficiency, network lifetime, communication overload, computation time and implementation cost. Comparative analysis with existing methods shows that the proposed ECC-EERP protocol shows improved performance in terms of both security and energy efficiency.
Chi H.R., IEEE Transactions on Consumer Electronics, 2023 [55]	Healthcare 5.0: In the Perspective of Consumer Internet-of-Things-Based Fog/Cloud Computing	It aims to analyze the Healthcare 5.0 concept from the perspective of fog/cloud computing based Consumer Internet of Things (CIoT). Methodologically, a comprehensive vertical and horizontal analysis of the processes from Healthcare 1.0–4.0 and Industry 1.0–4.0 was carried out. The findings of the research provide a detailed review of the current state of Healthcare 4.0 and the role of fog/cloud computing, and predict the potential development of Healthcare 5.0 based on Industry 5.0. As a result of the study, the potential applications, opportunities and challenges of CIoT and fog/cloud computing technologies in Healthcare 5.0 have been revealed and a new era for the future of fog/cloud computing in healthcare system development has been initiated.



**Figure 9.** Network map created with co-word analysis (Source: VOSviewer using data from Scopus).



**Figure 10.** Network map showing temporal transition of keywords (Source: VOSviewer using data from Scopus)

transition of common words reveals the evolution of concepts in the Healthcare 5.0 domain between 2022 and 2024. The color scale ranges from 2022 (blue) to 2024 (yellow), indicating the timing of the introduction of the concepts into the literature.

In 2022 (shades of blue), key technological concepts such as blockchain, AI, IoT and digital health started to appear in the literature. In this period, advanced analytical approaches such as deep learning and explainable AI are also seen in studies. In 2023 (shades of green), the central position of Healthcare 5.0 became evident, and the concepts of 5G technology and sustainability gained importance. In this period, digital production and Industry 5.0 were also included in the literature. As we approach 2024 (shades of yellow), application-oriented concepts such as cybersecurity awareness, smart contracts and health operators have come to the fore. During this period, specific topics such as XACML, multi-authorization and smart healthcare were added to the research field. The temporal analysis shows that the field has evolved from basic technological infrastructure to application and security-oriented topics.

#### 4.3.2. Thematic map analysis

Thematic maps are significant analytical tools that reveal the visual and conceptual structure of research domains in bibliometric analyses. This approach, developed by [73], presents a four-quadrant matrix where themes are positioned according to their centrality and density values in a specific research field. The thematic map analysis was performed on the data obtained in this study and the resulting map is shown in Figure 11. This figure reveals the conceptual structure of the Healthcare 5.0 area.

Thematic map analysis shows that research themes in the field of Healthcare 5.0 are positioned in four regions according to their centrality (relevance degree) and intensity (development degree). The motor themes (upper-right quadrant) encompass mature and central themes of the field such as Healthcare 5.0, blockchain technology, and smart healthcare. These themes constitute the backbone of the field with their high centrality and high density values.

The basic themes (lower right quadrant) region contains Healthcare 5.0, blockchain, federated learning, and security themes. These themes, with high centrality but low density values, represent topics with developmental potential in the field. Specific research areas such as smart contract, wearable technology and digital healthcare are located in the niche themes (top left quadrant). These themes are characterized by low centrality but high intensity, with topics developing in specific sub-fields.

The emerging or declining themes (lower left quadrant) include concepts such as industry 5.0 and society 5.0. These themes have both low centrality and low intensity values, indicating immature or declining topics in the field. Themes such as IoMT, healthcare 5.0, sustainability, resilience and transfer learning, located in the central region of the map, represent research topics in transition.

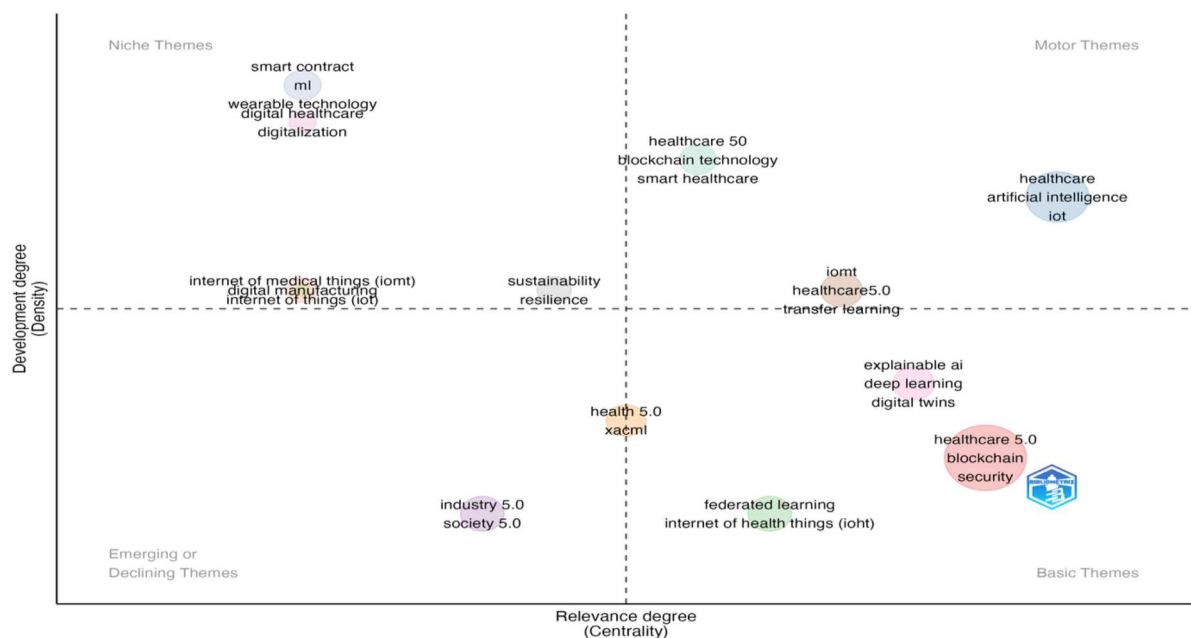


Figure 11. Thematic map (Source: Biblioshiny using data from Scopus).

## 5. Discussion

The bibliometric findings from this study reveal the development and intellectual structure of the Healthcare 5.0 research field since 2020. The results of the performance analysis show that the field has shown significant growth in the last five years and that there has been a remarkable increase in scientific production, especially in the period 2022-2023. This upward trend can be considered as an indicator that the field has entered the maturation process.

When analyzed at the country level, it is observed that Healthcare 5.0 research attracts global attention, but scientific production is concentrated in certain geographical regions. India's leading position in terms of both number of publications and citation impact reflects the importance the country attaches to digital health technologies. South Africa's high citation impact despite its low number of publications emphasizes the importance of quality research outputs. The global research collaboration structure appears to have developed on three different axes. The Asian axis, led by India and China, is the most comprehensive and technology-focused cooperation network, while the second axis, in which the United Kingdom and Saudi Arabia play a central role, includes efforts to integrate the health systems of the Europe-Middle East axis. The third axis, shaped by the United States, Portugal and South Africa, offers an intercontinental model of cooperation focusing on innovative practices. This complex network structure reveals that the Healthcare 5.0 field is developing on a global scale and that research centers are emerging in different regions. Intense interactions between clusters point to the integrated and dynamic structure of the field, and show that knowledge and experience sharing is taking place on a global scale.

Journal-based analysis reveals the interdisciplinary nature of the field. While the predominance of technology-oriented journals such as IEEE Access and IEEE Internet of Things Journal shows the strong technological foundation of Healthcare 5.0, the increasing interest of medical and health sciences journals in the field indicates that the topic is expanding towards clinical applications.

Author impact analyses have identified the pioneering researchers and institutional hubs of the field. The pioneering work of Tanwar Sudeep, Bhattacharya Prosanta and Gupta Rajesh has contributed to the theoretical foundations of Healthcare 5.0 and the expansion of its application areas. In particular, Nirma University was represented by more than one researcher, indicating that institutional centers of expertise are beginning to emerge.

The scientific mapping analysis, which shows how the conceptual structure and research priorities of Healthcare 5.0 have evolved, reveals that the field has developed a comprehensive research agenda, with five thematic clusters emerging from the common word analysis. The centrality of 'Healthcare 5.0' and 'blockchain' and their intense interaction with other clusters show that these technologies form the backbone of the field. This is in line with [71] findings on the transformative role of blockchain technology in healthcare. Temporal trend analysis shows that the field has undergone a significant conceptual evolution from 2022 to 2024. The fact that research focusing on basic technological infrastructure in 2022 is shifting towards application-oriented topics such as cybersecurity and smart contracts towards 2024 is an indication that the field is entering a maturation process. This development is in line with Gomathi et al.'s (2023) predictions for the security and application-oriented future of Healthcare 5.0.

The thematic map analysis reveals that the scientific development of the Healthcare 5.0 field has a dynamic structure consisting of several layers. One of the most striking findings is that key themes such as blockchain and security have high centrality values, signaling the future development potential of the field. This is in line with Healthcare 5.0's goal of building a trusted digital health ecosystem. The high intensity values of smart contracts and wearable technologies positioned in niche themes indicate that these areas tend to deepen in specific application areas. This finding indicates the diversification and specialization of Healthcare 5.0's practical applications. The positioning of Industry 5.0 and Society 5.0 concepts among emerging themes demonstrates that healthcare technologies are in the process of integration with broader societal and industrial transformations. The placement of themes such as sustainability and resilience in the transition zone suggests that these concepts will play a critical role in the future development of Healthcare 5.0.

Network analysis results demonstrate that Healthcare 5.0 has evolved as a multidisciplinary research domain across three fundamental dimensions: (1) technological infrastructure and systems, (2) security and privacy solutions, and (3) clinical applications. The emergence of India, China, and the USA as pioneering countries in this developmental process indicates that Healthcare 5.0 has established a global research

agenda. The high citation impact of journals such as IEEE Access and Global Health Journal reveals that the field is being addressed from both technological and health sciences perspectives. While pioneering researchers such as [50] and [70] focus on blockchain technology and AI applications, establishing the field's fundamental technological components, the works of researchers like [69] and [29] elucidate the challenges and opportunities confronting Healthcare 5.0. Notably, the increasing significance of security, privacy, and ethical considerations indicates that future research endeavors should be directed toward these domains. The thematic analysis results demonstrate a clear differentiation between the field's motor themes (AI, blockchain) and niche areas (clinical research), while the positioning of emerging technologies such as metaverse and quantum cryptography in the transition zone indicates future research opportunities.

## 6. Conclusions, limitations, and future research

In this study, the scientific structure of the Healthcare 5.0 domain has been comprehensively examined through bibliometric analysis methodology utilizing various visualization tools. The theoretical contributions of this study emerge in three fundamental areas. First, by systematically documenting the conceptual evolution of Healthcare 5.0, it has demonstrated the field's transition from a technology-centric approach to a human-centered paradigm. Second, by identifying the core components that constitute Healthcare 5.0's intellectual structure and the relationship networks between them, it has illuminated the field's scientific development. Third, by applying bibliometric analysis methodology to the Healthcare 5.0 domain, it has provided a methodological framework for future bibliometric studies.

The practical implications of the study indicate that the central position of Blockchain and AI technologies necessitates healthcare institutions to direct their digital infrastructure investments towards these domains. The increasing significance of security and privacy themes suggests that these issues should be prioritized in the digital transformation of healthcare services. Furthermore, the structure of international collaboration networks provides strategic roadmaps for inter-institutional knowledge transfer and experience sharing.

One of the primary limitations of this study is that the analysis encompasses only the Scopus database. Future research can be expanded to include different databases and may focus specifically on conducting in-depth analyses in areas that have not yet reached maturity, such as economics and collective intelligence.

Based on these bibliometric findings, future research directions should address critical gaps through specific research questions. The fundamental research questions are as follows:

'What socio-technical factors influence the adoption rate of Health 5.0 technologies in clinical settings?'

'How do blockchain-based health record systems affect patient trust and treatment compliance?'

In this context, future research directions particularly recommend researchers to focus on:

- Development and implementation of robust security and privacy protocols,
- Design and formulation of human-machine collaboration frameworks,
- Establishment of comprehensive ethical guidelines and frameworks,
- Standardization of regulatory frameworks.

The analyses conducted and findings obtained in this study provide both a comprehensive roadmap to guide the future development of Healthcare 5.0 and significant implications for researchers, practitioners, and policymakers regarding the sustainable development of the field.

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## Author contributions

Conceptualization, G.K.; methodology, G.K.; software, G.K.; formal analysis, G.K.; investigation, G.K.; research, G.K.; resources, G.K.; writing-original drafting, G.K.; visualization, G.K.; supervision, G.K. The author has read and accepted the published version of the article.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## Notes on contributor

*Lecturer Güler Koştı* received her M.Sc. in Health Management from İzmir Kâtip Çelebi University. She is currently a lecturer in the Department of Scientific Research Projects at Afyonkarahisar University of Health Sciences. Her research interests include health technology management and Health 5.0, with several publications in these areas.

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