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ANALYZING ARTIFICIAL NEURAL NETWORK ARTICLES WITH BIBLIOMETRIC MAPPING TECHNIQUE

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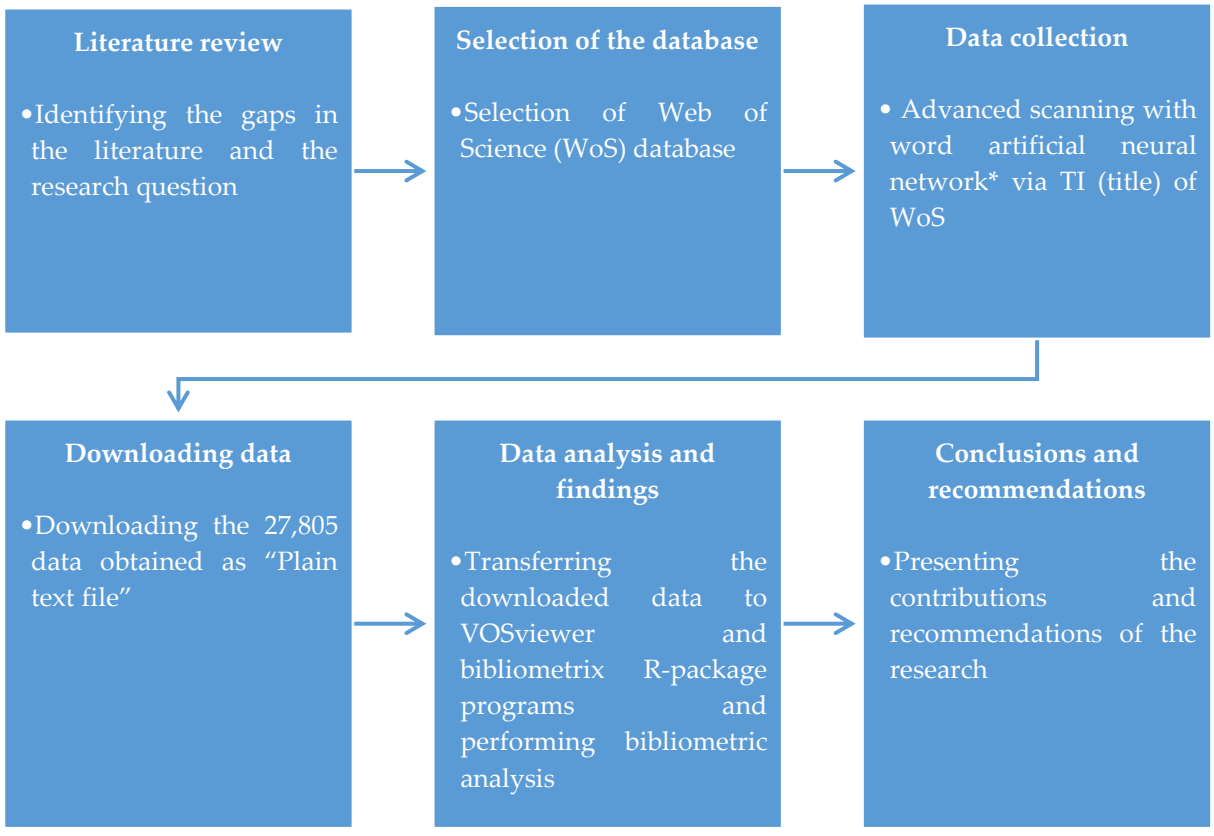
Highlights

- A comprehensive bibliometric analysis of articles on artificial neural network in Web of Science (WoS)
- Identifying the main trends neural network research
- Suggestions for future research directions in the field of artificial neural networks

Graphical Abstract



Flowchart of bibliometric research method

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ABSTRACT: The main purpose of this study is to reveal the general profile of artificial neural network articles published in the Web of Science (WoS) database through bibliometric analysis. Since it is an original study to examine the artificial neural network in the WoS database with bibliometric analysis method, it is extremely important in terms of guiding future research on the subject. In this context, 27,805 articles containing the word artificial neural network* in the TI (title) section of the WoS database were subjected to bibliometric analysis. The data obtained were analyzed in VOSviewer and bibliometrix R package program As a result of the analysis, it was determined that the articles titled artificial neural network were conducted between 1986-2024 as a result of the search in WoS. However, it has been concluded that there has been an increase in the number of articles on artificial neural networks in recent years. In conclusion, artificial neural networks have an important place in the academic literature. Therefore, further studies in this field are expected to make great contributions both theoretically and practically. In future research, it is suggested to perform bibliometric analysis on different databases related to artificial neural networks.

Keywords: *Artificial Neural Network, Bibliometrics, Sport*

1. INTRODUCTION

The human brain, with its superior cognitive abilities such as learning, problem-solving, pattern recognition, and decision-making, has been one of the most complex natural systems that has drawn the attention of scientists throughout history. Efforts to understand the workings behind this unique structure have evolved into not only biological but also mathematical and computational models. Particularly, mathematical models inspired by the neurophysiological structure of the brain laid the foundation for a new approach known as Artificial Neural Networks (ANNs) [1].

Artificial Neural Networks are defined as computer programs that mimic the learning process of the human brain and are capable of performing functions such as learning from various data, generalizing, recalling, and generating new information [2]. These technologies have been successfully applied in a wide range of fields, from production planning and healthcare services to meteorological forecasting and the automotive industry [3]. Due to their ability to handle complex and large data sets, ANNs have become indispensable in many fields, ranging from decision support systems to predictive models in today's information-intensive societies.

The rapidly developing literature on Artificial Neural Networks has created the need for researchers to systematically analyze the accumulated knowledge in this field. Bibliometric analysis, which evaluates scientific production through quantitative data, emerges as a powerful methodology to uncover trends, intellectual structures, and collaboration patterns within the literature. Bibliometric analysis helps to understand how research areas evolve over time, which topics have gained prominence, and identifies influential authors and collaborations, providing strategic directions for the field. In this regard, the number of bibliometric studies on Artificial Neural Networks is steadily increasing. However, most of the existing studies focus either on the general field of Artificial Intelligence or on specific application areas such as healthcare [4], agriculture [5], construction [6], and

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sports [7].

When reviewing bibliometric analyses on Artificial Neural Networks, it is evident that most of these studies rely on the Scopus database, while other important databases, such as Web of Science (WoS), are not sufficiently covered. In a study conducted using the "Current Contents/Life Sciences" and "Current Contents/Clinical Medicine" databases created by the Institute for Scientific Information (ISI), ANNs in the fields of medicine and biology published between 2000-2001 were analyzed. In this study, variables such as the number of articles, total impact factor, journal categories, country population, and gross domestic product were assessed. The five most productive countries were identified as the United States, the United Kingdom, Germany, Italy, and Canada, and the distribution of publications between the European Union and the United States, as well as the differences between clinical medicine and life sciences disciplines, were compared. In this regard, the study offers significant findings on the regional and thematic distribution of early ANN research [8]. However, it is observed that most recent bibliometric studies on ANNs are based on the Scopus database. These studies generally focus on fields like healthcare, agriculture, and construction or integrate ANNs into broader artificial intelligence frameworks. Study [9] conducted a Scopus-based analysis using the keywords "Artificial Neural Network and Machining". Study [10] analyzed ANN publications related to the construction sector using a search query in the Scopus database. Similarly, studies [11] and [12] also examined ANN publications published in Scopus in the context of general applications and offshore engineering, respectively. Study [13], although based on the ISI database, used broad keywords such as "neural net, neurofuzzy, Kohonen, Perceptron, Hopfield*," which did not provide an in-depth analysis specific to ANNs. Therefore, the number of studies conducting a comprehensive bibliometric analysis specifically focused on ANNs within the Web of Science (WoS) database is quite limited.

Therefore, while previous studies have generally focused on specific application areas such as healthcare, agriculture, construction, biology, and sports, this study does not limit its analysis to any particular domain. Instead, it aims to provide a holistic and interdisciplinary overview of ANN research. This methodological choice differentiates the study from the existing literature by revealing thematic developments and collaboration patterns across all scientific fields where ANN techniques are applied. As a result, the study not only identifies dominant themes and influential researchers but also highlights the interdisciplinary integration of artificial neural network research. In this context, there has been no bibliometric analysis conducted on ANN articles in the WoS database. Unlike previous studies, this research aims to fill a notable gap in the literature by conducting a comprehensive bibliometric analysis focusing solely on ANN-related articles indexed in the Web of Science (WoS) database. Given that WoS remains one of the most authoritative and widely recognized databases for citation-based analysis in scientific research, this represents a significant gap in the literature.

This study differentiates itself by focusing specifically on the ANN publications in the Web of Science (WoS) database. This approach enables a comprehensive, theme-specific, and data-source-specific analysis of ANN research, offering insights into publication trends, productive authors and institutions, collaboration patterns, citation networks, and conceptual structures derived through co-word analysis. Unlike previous studies with broader or more complex focuses, this study also uses advanced bibliometric analysis tools such as VOSviewer and Bibliometrix R to visualize co-authorship relationships, keyword co-occurrences, citation connections, and institutional collaborations in detail. This will not only provide a historical evaluation of ANN literature but also offer strategic insights for future academic trends.

Therefore, analyzing the ANN research in the WoS database through bibliometric analysis is of great importance for guiding future research on the subject. Bibliometric analysis serves as a powerful tool to examine academic trends, research intensity and impact, citation relationships, and collaboration networks through quantitative data. It is crucial for revealing how ANN research has evolved over time, identifying influential works, understanding which areas have garnered more interest, identifying key works with high citation impact, and determining emerging collaborations, thus developing strategic directions for future research

The primary aim of the current study is to conduct a detailed and thematic bibliometric analysis of the Artificial Neural Network (ANN) literature in the Web of Science (WoS) database. Given the high prestige and citation-based structure of WoS, a comprehensive ANN analysis based on this database has the potential to fill an important gap in the literature.

This study aims to fill an important gap in the literature by analyzing a previously underrepresented set of publications. How do the numbers of publications and citations evolve over the years? How are ANN publications distributed in terms of WoS scientific network categories, citation topics, and micro-citation topics? What are the most widely used publication languages in ANN literature? How has the thematic structure of the literature evolved, and which themes have emerged as prominent? Who are the most influential authors in the ANN field? Which institutions and countries stand out in this field? How are co-authorship and institutional collaboration networks structured? Which keywords have shaped the literature? What are the most frequently used sources? How do bibliometric network maps (author-keyword-institution-country-document-source relationships) created using VOSviewer and Bibliometrix R reveal the intellectual and structural evolution of ANN research?

The originality of this study lies in its comprehensive examination of the development and academic dynamics of ANN research in the WoS database, identifying gaps in the literature and uncovering future research opportunities. This study not only aims to understand the current state of the field but also seeks to identify new research opportunities and strategies in the field of artificial neural networks, highlight areas not yet sufficiently explored, and contribute to the literature. This research, by evaluating ANN publications in the WoS database, will both comprehensively reveal the current state of the field and highlight under-researched areas, making a significant contribution to the literature. In this regard, the study is methodologically and thematically significant and can guide future scientific research.

2. MATERIAL AND METHODS

Bibliometric analysis method was used as the data collection method of the study [14] Because bibliometric analyses enable the diversification of the information accessed and desired to be accessed in a field of science and provide more classified, easy and reliable access to information [15]. Therefore, bibliometric analysis is briefly defined as a method that contributes to measuring the effectiveness of scientific research by analyzing it [16]. In this context, a search was conducted using the word artificial neural network* in the TI (title) field in order to reveal the general profile of artificial neural network articles published in WoS. The bibliometric network mapping of WoS index, annual number of publications and citations, science network category, citation subject, micro-citation subject, publication language, FactorialMap, thematic map and author-common word-institution-country-document-resource of the obtained articles were analyzed using WoS, VOSviewer and bibliometrix R-package.

3. FINDINGS

In this section, after presenting the basic variables related to artificial neural networks, the findings obtained from VOSviewer and bibliometrix R package are presented.

3.1. Distribution by Basic Variables

In this section, findings on screen excerpt, annual number of publications and citations, science network category, citation topic, micro-citation topic, publication language and WoS index are presented.

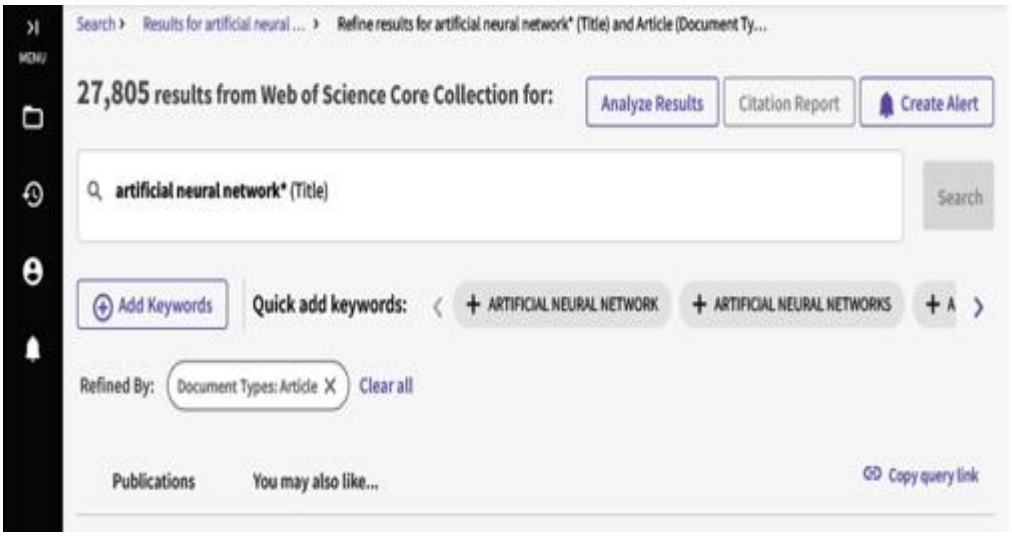

Figure 1. Screen excerpt

Figure 1 shows that bibliometric analysis was performed with 27,805 articles titled artificial neural network* in WoS.

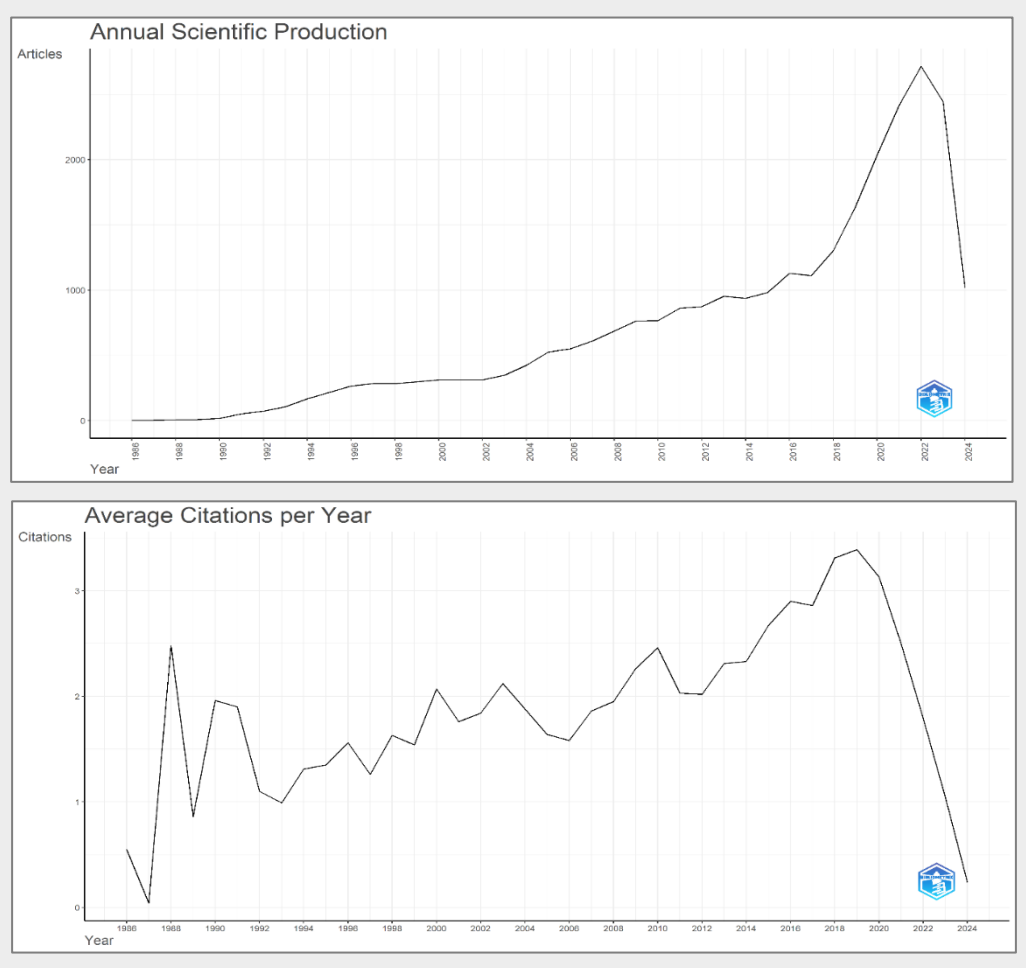

Figure 2. Annual number of publications and citations

As can be seen in Figure 2, the number of scientific publications on artificial neural networks in the Web of Science (WoS) database has shown a continuous increase since 1986. After the first article was

published in 1986, it is evident that the annual number of publications has steadily increased. Particularly after the 2010s, this growth accelerated significantly, with the number of publications reaching 2,034 in 2020, marking a substantial leap. The year 2021 saw a peak with 2,418 publications. This trend indicates a rapid increase in scientific production in the field of artificial neural networks and a growing interest in the topic. The citation count for artificial neural networks has also experienced a significant increase over the years. The year 2014 stands out as the peak year for citations. This peak can be attributed to several important factors: the growing applications of artificial neural networks in sectors such as healthcare, automotive, and agriculture, which fueled increased interest in research in this area. Additionally, 2014 marked a turning point with the introduction of new algorithms and technologies that enabled more efficient functioning of artificial neural networks. Major academic collaborations and institutional research in 2014 also contributed to the rise in citation counts.

However, after 2014, a decline in citation numbers was observed. This decline generally indicates a period when published studies offered less new information compared to previous research. Moreover, the increase in citations of earlier works has limited the citation potential of studies published after 2014. This suggests the beginning of a period in which newer publications receive fewer citations compared to studies conducted in earlier years.

Figure 3. Tree map of top 10 science network categories

As can be seen in Figure 3, artificial neural networks consist of science network categories such as “Engineering Electrical and Electronics”, “Computer Science Artificial Intelligence”, “Energy Fuels”, “Environmental Sciences”. The widespread presence of artificial neural networks across this broad range highlights the interdisciplinary nature of technology and research. These categories demonstrate the applicability of ANNs across a wide spectrum, from engineering and computational sciences to energy and environmental sciences. In particular, the prominence of the "Electrical and Electronic Engineering" and "Computer Science Artificial Intelligence" categories reflects the role and development of artificial neural networks in these fundamental disciplines. The inclusion of fields like "Energy and Fuels" and "Environmental Sciences" emphasizes the growing importance of ANNs in addressing global challenges such as sustainability, energy efficiency, and environmental management. The spread of artificial neural networks across various scientific network categories showcases the multidisciplinary nature of this technology and the broad impact it has across different fields. This suggests that ANNs not only make significant contributions to theoretical sciences but also provide valuable contributions to practical applications, indicating that they will continue to play an increasingly important role in various research areas in the future.

Figure 4. Tree map of the top 10 quote topics

As seen in Figure 4, artificial neural networks consist of citation topics such as “Power Systems and Electric Vehicles”, “Oceanography”, “Meteorology and Atmospheric Sciences”, “Artificial Intelligence”, “Machine Learning”. These topics highlight the broad impact of artificial neural networks in both theoretical and applied sciences, as well as the main scientific fields they interact with. In particular, subjects like "Artificial Intelligence" and "Machine Learning" reveal the strong relationship between artificial neural networks and these areas, while more specific and applied fields such as "Power Systems and Electric Vehicles" and "Oceanography" emphasize the importance of ANNs in developing practical solutions. These findings demonstrate that artificial neural networks are not limited to theoretical research but also establish significant connections with real-world applications and industrial solutions. Additionally, the interaction with natural sciences, such as "Meteorology and Atmospheric Sciences," points to the potential of these technologies in addressing environmental and climatic issues.

Figure 5. Tree map of the top 10 micro quote topics

As can be seen in Figure 5, artificial neural networks consist of micro citation topics such as “evapotranspiration”, “load estimation”, “chemometrics”, “nanofluid”. In particular, topics such as "evapotranspiration" and "load forecasting" reflect the applications of artificial neural networks in environmental and engineering fields, while subjects like "chemometrics" and "nanofluids" highlight the role of these technologies in more specific scientific areas such as chemistry and materials science. These findings demonstrate how diverse and in-depth artificial neural networks are used in micro-level topics and how effective they can be in producing results in these areas. Additionally, they emphasize the potential of these micro topics to address technical and practical issues across different disciplines.

Figure 6. Tree map of the top 10 publishing languages

As can be seen in Figure 6, studies on artificial neural networks are published in languages such as "English", "Chinese", "Spanish", "Portuguese" and "Turkish". The prevalence of these languages reflects the global impact of artificial neural network research and the contributions of academic communities from different regions to this field. In particular, the prominence of English as the leading language highlights its role as the primary language of international scientific communication in this domain. Publications in other languages reveal how artificial neural networks have spread across various regions of the world and how they are being researched within different cultural and linguistic contexts.

Figure 7. Tree map of the WoS directory

Figure 7 shows that the studies on artificial neural networks are mostly published in SCI-EXPANDED index. This situation indicates that research on artificial neural networks is primarily published in high-impact, prestigious journals, and that the scientific influence in this field is largely disseminated through SCI-EXPANDED journals. The SCI-EXPANDED index signals that research in this field has gained broad international visibility and is increasingly recognized by the academic community.

3.2. Bibliometric Network Mapping

In this section, bibliometric network mapping of authors, words, institutions, countries, documents, and sources is done. In this context, in the creation of a map of the bibliometric network in the artificial neural network field, values of 30 were chosen for the co-citation network as in the work of [16], 5 and 1 for the bibliometric matching network as in the work of [17], and 1 and 5 for other mappings as in the work of [18].

3.2.1 Bibliometric network mapping of authors

In this section, network mapping was performed according to co-author, author citation, co-citation and bibliometric matching of authors.

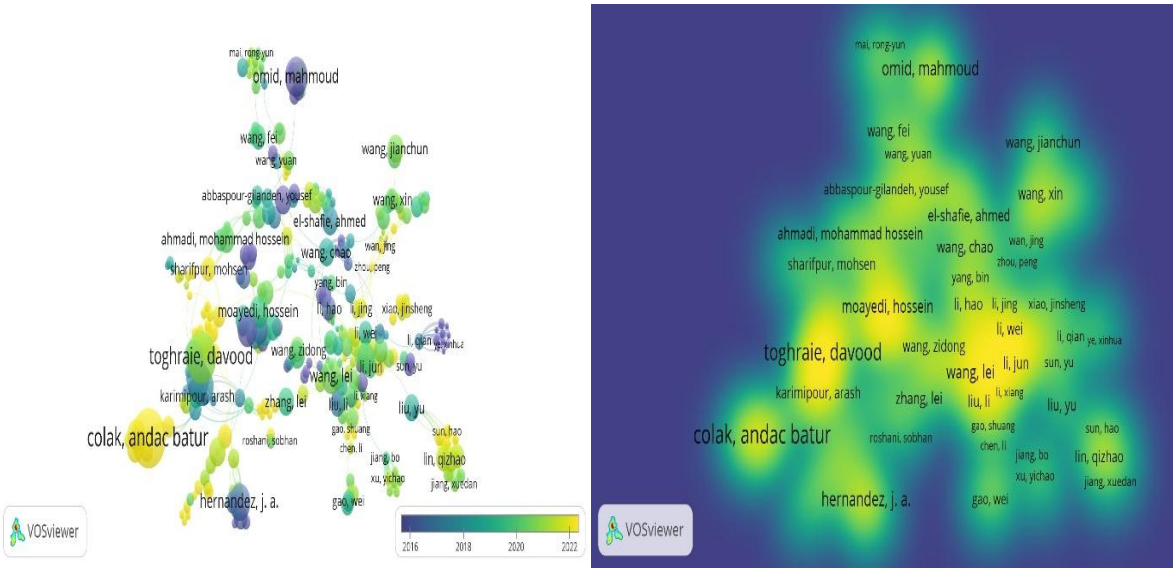

Figure 8. Author-co-author network and density map by year

The author-co-author map by year in Figure 8 has nodes: 30, clusters: 21, links: 775 and total link strength: 1760. The most influential author collaboration was Colak, Andaç Batur with 46 publications, followed by Egrioglu, Erol with 41 publications; Toghraie, Davood with 38 publications; Grossi, Enzo with 36 publications; Bas, Eren; Elkatatny, Salaheldin and Havel, J with 31 publications each. A transition from blue to yellow in the author-co-author network indicates an increase in author collaboration in recent years, reflecting a more intense academic interaction. In this context, authors such as Colak, Andaç Batur; Sun, Hao; and Lin, Qizhao have been found to have made significant contributions in recent years. The emphasis of yellow in the density map points to the most effective author collaborations. Notably, strong relationships are observed among authors such as Colak, Andaç Batur; Toghraie, Davood; Wang, Lei; and Liu, Li. These findings suggest that research in the field of artificial neural networks has developed through tighter collaborations and more intensive interactions between specific authors in recent years. Additionally, these collaborations appear to have contributed to the establishment of a strong academic and interdisciplinary network, particularly among these authors.

Node of the author citation map by year in Figure 9: 993, cluster: 16, link: 16101 and total link strength: 42933. The highest number of author citations was Pradhan, Biswajeet with 37000 citations-15 publications, followed by Hsu, Kl with 2766 citations-5 publications; Afrand, Masoud with 2544 citations-25 publications; Lee, Saro with 2523 citations-20 publications; Lek, S with 2454 citations-14 publications. At the same time, it was determined that authors such as Colak, Andaç Batur; Toghraie, Davood, Lin, qizhao; Wangi Lei have been cited in recent years. However, it has been determined that the citation of authors such as Omid, Mahmoud; Moayedi, Hossein; Ghaedi, M is intensely related. These findings indicate that research in the field of artificial neural networks points to an increasing network of citation interactions and scholarly interactions among certain authors in recent years.

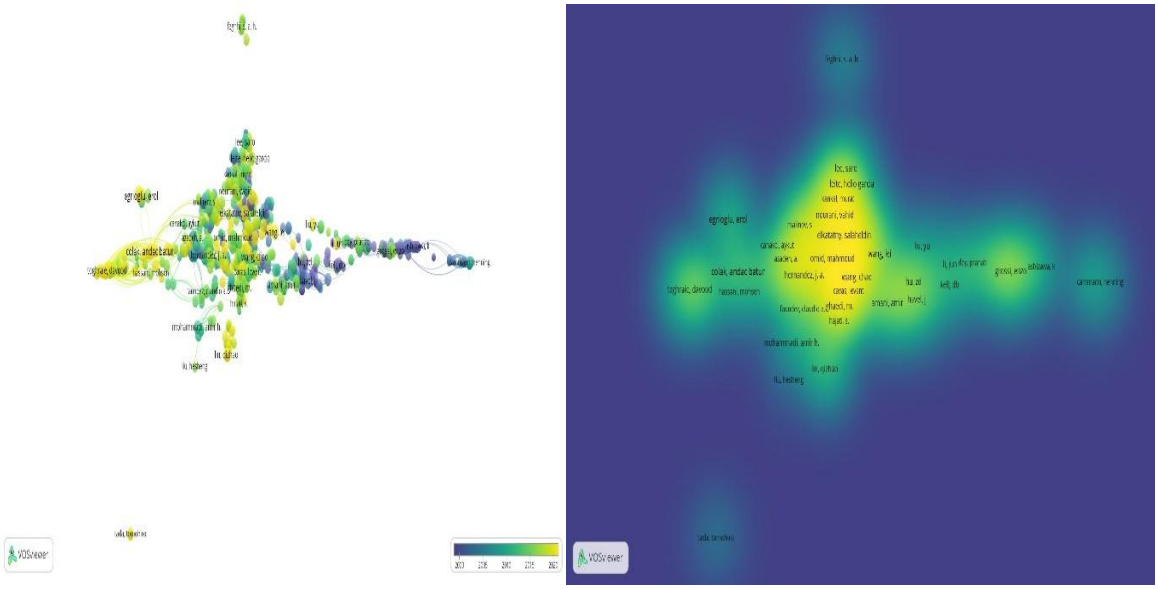

Figure 9. Author citation network and density map by year

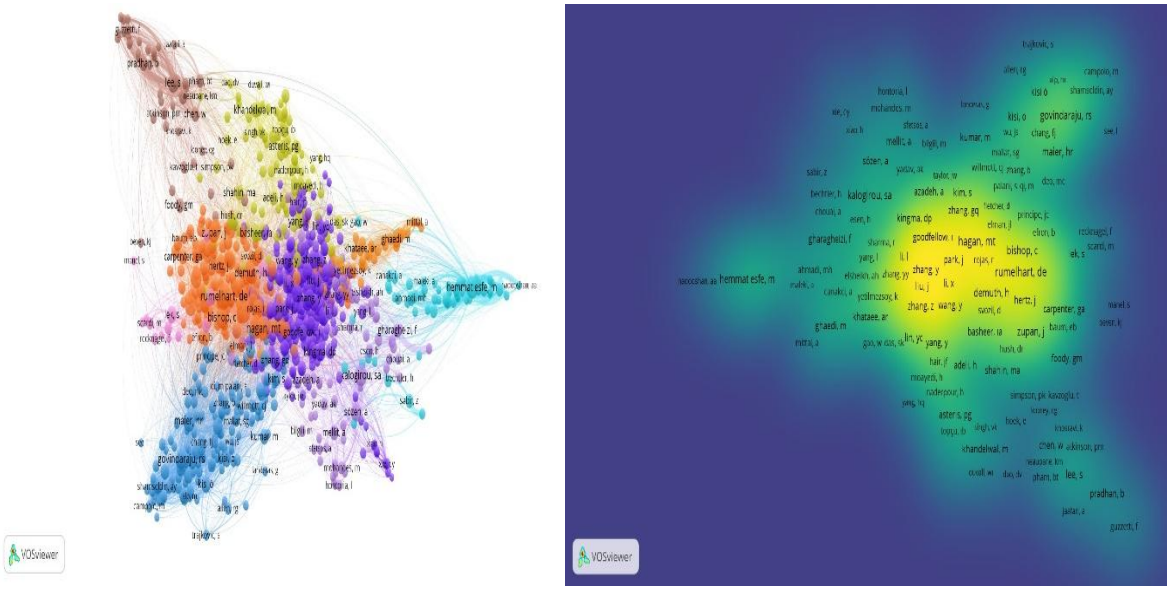

Figure 10. Author co-citation network and density map

Node of the co-author citation map in Figure 10: 1000, cluster: 9, link: 150118 and total link strength: 627461. The highest number of co-citations is Rumelhart, De with 2205 citations-15547 total link strength, followed by Hagan, Mt. Hornik, K with 1634 citations-12614 total link strength; Haykin, S with 1528 citations-9238 total link strength; Hemmat Esfe, M with 1089 citations-15887 total link strength. At the same time, the co-citation of authors such as Hagan, Mt; Rumelhart, De; Wang, J; Zhang; Gq; Bishop, C was found to be highly correlated. These findings reveal that there is a strong co-citation interaction and intense collaboration network among these authors in academic research in the field of artificial neural networks.

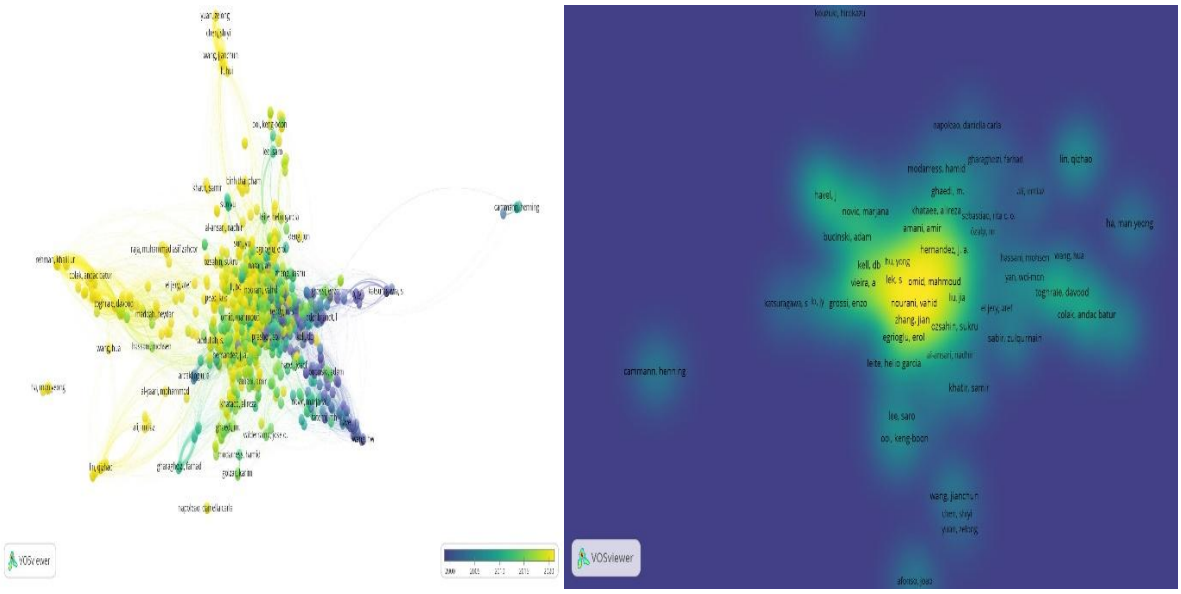

Figure 11. Author bibliometric matching network and density map by year

Node of the author bibliometric matching map by year in Figure 11: 1000, cluster: 20, link: 173702 and total link strength: 1265152. The author with 5 independent publications citing a joint publication the most is Pradhan, Biswajeet with 37000 citations, followed by Hsu, Kl with 2766 citations; Afrand, Masoud with 2544 citations; Lee, Saro with 2523 citations; Lek, S with 2454 citations. At the same time, it was determined that authors such as Colak, Andaç Batur; Ali, İmtiaz, Khatir, Samir; Wangi Jianchun have been cited in recent years. In addition, it has been determined that authors such as Omid, Mahmoud; Prasher, So; Li, Jun; Zhang, Min; Reddy, N.S. are highly related. These findings show that the analysis conducted through the biblio-metric matching network reflects the temporal evolution of authors' citations and collaboration networks.

3.2.2 Bibliometric network mapping of common words

In this section, network mapping, thematic mapping and frequency of keywords over time were analyzed, FactorialMap and keywords were visualized in the word cloud.

The common word map in Figure 12 has nodes: 999, cluster: 16, link: 16590 and total connection strength: 38325. The most common word is artificial neural network in 8063 publications, followed by artificial neural networks in 4706 publications, neural networks in 1323 publications, ann in 1253 publications. Neural network in 1223 publications, artificial neural network (ann) in 1115 publications, machine learning in 1022 publications, artificial intelligence in 687 publications. 663 in prediction, 591 in genetic algorithm, 559 in optimization, 511 in modeling. 342 in response surface methodology, 287 in forecasting, 284 in classification, 264 in deep learning. In 259 publications, it was seen that words such as multilayer perceptron followed. At the same time, the words artificial neural network and prediction were found to be highly related. However, the least common words used in 5 publications each are analytical models, nitrogen dioxide, rotors, diagnostics information, time-domain analysis. Batteries, lattice strain, optical sensors, carbon monoxide, microgrids, satellites, dielectrics. It was determined that there are words such as opticial fibers, indexes. These findings suggest that the most frequently encountered terms in the artificial neural network (ANN) literature include concepts such as machine learning, deep learning, prediction, optimization, and classification. Furthermore, the strong relationship between artificial intelligence and prediction among these common terms indicates that artificial neural networks are being used more effectively in applications across various disciplines, including healthcare, agriculture, and construction. Additionally, these terms also play a significant role in areas like sports and physical activity, where they contribute to the increasing use of ANNs in performance analysis and

athlete productivity. Specifically, terms like "prediction" and "machine learning" have been observed to be heavily utilized in predicting athlete performance and analyzing training data. Thus, this literature demonstrates the importance of ANNs not only in theoretical contexts but also in applied settings, particularly in sports sciences and physical activity domains.

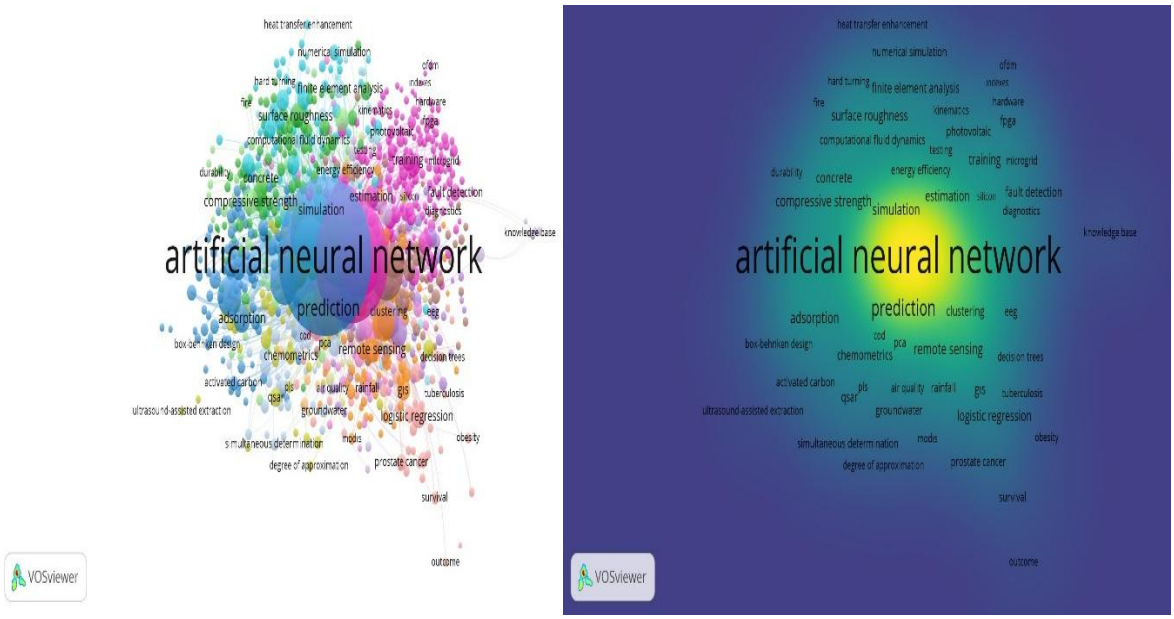

Figure 12. Common word network and density map

Figure 13 shows that the usage rate of words related to artificial neural networks has increased over the years. In the early 1990s, the artificial neural network (ANN) literature was represented by a limited number of publications, and the terminology used was generally basic. In 1990, only concepts like “model” and “classification” were visible. However, by the year 2000, the diversity of ANN applications had expanded, as evidenced by the usage of terms such as “prediction” (61), “model” (56), “optimization” (34), “performance” (22), “design” (80), and “system” (31).

After 2000, ANN applications spread across various disciplines, notably in environmental engineering, energy systems, water resources management, biomedical analysis, and movement sciences. During this period, a significant increase was observed in the annual usage of domain-specific terms such as “simulation,” “parameter,” “diagnosis,” “behavior,” and “water.” By 2010, ANN had become a fundamental tool in decision-making processes across numerous fields, from engineering to health sciences, with keywords such as “optimization” (184), “model” (381), “prediction” (655), “algorithm” (95), and “diagnosis” (128).

Following 2015, with the introduction of more advanced artificial intelligence methodssuch as deep learning, machine learning, and multilayer neural networks interdisciplinary collaborations increased, and the use of ANNs expanded into diverse fields such as social sciences, sports sciences, climate research, and manufacturing engineering. In 2020, the high frequency of keywords like “prediction” (2441), “optimization” (945), “system” (677), “performance” (785), “algorithm” (415), and “diagnosis” (423) clearly reflected the capacity of ANNs to offer solutions for multidimensional problems.

As of 2024, ANN-related terms have reached their highest usage levels to date. Keywords such as “prediction” (3403), “model” (2256), “optimization” (1746), “performance” (1218), “system” (951), “algorithm” (732), “diagnosis” (586), “temperature” (648), and “regression” (578) indicate that ANNs have taken on a central role in both technical and socially-oriented studies. This evolution demonstrates that ANNs have moved beyond being merely technological tools and have become a driving force of interdisciplinary interaction in the processes of knowledge production.

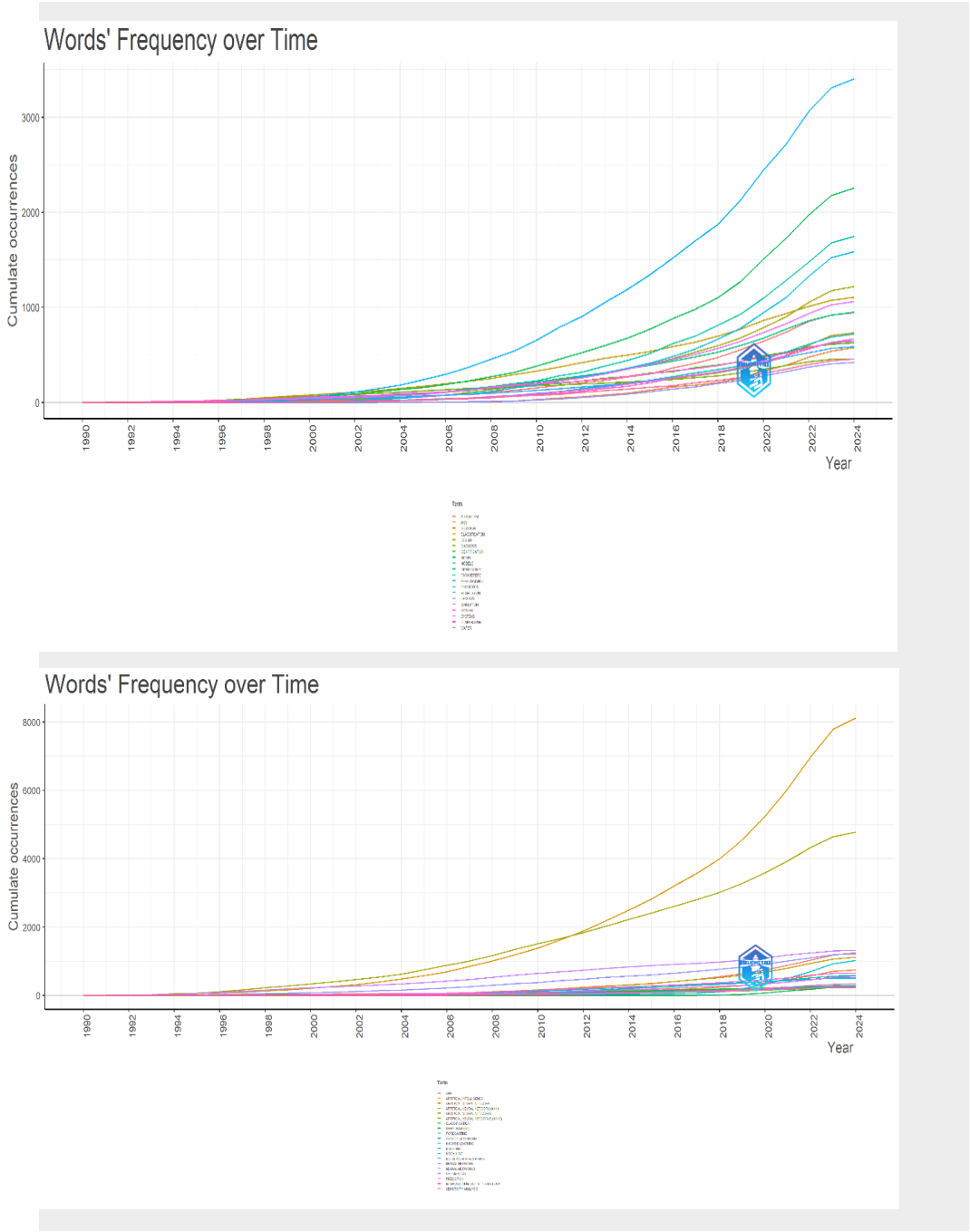

Figure 13. Frequency of words over time

In this context, the year over year trends in keywords used in ANN articles reveal that knowledge generation has transcended traditional engineering paradigms and that these technologies have increasingly integrated with different scientific traditions. The growing terminological diversity and conceptual depth provide clear evidence that artificial neural networks now play a critical role in multidimensional frameworks such as interdisciplinary information systems, predictive analytics, and performance modeling.

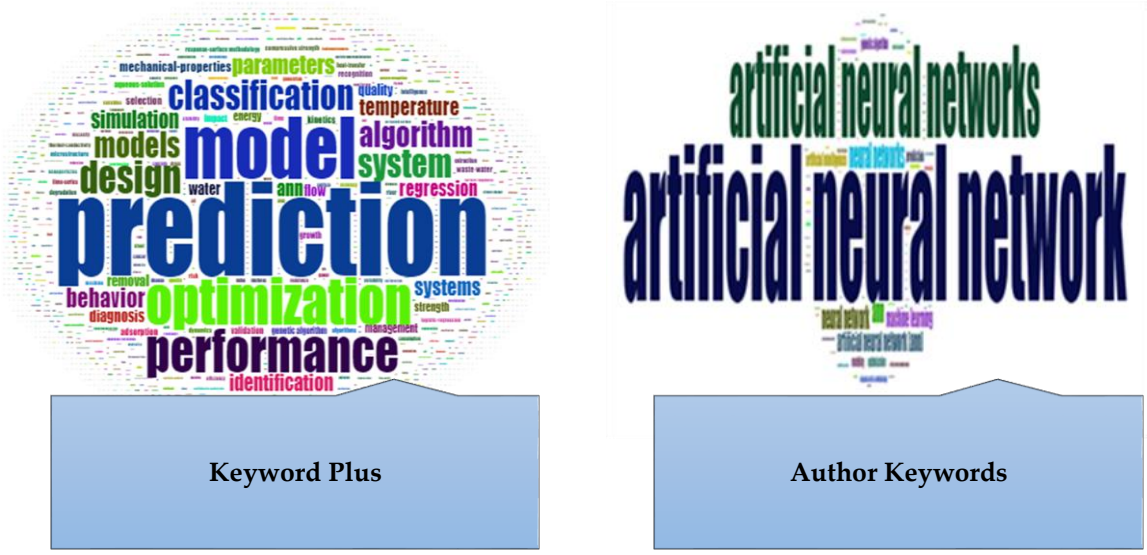

Figure 14. Word cloud for keywords

Figure 14, the findings obtained under the title "Bibliometric Mapping Analysis of Artificial Neural Network Articles" clearly demonstrate not only the quantitative growth of the artificial neural network (ANN) literature but also its interdisciplinary diversification. According to the keyword frequency for 2024, ANN research is now integrated with many scientific fields. High-frequency key terms such as prediction (3403), model (2256), optimization (1746), and performance (1586) show that ANN is widely used in forecasting, decision support, and system improvement processes. Moreover, terms like design (1218), classification (1106), algorithm (946), behavior (732), and parameters (719) indicate that ANN has positioned itself as a methodological tool across a wide range of disciplines, including engineering, computer science, psychology, and biomedical engineering. The data also show that ANN applications are not limited to technical fields; they are increasingly present in community-based disciplines such as environmental sciences (water, temperature, wastewater, climate change, air pollution) and health sciences (diagnosis, prognosis, cancer, mortality, diseases). The frequency of concepts like water (457), temperature (651), regression (586), diagnosis (628), prognosis (458), and cancer (152) highlights ANN's contribution to solving global issues related to sustainability, climate adaptation, and public health. Additionally, the frequency of technical terms such as simulation (670), time series (179), algorithms (181), and validation (266) demonstrates that these methods play a critical role in system modeling, prediction accuracy, and the development of data-driven decision systems. The broad range of interdisciplinary research areas indicates that various concepts from physics, chemistry, material science, and biotechnology such as genetic algorithms, nanoparticles, microstructure, kinetics, impact, adsorption, biomass, heat transfer, and viscosity—are frequently used alongside ANN. In this context, the bibliometric mapping analysis reveals that ANN research has evolved into an interdisciplinary structure over the years, becoming a central methodological framework in both basic and applied sciences. The multifaceted spread of ANN indicates that new methodological boundaries are being opened in the production and application of scientific knowledge.

The author keywords reflect the research intensity in various application areas of ANN, its role in numerous sectors, and its multidisciplinary nature. The term "artificial neural networks" and its derivatives, used 4783 times, highlight the dominance of this field, while thematic diversity within the literature becomes more apparent. The high frequency of keywords such as "prediction" (665) and "model" (514) indicates that these are among the most common areas of ANN application. These terms show that ANN is an essential tool in predictive analysis and modeling processes. Furthermore, the prominence of the term "optimization" (561) underscores ANN's critical role in problem-solving and performance improvement in complex systems. The association of ANN with terms like "training" (92)

and "algorithms" (21) suggests that intensive research has been conducted on learning processes and algorithmic approaches. From an interdisciplinary perspective, applications in environmental science, engineering, and healthcare are particularly prominent. Terms like "wind energy" (28), "water treatment" (44), and "wastewater treatment" (52) demonstrate the role of ANN in environmentally friendly applications and its potential for providing solutions in this area. Additionally, keywords such as "genetic algorithms" (149), "deep learning" (267), and "backpropagation" (86) highlight the integration of these technologies with ANN and their contributions to solving more complex problems. The study also reflects the use of ANN in healthcare. Medical terms like "prostate cancer" (41) and "epilepsy" (16) illustrate ANN's contributions to disease diagnosis and prognosis.

Thus, it is understood that ANN's potential in biomedical and biotechnological fields is growing, and its impact on the healthcare sector is increasing. The data obtained show that ANN is used as an interdisciplinary tool across a wide range of applications, and these areas are increasingly diversifying. Research in energy systems, environmental management, healthcare, and biotechnology further strengthens ANN's ability to provide solutions to challenges in different disciplines. These findings suggest that future developments in ANN will bring significant advances not only in engineering but also in critical areas such as environmental and health sciences.

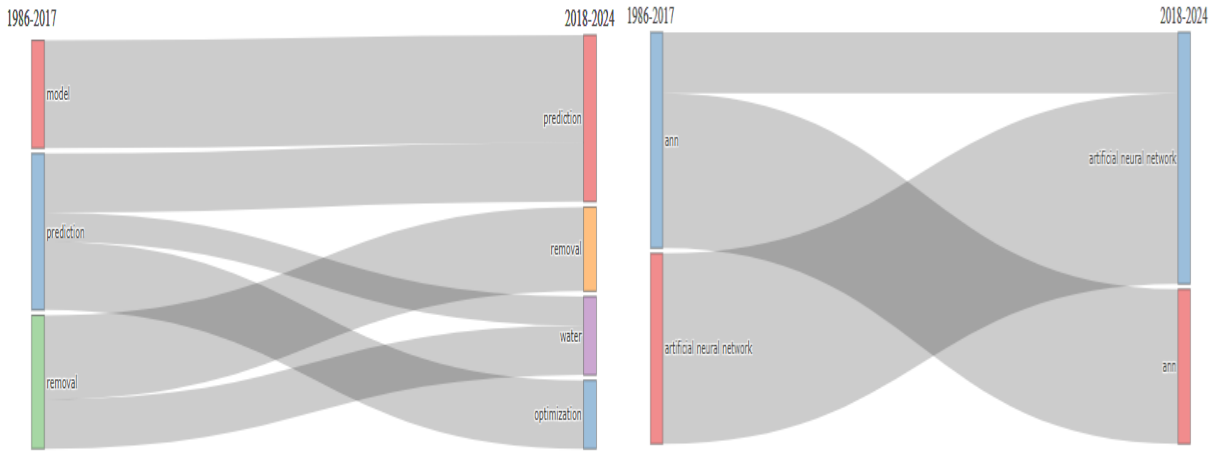

Figure 15. Thematic map of keywords

The keywords response surface methodology, adsorption in the niche themes in the keywords in Figure 15 show that the words are specialized but the connection with other themes is weak. The bibliometric mapping analysis of Artificial Neural Network (ANN) articles examines the evolution of the literature published between 1986 and 2024 in detail. This study highlights the development of research on artificial neural networks and the changes in key concepts in this field over time. Artificial neural networks, particularly beyond engineering and computer science, have expanded into a wide range of application areas by interacting with various disciplines such as healthcare, environmental engineering, finance, and energy. The analysis of the period from 1986 to 2017 shows that ANN research has covered a broad spectrum, with 980 events and a weighted coverage index of 0.81. During this period, prominent keywords included "modeling," "algorithm," "regression," "diagnosis," and "selection," indicating that ANN focused primarily on technical fields such as modeling and algorithm development. In contrast, the data for the period from 2018 to 2024 show 698 events and a weighted coverage index of 0.51, with optimization and performance topics becoming more prominent, highlighting the applicability of ANN in environmental and engineering fields. Notably, concepts such as "genetic algorithms," "mechanical properties," and "temperature" were introduced in this period. Interdisciplinary interactions reveal that artificial neural networks are widely used not only in technical fields but also in diverse disciplines such as healthcare, environmental sciences, and economics. In healthcare, terms like "prediction," "sensitivity analysis," and "multiple linear regression" show the important role of ANN in diagnostic systems. In

environmental sciences, keywords such as "water," "extraction," and "adsorption" reflect the use of ANN in water treatment and environmental pollution studies. Moreover, terms like "optimization" and "performance" frequently appear in financial analysis and energy efficiency in engineering fields. In conclusion, the development of artificial neural networks in scientific literature is observed as a reflection of both technical advancements and interdisciplinary interactions, extending across a broad academic spectrum. A strong foundation was established with 980 publications between 1986 and 2017, during which significant progress was made in the core research areas of ANN, with a weighted coverage index of 0.81. Between 2018 and 2024, with 698 publications and a weighted coverage index of 0.51, a wider interaction was observed in optimization, environmental engineering, and healthcare. During this period, as interdisciplinary interactions increased, ANN started to be more widely applied in fields such as healthcare, environmental engineering, and finance, in addition to engineering and computer science. ANN, particularly in healthcare, has found more research space in topics like "prediction" and "sensitivity analysis," and in environmental sciences, terms like "water" and "adsorption" emerged.

It is clear that artificial neural networks play an important role not only in engineering and information technology but also in diverse fields such as healthcare, environmental sciences, and finance. These interdisciplinary contributions expand the potential application areas of ANN and are expected to contribute to future research directions. This study demonstrates that bibliometric analyses are important research tools in rapidly evolving fields such as ANN and help us better understand the impact of this technology across various disciplines. It is anticipated that in the future, such analyses will allow us to gain a deeper understanding of academic trends and multidisciplinary applications in the field of artificial neural networks.

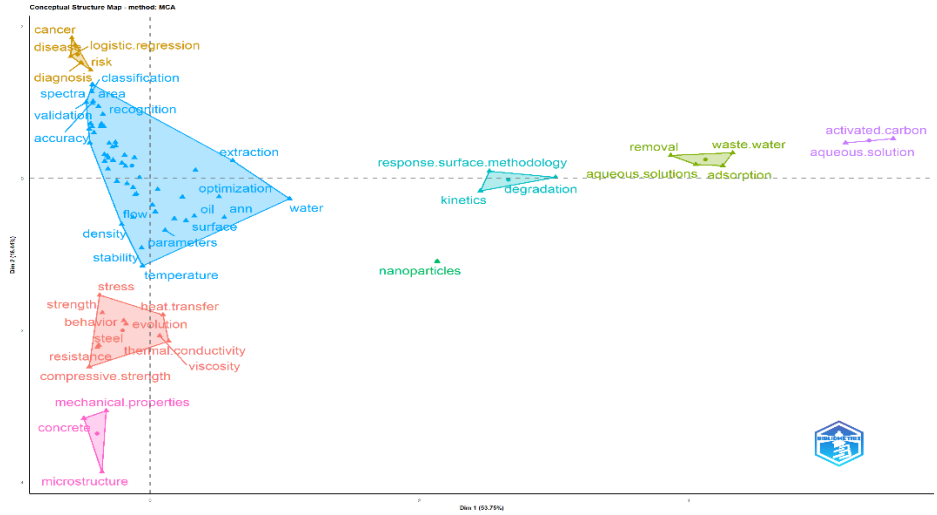

Figure 16. FactorialMap

The data presented in Figure 16 reveal distinct clusters categorized based on the relationships between terms. Terms like "extraction" (3.87, 0.30) and "aqueous solution" (5.16, 0.47) are strongly associated with clusters 4 and 7, which are related to environmental engineering and water treatment technologies. "ANN" (0.55, -0.51) and "regression" (-0.32, 0.30) are located in cluster 1, indicating their widespread use in artificial intelligence and machine learning applications, particularly in data classification and prediction models. Additionally, as shown in cluster 3, terms such as "cancer" (-0.58, 1.85) and "disease" (-0.56, 1.75) reflect the significant contributions of ANNs in the fields of health sciences and biotechnology. The data also reveal that areas like "energy" (-0.17, -0.07), "performance" (0.04, -0.44), and "efficiency" (0.24, -0.25) are crucial for demonstrating the applications of ANNs in energy systems, sustainable technologies, and performance optimization. Furthermore, the inclusion of terms like "mechanical properties" (-0.33, -3.06) and "pressure resistance" (-0.46, -2.48) in clusters 5 and 2

indicates their relationship with engineering disciplines, particularly material science and structural analysis. This reflects the interdisciplinary nature of ANN applications across various fields, from environmental sciences to mechanical and civil engineering. This bibliometric mapping analysis highlights the dynamic and broad role of artificial neural networks across multiple scientific domains. The significant clustering of relevant terms in specific areas emphasizes the interdisciplinary nature of ANN research. Terms like "genetic algorithms" (0.34, 0.11) and "classification" (-0.43, 1.14) are integral parts of ANN optimization and data mining processes, while "time series" (-0.42, 0.60) and "simulation" (-0.13, -0.12) underline their importance in prediction and system modeling.

The study concludes that bibliometric mapping techniques provide a robust framework for understanding the breadth of ANN applications. Moreover, this approach captures the trends and relationships between core research topics, offering deeper insights into how ANN technologies impact a wide range of scientific disciplines. Therefore, the matching data presented in Figure 16 clearly show how these terms are interconnected and how the application of ANN technologies has evolved across different fields over time.

3.2.3 Bibliometric network mapping of documents

In this section, citation network mapping of the documents is performed and the top 10 most cited documents globally are included.

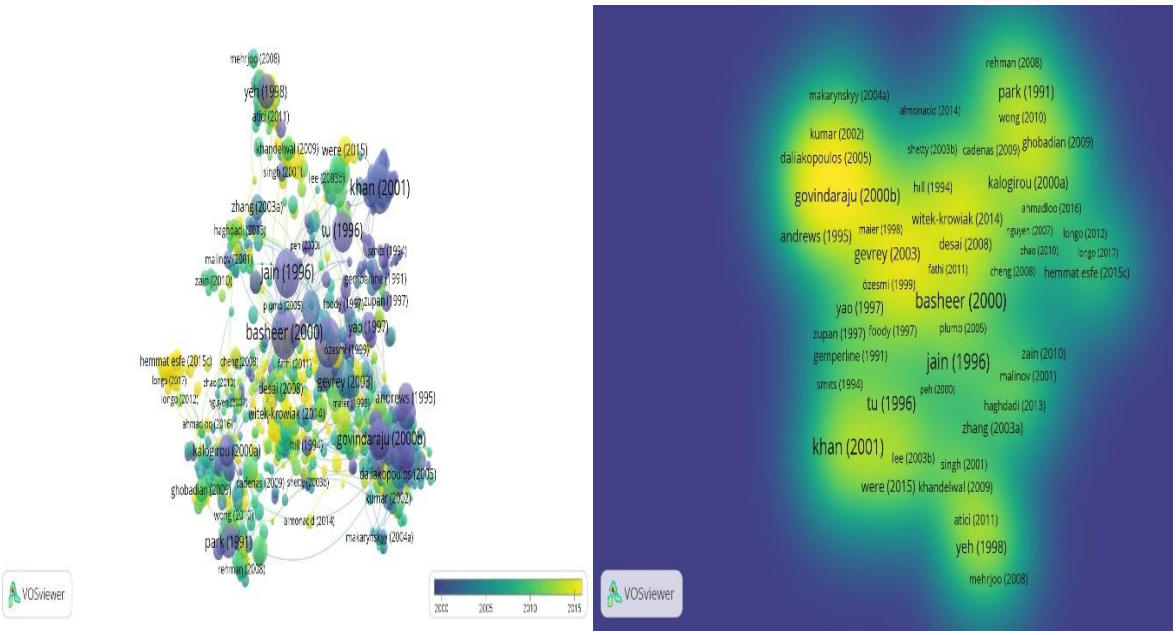

Figure 17. Document citation network and density map by year

Nodes of the document citation map by year in Figure 17: 979, cluster: 16, link: 4492. It was observed that Basheer (2000) had the highest number of document citations with 2072 citations, followed by Gardner (1998) with 1942 citations; Khan (2001) with 1922 citations; and Jain (1996) with 1866 citations. At the same time, it was determined that documents such as Hemmat Esfe (2015c); Were (2015); Witek-Krowiak (2014) have been cited in recent years. However, it has been determined that the citation of documents such as Gevrey (2003); Khan (2001); Valipour (2013) is intensely related. These findings indicate that citations to specific works in the artificial neural network (ANN) literature have evolved over time, with key studies, particularly those by Basheer (2000) and Gardner (1998), occupying a central position in terms of citations. This suggests that essential foundational knowledge and methodologies related to artificial neural networks are concentrated in these sources, and these documents represent important milestones in the scientific development of ANN research. Additionally, the increase in

citations to certain papers in recent years reflects new developments and trends in the field, indicating that researchers have focused on these particular studies, further strengthening their impact in the literature. The dense relationships in this citation network particularly reflect the development of current research in the field of artificial neural networks, helping us understand the deeper connections between related studies. In this context, it can be said that there is a strong and ongoing exchange of information and interdisciplinary interaction within the ANN literature.

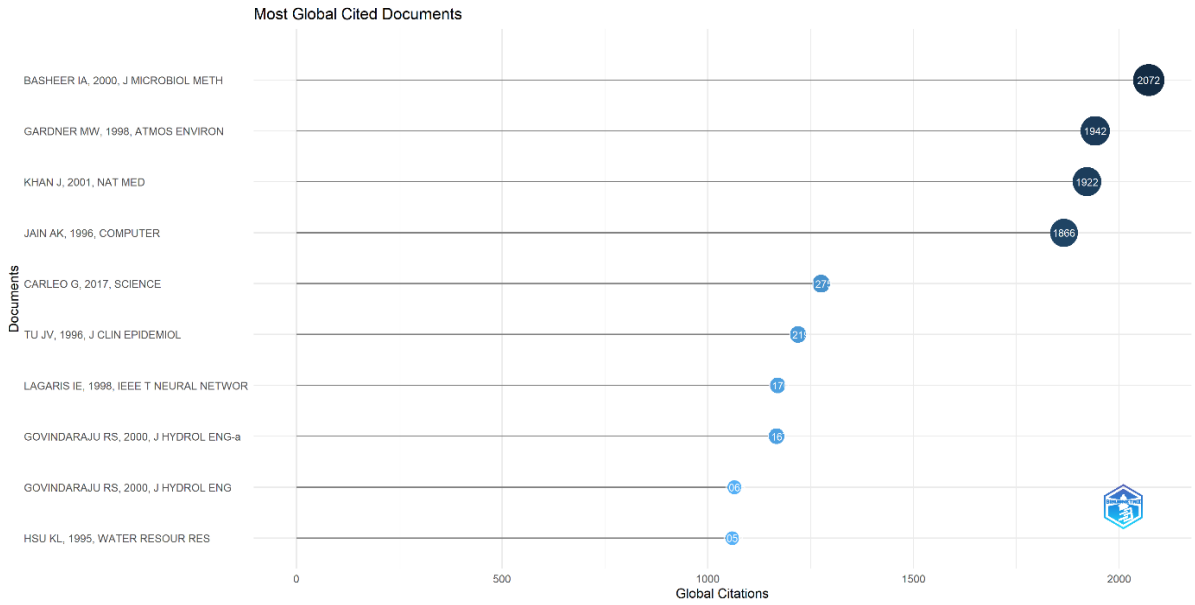

Figure 18. Most cited documents globally

Figure 18 shows that the most cited document globally is Basheer IA 2000. It was found that this article was followed by authors such as Gardner MW, 1998, Khan J, 2001. The high number of citations of this article reflects its long-term impact and its fundamental role in the development of the field.

3.2.4 Bibliometric network mapping of countries

In this section, the common author network mapping of countries, the production of countries over time and the world map of countries' cooperation are presented.

Node of the country-co-author network map in Figure 19: 164, cluster: 19, link: 2147 and total connection strength: 12927. The most effective country co-author collaboration is Peoples R China with 4197 publications-77217 citations, followed by Iran with 3219 publications-84060 citations, USA with 3019 publications-109394 citations. India with 2976 publications-58964 citations, Turkey with 1984 publications-54242 citations. However, it was determined that countries such as Turkey, Peoples R China, England, and Canada are intensely related. These data were visualized on the world map of countries' cooperation. These findings highlight the magnitude of contributions from different countries in the field of artificial neural network (ANN) research and emphasize the international collaboration in this area. Additionally, countries such as Turkey, the People's Republic of China, the United Kingdom, and Canada have been found to collaborate intensively with each other in ANN research. The interactions between these countries play a crucial role in the scientific development and knowledge sharing in the literature. This collaboration enables researchers from different geographical regions to work together, facilitating the faster advancement of the field.The data clearly visualize the intensity of collaboration between countries on a world map. This visualization allows us to better understand the spread of global collaboration in the field of artificial neural networks by showing country-specific collaboration networks. Furthermore, such international partnerships foster the interdisciplinary and cross-border nature of ANN research.

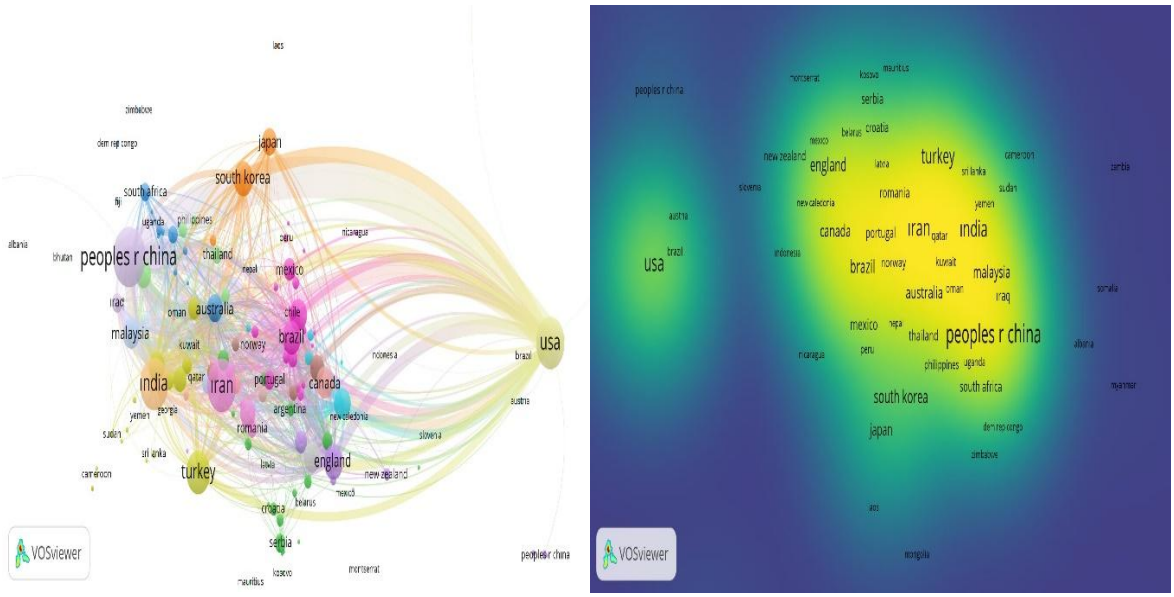

Figure 19. Country-common author network and density map

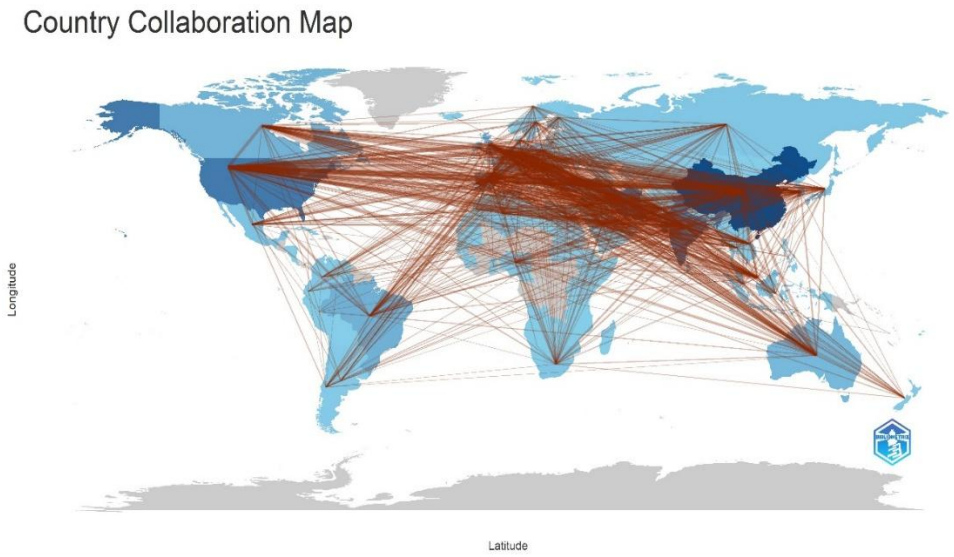

Figure 20. Cooperation of countries world map

Figure 20 shows the countries with the most collaboration. The collaboration between China and the USA stands out with 307 publications. This reflects a strong and sustained academic relationship in line with both countries' shared interests in advanced technologies such as artificial intelligence and machine learning. Both China and the USA are global leaders in these fields, making significant contributions to global research output. Collaborations like China-UK (161 publications), Iran-USA (156 publications), and Saudi Arabia-Egypt (145 publications) demonstrate that research collaborations transcend geographic and political boundaries, shaping according to common technological or industrial goals. The strong academic cooperation history between China and the UK in engineering and AI, as well as the collaboration between Iran and the USA, which, despite broader political tensions, draws from shared research interests in technology and innovation, are notable examples. Collaborations such as Saudi Arabia-Pakistan (137 publications), China-Saudi Arabia (118 publications), and Saudi Arabia-Iran (117 publications) reveal an increased research synergy in the Middle East and South Asia. Growing investment in technologies like artificial intelligence, especially in sectors such as healthcare and infrastructure, supports these collaborations in the region. The India-Saudi Arabia collaboration, with

110 publications, further emphasizes the rising research efforts in artificial intelligence in the Middle East and South Asia

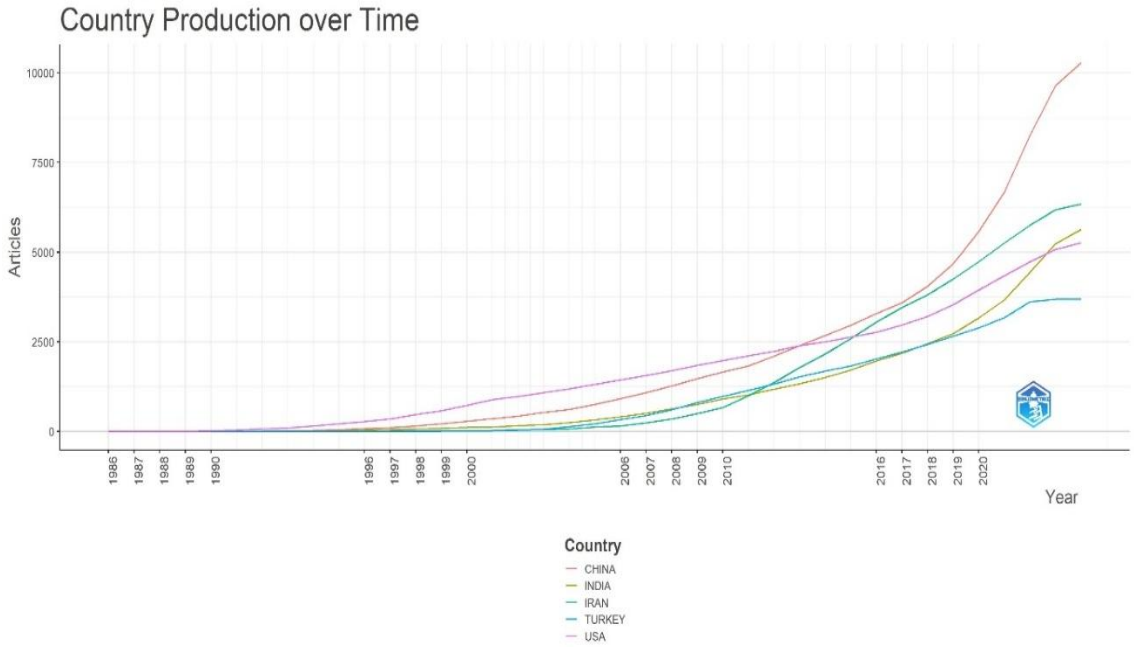

Figure 21. Production of countries over time

Figure 21 shows that the number of studies on artificial neural networks (ANN) in the People's Republic of China, Iran, the United States, India, and Turkey has increased each year, with a peak in growth observed after 2020. The continuous rise in ANN research in these countries indicates that this field has gained more global attention, with an increase in academic work driven by evolving technologies. China is a global leader in artificial intelligence research, particularly making significant strides in areas such as deep learning and artificial neural networks. In developing countries like Iran and Turkey, there has been a noticeable surge in scientific research in recent years, accompanied by more investments and infrastructure support in this field. The increase in research in technology-driven countries like the United States and India has been further accelerated by the support of strong research institutions and technology companies. The growth in ANN research in these countries reflects the expansion of the global AI ecosystem and the widespread adoption of these technologies in sectors such as healthcare, automotive, finance, and agriculture. Furthermore, the peak observed after 2020 points to the growing demand for digitalization and artificial intelligence following the COVID-19 pandemic.

3.2.5 Bibliometric network mapping of institutions

In this section, co-author network mapping of the institutions was carried out.

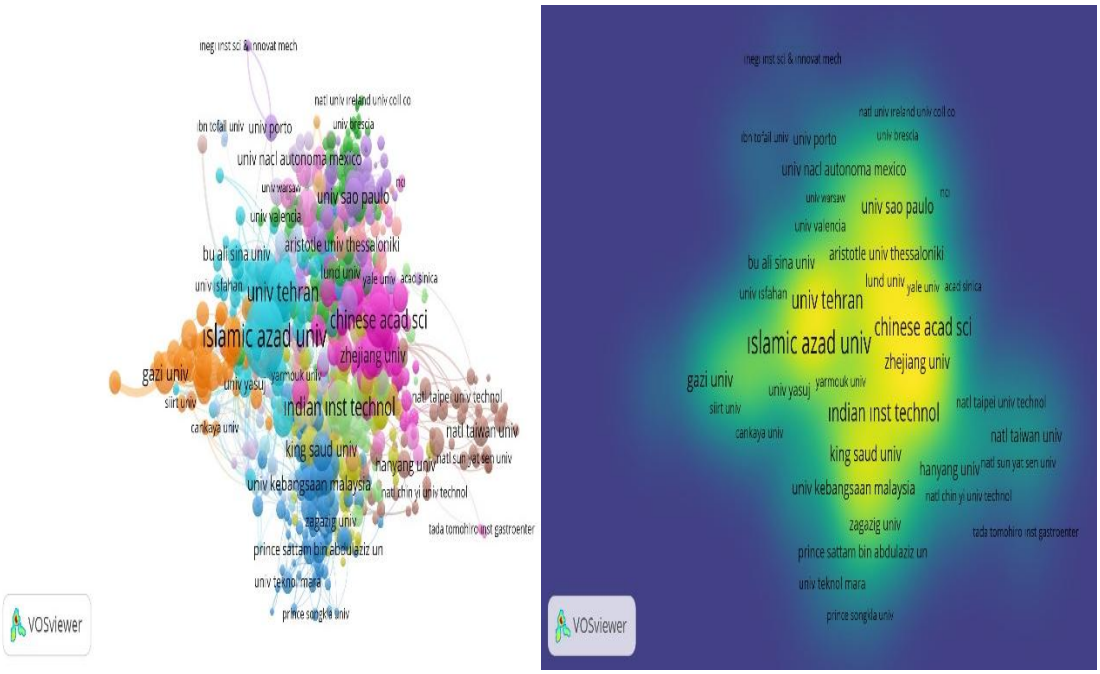

Figure 22. Institution-co-author network and density map

Nodes of the institution-co-author network map in Figure 22: 1000, cluster: 17, link: 9312 and total connection strength: 13866. The most influential institutional co-author collaboration is Islamic Azad Univ with 775 publications-22652 citations, followed by Univ Tehran with 358 publications-11362 citations; Chinese Acad Sci. Indian Inst Technol with 295 publications-1272727 citations; Natl Inst Technol with 207 publications-4864 citations, Amirkabir Univ Technol with 193 publications-3733 citations. Univ Tabriz with 168 publications-5759 citations; Tarbiat Modares Univ with 159 publications-5661 citations; Sharif Univ Technol with 158 publications-4265 citations; Gazi Univ with 149 publications-3394 citations. However, it was determined that institutions such as Islamic Azad Univ; Univ Malaya are heavily associated. These findings highlight that, in artificial neural network research, institutions such as Islamic Azad University and the University of Tehran have emerged as significant contributors, making substantial contributions to the development of the field. Additionally, the intense collaboration between Islamic Azad University and the University of Malaysia has been notably identified. This partnership fosters the widespread adoption of a multidisciplinary approach between artificial neural networks and other engineering disciplines. The strong collaboration between these institutions promotes the advancement of research on an international platform, facilitating the integration of knowledge from different disciplines. The interaction between these institutions not only contributes to the boundary-crossing development of artificial neural network technologies but also underscores the importance of academic collaboration on a global scale.

3.2.6 Bibliometric network mapping of sources

This section includes attribution network mapping of resources and local impact of resources.

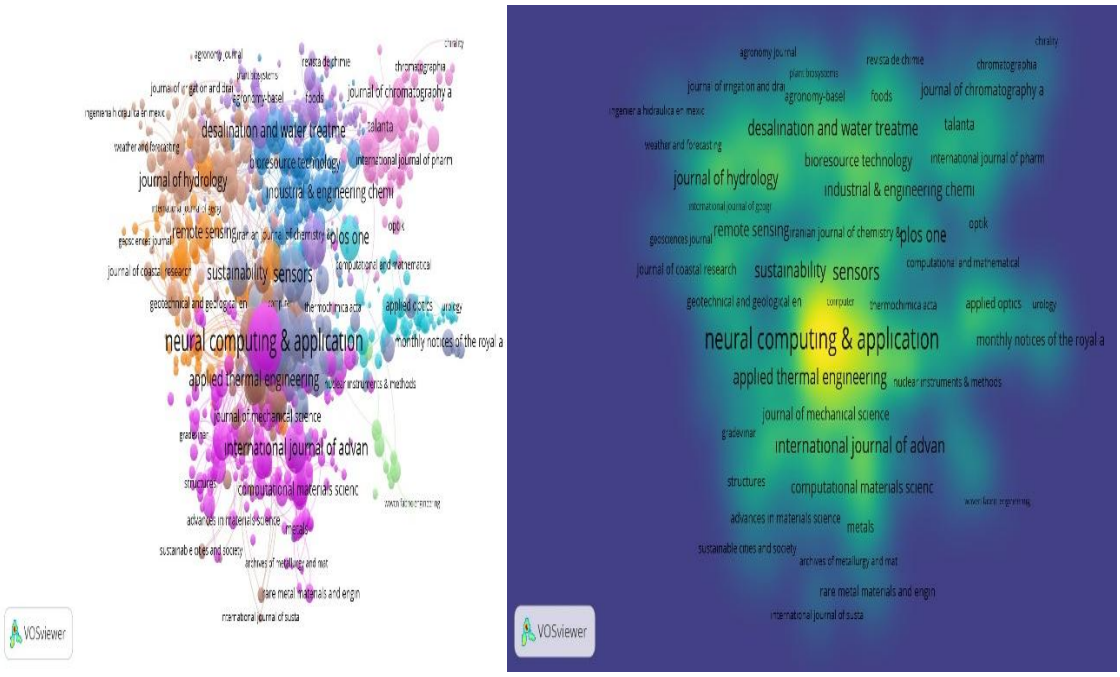

Figure 23. Source citation network and density map

The source citation network map in Figure 23 has nodes: 1000, cluster: 12, link: 21529 and total link strength: 45235. It was observed that Expert Systems With Applications had the highest number of citations with 13698 citations-243 publications, followed by Journal of Hydrology with 9420 citations-94 publications and Applied Energy with 8410 citations-88 publications. However, resources such as Neural Computing & Application; Energies were found to be highly relevant. These findings reveal that a significant portion of the literature in the field of artificial neural networks is concentrated in specific sources. Notably, Expert Systems With Applications emerges as a primary source for research, while journals such as Journal of Hydrology and Applied Energy also hold a strong influence in the field. Additionally, Neural Computing & Applications and Energies journals stand out with high citation numbers, particularly in more specialized application areas. The dense citations between these sources indicate the broad range of applications for artificial neural network technologies across various disciplines and their interactions with other scientific fields. Moreover, these journals play a crucial role in enhancing scientific interaction and in the emergence of new research areas. This underscores that artificial neural network research has gained an interdisciplinary dimension, strengthening the exchange of knowledge across different scientific domains

As seen in Figure 24, it is determined that the h_index is highest in the EXPERT SYSTEMS WITH APPLICATIONS source. The first 10 of these data are presented in the table of local effects of the sources. This indicates that the journal EXPERT SYSTEMS WITH APPLICATIONS is one of the most influential sources for research on artificial neural networks (ANN) and similar areas, making a significant academic contribution to the field.

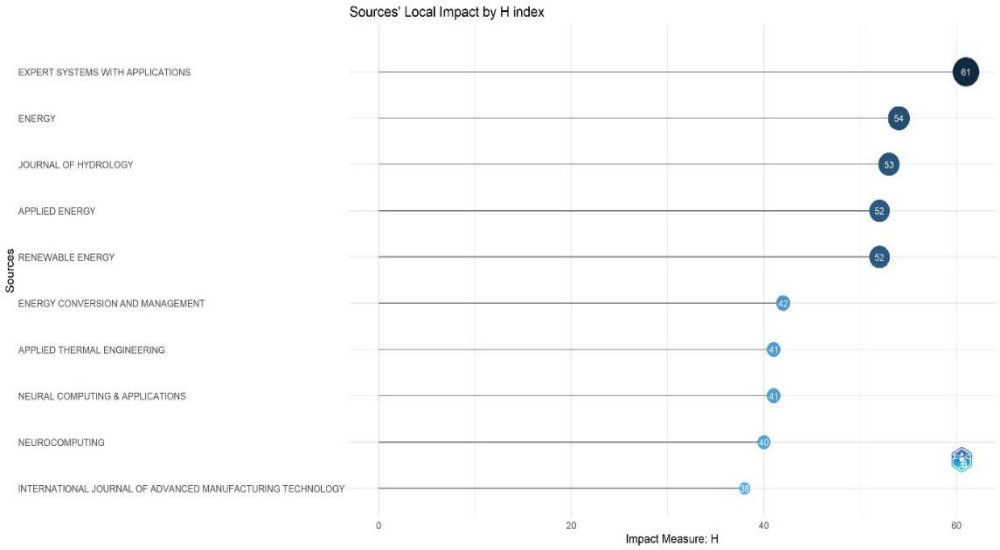

Figure 24. Local impact of resources

4. RESULTS AND DISCUSSION

Artificial Neural Networks (ANNs) have become powerful computational tools that are effectively used across numerous disciplines in recent years. In fact, ANNs are no longer limited to technical fields such as computer engineering or statistics; they are now widely and effectively applied in a range of diverse domains including health sciences, sports, physical sciences, and social sciences. The bibliometric mapping analyses conducted in this study clearly reveal the interdisciplinary nature of ANNs, providing strong evidence of their diverse applications in fields such as medicine [19], sports sciences [20], technology [21], biology [22], engineering [23], physics [24], and psychology [25].

[26] provided a significant perspective on the information processing capacity of ANNs, particularly emphasizing their nonlinear structure, parallelism, and fault tolerance features that explain why they are often preferred over traditional models. This study highlights the importance of ANNs' learning and generalization capabilities, especially in the modeling of complex systems. However, the literature also indicates that ANNs still face several challenges, particularly regarding training processes and the accuracy of the datasets used.

The study by [27] explored how ANNs are utilized in atmospheric sciences, showing that, as an alternative to traditional statistical models, ANNs can produce much more efficient and accurate results. While this research demonstrates the strong potential of ANNs in data analysis and forecasting, it also stresses the importance of data quality and the accuracy of the modeled environment. Moreover, the study points out that the application of such systems in atmospheric sciences may be limited by issues such as data deficiencies and modeling accuracy.

[28] conducted a comprehensive review of artificial neural networks (ANNs) inspired by biological neural systems, focusing on their wide range of applications such as pattern recognition and optimization. The authors emphasized that while ANNs can be beneficial across many fields, customized models are often required for each specific application. This flexibility and adaptability of ANNs offer a major advantage, but at the same time, can lead to the development of limited models that may not generalize well to all problems. [29] applied ANNs to classify cancer types based on gene expression profiles. In this study, small round blue-cell tumors (SRBCTs) were used as a model, enabling accurate classification into four distinct diagnostic categories. The research demonstrated that ANNs can be a powerful tool in clinical diagnostics, especially in overcoming diagnostic challenges and identifying therapeutic targets. Notably, the ANN not only correctly classified the samples but also identified the most relevant genes for classification providing significant insight into potential clinical applications.

These findings underscore the usefulness of ANNs in cancer diagnosis and the discovery of genetic targets for treatment. [30] proposed a novel method employing ANNs to solve initial and boundary value problems for differential equations. This approach demonstrated that ANNs can satisfy both the equations and their boundary/initial conditions simultaneously. The study showed that this method provides an efficient and fast alternative to traditional techniques such as the Galerkin finite element method, particularly when combined with the speed gains enabled by digital signal processors and neuroprocessors. The advantages demonstrated by ANNs in solving engineering and physics-related problems highlight the potential for further exploration in these domains. [31] made significant progress in solving the many body problem in quantum physics using ANNs. By reducing the complex correlations encoded in the wave functions of many-body systems into a more manageable computational form, the study achieved high accuracy in modeling both the ground states and unitary time evolution of quantum systems. This research highlights the potential of ANNs to tackle highly complex problems in quantum mechanics and illustrates how artificial intelligence and machine learning can open new frontiers in the study of physical systems. The approach is particularly promising for modeling strongly interacting systems. [32] conducted a noteworthy study that employed ANNs to predict the performance of bowling players in large-scale professional sports events like the Indian Premier League (IPL). The objective of the study was to analyze past performance data of bowlers and predict their future outcomes in subsequent seasons. The results enabled IPL franchises to make more informed strategic decisions regarding player selection. This application demonstrates the effectiveness of ANNs in performance evaluation and forecasting in the sports domain, where data analysis and predictive accuracy are critical. [33] examined the co-occurrence of anxiety, depression, and substance use disorders among individuals receiving mental health treatment. Utilizing both ANN and logistic regression analyses, the study identified key characteristics of individuals experiencing these comorbid conditions. The ANNbased analysis achieved strong success in detecting cases of co-occurring mental health and substance use disorders. The study emphasized the vital role of mental health service providers in identifying and addressing such conditions with integrated treatment strategies. Additionally, the capacity of ANNs to analyze large datasets significantly contributes to a better understanding of mental health issues and the enhancement of treatment processes.

The common thread across these studies is that ANNs have evolved into an interdisciplinary research and application tool. They are not merely a technical computation method, but rather a core technology capable of processing diverse datasets, solving unique problems, and facilitating scientific collaboration. This flexible structure, which can be tailored to the specific needs of various disciplines, forms the foundation of ANNs' contribution to scientific advancement. However, this diversity also presents challenges.

The success of ANN applications depends heavily on model accuracy, dataset suitability, and discipline-specific customizations. Therefore, effective use of these technologies requires robust collaboration across different fields. The existing body of literature clearly shows that ANNs, as of today, have become a shared methodological tool not only for computer engineering or artificial intelligence but also for fields such as medicine, physics, sports sciences, environmental sciences, and social sciences. Thanks to their interdisciplinary nature, ANNs hold the potential to drive substantial transformations both in academia and in industrial applications. Accordingly, it is anticipated that ANNs will continue to evolve and play a central role in multidisciplinary research in the future. This study comprehensively examined the scientific structure, development, and interdisciplinary interactions in the field of artificial neural networks (ANNs) by employing bibliometric mapping techniques on the literature published between 1986 and 2024. The analyses revealed a significant increase in publications and citations related to ANNs, particularly after 2010. This rise is directly linked not only to technical advancements in ANN algorithms but also to the growing application potential of these technologies in various disciplines such as energy, healthcare, environmental sciences, finance, agriculture, and materials science. The innovation of the bibliometric mapping methodology lies in its ability to visualize the conceptual structures and research trends in the literature, enabling both

quantitative and qualitative inferences [34]. Through this method, multi-layered structures such as macro and micro citation themes, interdisciplinary collaborations, distribution of publication languages, and the most productive institutions and countries have been analyzed.

Scientific production in the field of artificial neural networks has shown a continuous increase since 1986. However, after the 2010s, this growth accelerated significantly. The increase in both publications and citations after 2010 can be attributed to several key factors. First, the expansion of artificial neural network applications across various sectors such as healthcare [35, 36], automotive [37], finance [38], and agriculture [39] has led to an increase in the number of research papers. Additionally, during the 2010s, revolutionary developments in artificial neural networks, such as deep learning and big data analytics, made these technologies more efficient and widely used [40]. These technological innovations sparked significant interest both in the research world and industry, leading to a rapid increase in publication numbers. The year 2014 stands out as the peak year for citation counts. This peak can be explained by a combination of factors. 2014 was a turning point with significant scientific and technological advancements in artificial neural networks. The discovery of new algorithms, such as deep learning, made artificial neural networks more efficient, attracting more researchers to the field [41]. Furthermore, large academic collaborations and international projects during this period were key contributors to the rise in citations. The research conducted during these years provided important theoretical and applied findings, forming the foundation for further studies. As a result, these factors directly contributed to the citation peak in 2014. The decline in citation counts observed after 2014 indicates a period in which research offered less new information based on previous studies, leading to fewer citations. Most of the studies published after 2014 were built upon earlier findings, limiting the amount of new information available for citation. Moreover, the increasing citations of studies published before 2014 affected the citation counts for newer papers, explaining the decline. This suggests that scientific production in the field of artificial neural networks has reached a certain saturation point, and the rise in citations of prior works has resulted in a decrease in the citation potential for newer studies.

In the science network categories, it was revealed that artificial neural networks have a wide range of applications. Its place in disciplines such as engineering, computer science and environmental sciences contributes to the acceptance of artificial neural networks as an interdisciplinary technology. Macro citation topics and micro citation topics provide further insights into specific application areas of ANN. In particular, they illustrate the potential of applications such as load forecasting in energy efficiency and management, and chemometrics and nanofluidics in health and materials science. It draws attention to how artificial neural networks can be used in different fields by taking advantage of the flexibility and power they provide in terms of the analysis and optimization of complex systems. In this respect, it has shown that artificial neural networks are a tool that plays a very important role in data-intensive applications, in the development of models and in solving real-world problems. In terms of publication languages, it is seen that the studies on artificial neural networks are mostly published in English. However, the presence of publications in other languages such as Chinese, Spanish and Turkish reveals the global interest in this field and a multilingual research environment. The WoS index distribution shows that artificial neural networks are heavily published in the SCI-EXPANDED index. This is important for increasing the quality and visibility of research. In this respect, researchers who plan to conduct studies on the subject should aim for more interdisciplinary integration and expansion of application areas related to artificial neural networks. It is thought that this situation will contribute both to the diversification of the application areas of artificial neural networks and to the increase of multidisciplinary collaborations and to increase the number of publications and citations related to artificial neural networks.

The bibliometric analysis performed with the data obtained reveals the literature and main trends in the field of artificial neural networks in a comprehensive manner. The findings reveal that artificial neural networks are attracting more and more attention and studies in this field are diversifying. In the neural network literature, authors such as Pradhan and Biswajeet have an important place with high citation numbers. The high number of citations in the neural network literature reflects the fact that the

works of these authors are considered by a wide audience, provide applicable results and their contributions in this field are important. The fact that the concept of "artificial neural network" appears in more than 8000 publications reveals that this topic is directly related to its importance in the field. In addition, the frequent use of terms such as "machine learning" and "artificial intelligence" in the literature indicates that artificial neural network, as a multidisciplinary research field, offers new perspectives in different fields by spreading to a wide range of applications. It has been observed that countries such as China, Iran, USA and India stand out among the countries with the highest number of collaborations. Collaborations at the country level emphasize that the neural network literature has gained a global dimension and its importance in neural network research. At the same time, these collaborations between countries play an important role in the international exchange of information, sharing innovative ideas and contributing to the development of research infrastructure in this field.

International scientific collaborations are one of the key dynamics that enhance the depth and impact of research in the field of artificial neural networks (ANN). The importance of such collaborations stems from the ability to bring together disciplinary expertise from different countries, enabling the realization of larger-scale and multidisciplinary projects [42]. Countries like China and the United States possess strong academic expertise in artificial intelligence and deep learning technologies [43], while countries such as Iran and Saudi Arabia play a significant role in the dissemination and adaptation of technical and theoretical advancements in the field [44]. Joint research projects conducted among these countries not only boost the volume of scientific publications but also promote technology transfer, data sharing, and standardization in research methodologies. This facilitates the global development of scientific innovations in rapidly evolving and sophisticated areas such as artificial neural networks, while also enabling smoother international knowledge exchange.

Similarly, institutional collaborations help to broaden and deepen the scope of knowledge production at the organizational level. Strong academic and industrial ties between institutions foster information exchange and support the realization of innovative research. Institutions with high publication and citation counts, such as Islamic Azad University, not only support research efforts in Iran but also contribute to the development of regional scientific capacity through collaborations with many institutions across the Middle East and Asia. These robust academic and industrial networks lead the development of ANN-based solutions in application areas such as big data analytics, health technologies, sports sciences, and the automotive industry [45, 46]. Collaborations carried out at both the national and institutional levels have significantly contributed to the advancement of artificial neural networks and other artificial intelligence technologies, while also allowing for the expansion of sectoral applications. On a global scale, such collaborations not only enhance academic success but also facilitate the widespread adoption of these technologies in industrial practices. The key terms highlighted in the analyses, such as prediction, optimization, simulation, regression, ANN, and classification, demonstrate that ANNs respond to fundamental research needs such as modeling, forecasting, and optimization of data-intensive and complex systems. The popularity of these terms stems from their interdisciplinary translatability and their high-resolution capabilities for real world applications. In this context, ANNs play significant roles, particularly in areas such as energy efficiency, climate modeling, disease diagnosis, process optimization, and financial risk analysis. The findings of the study also show that some areas within the ANN literature have not been sufficiently addressed. These areas include:

Applications of ANNs in marine sciences, atmospheric sciences, and oceanography, ANN-based decision systems in sports sciences, psychology, and educational technologies, AI-based medical imaging applications, ANN based prediction models in disaster management and early warning systems, Modeling studies with ANNs in sustainable agriculture and food security. These themes have not been adequately explored and are identified as open for future research. Developing these topics will provide significant contributions to the literature, both practically and theoretically. Furthermore, when examining application results in more detail, it is observed that ANN-based studies primarily focus on predictive modeling, classification, and optimization. However, these applications could also be transferred to emerging fields such as decision support systems, smart city planning, bioinformatics, and

the integration of renewable energy systems. This suggests that future research could focus on developing new methodological approaches and conducting analyses with alternative data sources. The frequently encountered key terms classification, optimization, regression, predictive modeling, ANN highlight the effectiveness of ANNs, particularly in modeling, forecasting, and decision support systems. The prevalence of these terms reflects researchers' increasing need for data-driven, predictive, and adaptable systems. However, the analysis reveals that some areas have not been sufficiently explored or remain at a secondary level in the literature. In this context, certain areas for future research are suggested:

Climate modeling and atmospheric forecasting, Disaster risk prediction and early warning systems, Behavioral modeling and cognitive science applications, Smart farming and precision livestock systems, Renewable energy management and microgrids, Digital humanities and cultural heritage preservation, Adaptive learning systems and educational technologies. These proposed areas are open for development and can benefit from ANNs' high computational power and generalization capacity. In conclusion, this study has evaluated the place of artificial neural networks in academic literature from an interdisciplinary perspective, providing a comprehensive analysis by visualizing common application areas and research trends through bibliometric mapping. Based on the findings, it is suggested that academic production in the ANN field be enriched with more qualified content, interdisciplinary collaborations, and innovative application areas. In future studies, comparative bibliometric analyses using different academic databases such as Scopus, ProQuest along with in-depth literature reviews through text mining and thematic analysis methods, would be beneficial for the development of the research field. In all these cases, the artificial neural network literature has started to enrich and develop with international collaborations. This reveals that increasing interdisciplinary interactions is extremely important for the sustainability of the developments in the artificial neural network literature. It was suggested that niche themes should be developed to fill gaps in the literature by strengthening research collaborations, using new keywords related to emerging technologies and methods, increasing training and awareness, conducting more in-depth research and encouraging research on less studied areas.

5. CONCLUSIONS

As a result of the search in WoS, it was concluded that the articles titled artificial neural network were realized between 1986-2024 and the number of these articles has increased in recent years.It was concluded that the science network categories of the articles titled artificial neural networks are mostly Engineering Electrical Electronics, Computer Science Artificial Intelligence, Energy Fuels, Environmental Science. On the other hand, it was determined that Power Systems and Electric Vehicles, Oceanography, Meteorology and Atmospheric Sciences, Artificial Intelligence and Machine Learning were the most frequently cited topics. In parallel with all these cases, it was revealed that the most used micro-citation topics were evapotranspiration, load forecasting, chemometrics, nanofluid, and neural network ann, neural network and prediction model performance had strong links with other themes. All these results obtained as a result of the examinations are associated with the fact that the artificial neural network model forms the basis of artificial intelligence and machine learning models. The frequently encountered key terms in the study classification, optimization, regression, predictive modeling, and ANN highlight the effectiveness of ANNs, particularly in modeling, forecasting, and decision support systems. The prevalence of these terms reflects researchers' increasing need for data-driven, predictive, and adaptable systems. However, the analysis also reveals that some areas have not been sufficiently explored or remain at a secondary level in the literature. In this context, specific areas for future research are suggested as follows:

Climate modeling and atmospheric forecasting, disaster risk prediction and early warning systems, behavioral modeling and cognitive science applications, smart farming and precision livestock systems, renewable energy management and microgrids, digital humanities and cultural heritage preservation, adaptive learning systems and educational technologies. These proposed areas are open for development and can benefit from ANNs' high computational power and generalization capacity, and

they have not yet reached saturation, making them promising fields for future growth. In future research, it is suggested to perform bibliometric analysis on different databases related to artificial neural networks.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Credit Authorship Contribution Statement

MED: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision. **ŞD:** Conceptualization, Methodology, Validation, Formal analysis, Writing - Original Draft, Visualization

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

The datasets analyzed during the current study are available in the Web of Science database.

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