A bibliometric analysis of artificial intelligence applications in geospatial and geographic intelligence

Chatarina Muryani[1,2], Singgih Prihadi[1], Gentur Adi Tjahjono[1], Albertus Erico Jerry Krisna Nugroho[1], Fitria Dewi Kartika[1]

[1]Department of Geography Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Surakarta, Indonesia
[2]Center for Research and Disaster Management, Institute for Research and Community Service, Universitas Sebelas Maret, Surakarta, Indonesia

Article Info

Article history:

Received May 2, 2025
Revised Jul 13, 2026
Accepted Jul 21, 2026

Keywords:

Artificial intelligence
Bibliometric analysis
Geographic intelligence
Geospatial
VOSviewer

ABSTRACT

This study presents a comprehensive bibliometric analysis of the application of artificial intelligence in geospatial research and geographic intelligence. Using the Scopus database and visualization tools such as VOSviewer and Microsoft Excel, this study systematically maps the scientific literature across the five analytical dimensions: publication trends, citation structure, co-citation patterns, bibliographic merging, and keyword co-occurrence. The findings indicate a significant increase in global research interest, especially after 2020, with major contributions from the United States, China, and the United Kingdom. The results also reveal thematic clusters ranging from remote sensing and disaster response to smart city planning and spatial prediction. Through science mapping and performance analysis, the study highlights the intellectual structure and conceptual evolution of the field. The study contributes to academic understanding by identifying research gaps, emerging themes, and collaboration patterns, which can guide future interdisciplinary research in the artificial intelligence and geospatial domain.

Corresponding Author:

Chatarina Muryani
Department of Geography Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret
Ir. Sutami Road Number 36, Surakarta City, Central Java Province 57126, Indonesia
Email: chatarinamuryani@staff.uns.ac.id

1. INTRODUCTION

Over the past two decades, artificial intelligence has experienced tremendous development by changing the way humans interact with technology [1]. Artificial intelligence has surpassed theoretical limits in the fields of computer science and engineering so that it has been widely used in everyday life, such as systems that provide recommendations and decision making through large databases [2]. The advancement of artificial intelligence does not only have an impact on the economic, social or industrial sectors but the impact of artificial intelligence is also developing in the field of geography [3]. The integration of artificial intelligence with spatial data has resulted in new approaches in processing, analyzing, and interpreting more complex and dynamic geospatial information [4]. Recent advances in artificial intelligence have accelerated the development of geospatial artificial intelligence (GeoAI), defined as spatially explicit artificial intelligence techniques that integrate geographic knowledge, spatial relationships, and learning algorithms to enhance geospatial analysis and decision making [5]. This development is the basis and strengthens the role of digital geography in various aspects of substance such as regional spatial planning, disaster mitigation, land use change to artificial intelligence-based geography learning [6]. This is realized in various artificial intelligence research results in the development of geospatial technology by providing hope and a better future for the development of geospatial technology [7].

The development of artificial intelligence in geospatial technology has been integrated and used in various lives. According to Wang *et al.* [8], artificial intelligence is used to improve the classification of satellite images in terms of land cover mapping. The use of technology integration such as convolutional neural network (CNN) has been shown to provide accuracy resulting in differences between land types compared to conventional mapping methods. These findings provide opportunities for new efficiencies in environmental monitoring and regional planning. In line with that, Nagaiah *et al.* [9] suggest that artificial intelligence has an important role in the development of real-time spatial data-based natural disaster early warning systems. With faster results and accuracy ranging from 87% to 93.5%, it provides very important geospatial anomaly detection results. Artificial intelligence is able to enrich spatial analysis in geographic information systems through the automation of the given analysis and proper assessment of spatial data and the resulting machine learning algorithms are able to produce identification of spatial patterns that were previously difficult to find by traditional spatial statistical approaches [10].

In the context of policy and regional planning, artificial intelligence in spatial modeling can accelerate spatial simulation based on accurate analytical data. This contributes to evidence-based decision making, especially in the context of sustainable urban planning and resource management [11]. In the context of land use prediction, artificial intelligence provides guidance on recommendations and interpretation of results that can provide accurate modeling and predictions based on local government policies [12]. Recent studies have demonstrated the effectiveness of artificial intelligence-based geospatial models in supporting spatial decision making for disaster mitigation, particularly in optimizing the site selection of earthquake emergency shelters [13]. The importance of artificial intelligence in managing large-scale geospatial data that cannot be handled efficiently by manual approaches so that artificial intelligence algorithms need to be reconstructed by humans to produce feature extraction from remote sensing data in large-scale projects [14]. However, despite these significant contributions, there is still a gap in the mapping of scientific knowledge about artificial intelligence in the geospatial field, which has developed into geographic intelligence [3]. Many researchers are conducting research related to artificial intelligence by integrating geospatial technology, but it is difficult to understand the direction of development and research collaboration in this field as a whole if it is not analyzed more deeply.

Bibliometric analysis as a quantitative approach and visualizing the study of scientific literature is able to provide a comprehensive mapping of knowledge structures, global research trends, global topics, keywords, authors, and relationships between publications in a particular field [15]. This approach has been used in various disciplines to identify the intellectual map and future direction of research [16]. Some previous studies have used bibliometric approaches in the field of artificial intelligence in general. However, there are not many bibliometric studies that specifically highlight the application of artificial intelligence in the field of geospatial and geographic intelligence, especially with data visualization approaches such as co-citation, bibliographic coupling, and keyword analysis. The few bibliometric studies that address the role of artificial intelligence in remote sensing have limited coverage in the remote sensing domain [17], [18]. This suggests the need for a broader, cross-disciplinary study that integrates the fields of geographic information systems, remote sensing, spatial planning, and geographic intelligence in greater depth.

This research is relevant to provide a more comprehensive and strategic overview of scientific developments at the intersection of artificial intelligence and geospatial. This analysis will cover important elements in the academic knowledge ecosystem such as publication trends, geographical distribution of research, key sources, author collaboration networks, and thematic findings through the unit of analysis conducted in this bibliometric approach research [19]. Therefore, this study was designed to answer the research question:

RQ 1: what are the trends in scientific publications related to the application of artificial intelligence in geospatial and geographic intelligence over time?

RQ 2: who are the most contributing authors, institutions and countries in this field?

RQ 3: what are the dominant research themes emerging, and how do they relate to each other?

RQ 4: what is the structure of citation and collaboration networks within this scientific community?

Understanding these knowledge patterns will help researchers, academics and policy makers understand the scientific landscape and identify potential collaborations and future research directions in artificial intelligence and geospatial integration. This is important in addressing global challenges such as climate change, urbanization, and disaster management. Overall, the aim of this study is to map and analyze scientific publications on artificial intelligence applications in geospatial and geographic intelligence bibliometrically. This research not only provides an overview of how this topic has evolved, but also points out new gaps and opportunities for future exploration. So that it can be utilized by researchers, government, educators, and the public in understanding the integration of artificial intelligence in geospatial and geographic intelligence comprehensively.

2. METHOD
2.1. Study framework
This research was designed as a quantitative descriptive bibliometric study, with the aim of mapping the development of scientific literature on the application of artificial intelligence in the context of geospatial and geographic intelligence. The bibliometric approach allows researchers to identify intellectual structures, topic trends, and scientific collaborations within a field based on publication metadata made available by academic databases [15]. Bibliometric approaches have also been increasingly applied in geography-related domains to map research trends and intellectual structures, demonstrating their relevance for analyzing interdisciplinary fields that integrate technology and spatial sciences [20]. Bibliometric studies are important in this context because the field of artificial intelligence in geospatial shows rapid growth but has not been fully documented in the form of systematic scientific mapping. Therefore, this approach is used not only to determine the level of scientific productivity, but also to evaluate the impact and interconnectedness of researchers, institutions, and thematic keywords used in publications [21]. The analytical framework in this study is based on two main pillars, namely performance analysis and science mapping. Performance analysis aims to measure scientific contributions through the number of publications, citations, and productivity levels of various entities such as authors, journals, countries, and institutions [22]. Meanwhile, science mapping serves to illustrate conceptual and structural relationships through the analysis of co-citation, bibliographic coupling, and keyword co-occurrence [23].

This study also refers to the bibliometric approach developed by [15], in compiling the stages of bibliometric analysis, starting from the formulation of research questions, data retrieval, article screening, bibliometric analysis, to interpretation of visualization results. This approach is believed to be able to produce an accurate and comprehensive picture of the dynamics of knowledge development in the field under study. The researcher designed this study by focusing on scientific articles that explicitly discuss application of artificial intelligence in geographic information systems, remote sensing, spatial analysis, and other fields related to digital geography. The literature search was conducted on the Scopus database as one of the most extensive and highly reputable bibliographic databases in the international scientific literature [24]. The entire research process was carried out systematically to ensure the validity of the data. Starting from the formulation of relevant keywords, applying Boolean formulas in the search, to filtering data based on document type, publication language, and content relevance [25].

This stage uses preferred reporting items for systematic reviews and meta-analyses extension for scoping reviews (PRISMA-ScR) to assist researchers in representing the existing literature [26]. The results of the initial search were then filtered to obtain a dataset that truly reflected the research theme being studied. By using a bibliometric approach, this research is not only retrospective, but also prospective. That is, in addition to capturing developments that have occurred, this study also aims to identify future research directions through patterns of topic linkages and scientific collaboration [19]. This makes a strategic contribution to strengthening the multidisciplinary research agenda between computer science, geography and spatial planning. Overall, the framework of this study provides a solid methodological foundation for understanding how artificial intelligence has been and will continue to be used in the geospatial field. Through this approach, this research is expected to bridge the knowledge gap and strengthen the integration between smart technology and earth science in supporting spatial data-based decision-making.

2.2. Data retrieval strategy
Bibliographic data searches in this study were conducted using the Scopus database because it has a broad, trusted, and internationally indexed coverage of scientific literature, especially in the fields of technology, geography, and computer science. Besides, Scopus indexed articles are highly reputable academic scientific publications [24]. The search process was carried out using a combination of the main keywords with the following Boolean query string in the Scopus database: TITLE-ABS-KEY ("geoAI" OR "Geospatial intelligence" OR "geography intelligence").

2.3. Eligibility criteria
The literature selection phase was executed methodically to guarantee that only pertinent and high-quality papers were examined in this study. The selection was done after an initial search process in the Scopus database using a Boolean formula that produced a number of raw documents based on predetermined keyword combinations [27]. Inclusion and exclusion criteria were used to clarify the study boundaries and maintain data validity [28]. The inclusion criteria included documents that directly addressed artificial intelligence, geospatial and geographic intelligence with publications in reputable journals and peer-reviewed. Meanwhile, documents that were not directly related to Boolean formulas were excluded. The criteria are organized and presented in more detail at Table 1 to provide a clear overview of the literature selection process. The selection was conducted after an initial search in the Scopus database using a Boolean

formula that produced a set of raw documents based on predetermined keyword combinations [29]. Inclusion and exclusion criteria were subsequently applied to define the study boundaries and ensure data validity [30].

Table 1. Inclusion and exclusion criteria literature

Aspects	Inclusion	Exclusion
Year of publication	2010 - to 2025 (current)	Prior to 2010
Language of publication	Documents in English	Documents not in English
Type of document	Only scientific articles, conference papers, and review papers	Does not include editorials, notes, book chapters, or thesis/dissertations.
Subject area	Social sciences, earth and planetary science, environmental science, computer science, engineering	Other than sciences, earth and planetary science, environmental science, computer science, engineering
Access to metadata	Documents have titles, abstracts, and keywords available	Documents do not have titles, abstracts, and keywords available
Topic	Artificial intelligence, geospatial and geographic intelligence	Other than artificial intelligence, geospatial and geographic intelligence

2.4. Analytical procedures

This study developed a systematic analysis model to support bibliometric studies related to the application of artificial intelligence in the field of geospatial and geographic intelligence. This model consists of five main stages that are logically and methodologically interrelated, namely the formulation of the study framework, data search strategy, document screening process, bibliometric analysis, and visualization and interpretation of results [31]. Each stage is organized sequentially to ensure accuracy and transparency throughout the analysis process [32].

The first stage began with the formulation of the study framework, which became the conceptual basis for determining the scope of the research. In this case, the focus was on the scientific literature that addresses the integration of artificial intelligence in geographic information systems, remote sensing, and artificial intelligence-based spatial analysis. This framework also helped in formulating research questions and developing an effective search strategy. Furthermore, in the second stage, a data search strategy was implemented through the utilization of the Scopus database, with the use of specific keywords and Boolean formulations to obtain relevant and high-quality data. After the data was collected, the third stage was conducted using the PRISMA-ScR approach as a tool to systematically filter and select documents. The procedure includes four main steps: identification, screening, eligibility check, and final inclusion [15]. A PRISMA-ScR diagram was prepared to transparently document the flow of article selection, which is presented in Figure 1 [33].

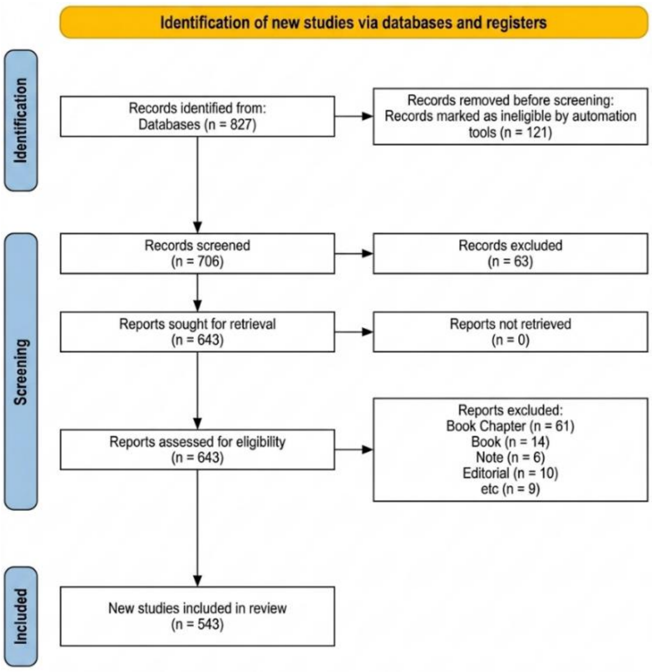

Figure 1. PRISMA-ScR [26]

In the fourth stage, the process of performance analysis and scientific mapping using a bibliometric approach was carried out. This analysis includes several main techniques, including citation analysis, co-citation analysis, bibliographic coupling, and co-occurrence analysis [34]. The final stage in this model is visualization and interpretation of the results. All bibliometric analysis results are visualized in the form of scientific networks using VOSviewer and Microsoft Excel software. This visualization includes author collaboration networks, keyword clustering, and citation relationships between documents, which are then interpreted to illustrate intellectual structures, research trends, and opportunities for future scientific collaboration [35]. By integrating these five stages presented in Figure 2, the analysis model built in this study is expected to provide a complete picture of the dynamics of knowledge and the direction of development of the field of artificial intelligence in the geospatial domain systematically and objectively.

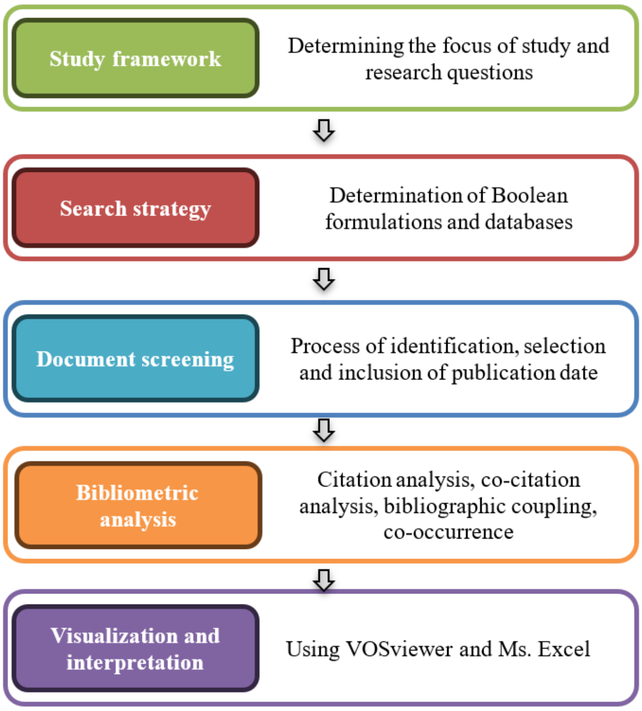

Figure 2. Analytical procedures

3. RESULTS AND DISCUSSION

3.1. Mapping research output and trends

The growth in the number of publications that discuss the application of artificial intelligence in geospatial and geographic intelligence has increased significantly in the last two decades. As shown in Figure 3, from 2010 to 2020, the development of publications was still relatively fluctuating and relatively limited. However, this trend changed drastically after 2020, where a surge in the number of publications began to be seen consistently. This increase indicates the increasing attention of the scientific community to the integration of artificial intelligence and geospatial technology as one of the strategic topics in multidisciplinary research. One of the main reasons for this increasing publication trend is the development of deep learning technology and the widespread availability of high-resolution spatial data [36]. The combination of advances in artificial intelligence algorithms and geospatial big data opens up new opportunities in spatial modeling, area mapping, and automatic detection of environmental changes [37]. The COVID-19 pandemic is also one of the triggering factors, where the need for remote monitoring technology is very important [38]. Artificial intelligence was used to model the spatial distribution of the pandemic and optimize resource allocation. This situation strengthens the position of GeoAI as a solution to the global crisis and expands its application to the fields of health, logistics, and adaptive urban planning so that many artificial intelligence applications emerge during the COVID-19 pandemic [39].

Figure 4 illustrates the main publication channels in this topic, with dominance by journals from the fields of computer science, geoinformatics, and environmental science. Some of the top journals that consistently publish related articles include Remote Sensing, ISPRS International Journal of Geo-Information, Sensors, and IEEE Access. This indicates that the topic is widely accepted across various scientific disciplines. The multidisciplinary character of the publications is evident, where a single topic can be found in journals oriented towards technical algorithms, spatial data processing, or location-based decision making. This emphasizes that artificial intelligence-geospatial studies do not stand in a particular scientific silo, but at the intersection of engineering, earth sciences, and policy. In addition to scientific journals, many publications come from conference proceedings such as International Geoscience and Remote Sensing Symposium (IGARSS) and ACM Special Interest Group on Spatial Information (ACM SIGSPATIAL). This shows that the development of artificial intelligence-geospatial technology is fast-paced and widely discussed in annual scientific forums, which enables dynamic knowledge exchange. These early publication trends reflect the emergence of GeoAI as an interdisciplinary research area, with initial applications extending beyond traditional geospatial analysis into domains such as environmental and health-related studies, as highlighted in earlier conceptual discussions of GeoAI [40]. The frequency of publications in open-access journals is also increasing. This benefits the global research community as it expands access to references and accelerates technology transfer.

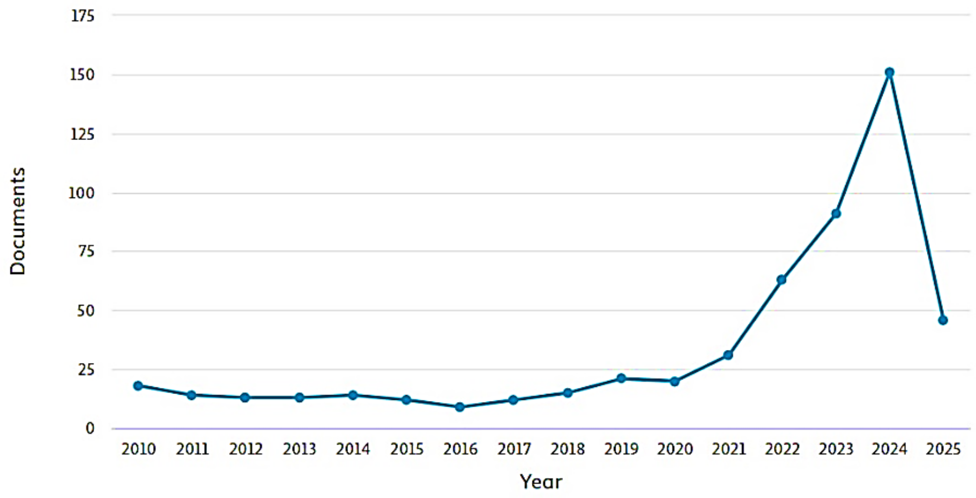

Figure 3. Document by years

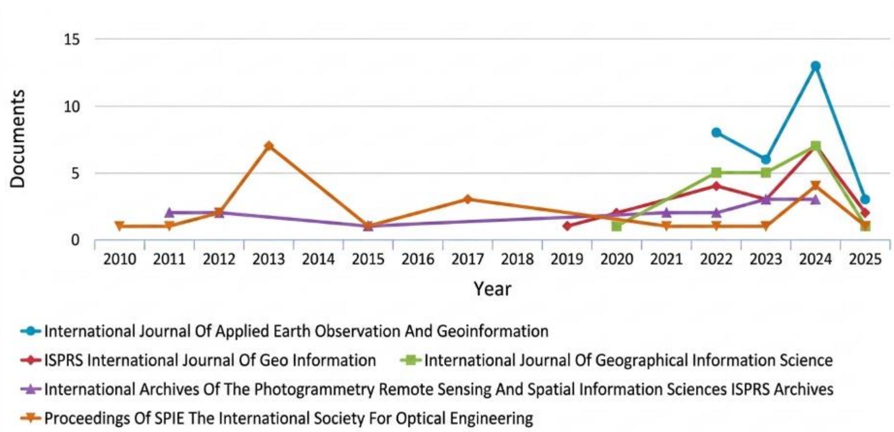

Figure 4. Document by sources

Figure 5 displays the authors who have the highest number of publications on this topic. Although the concentration of authors is not very high, there are several names that appear consistently in the literature, indicating that they are core contributors in the development of this science. Their presence is important for understanding the network of collaboration and the direction of the research being developed. This analysis also shows that many authors are active in collaborative research groups, both nationally and internationally. This means that the topic is not only developing at the individual level, but is also supported by large-scale research consortia and multi-institutional projects. It is important to note that there are also contributions from early career researchers or institutions in developing countries, albeit on a limited scale. This is a positive sign that access to artificial intelligence technologies and spatial data is becoming more equitable, although their role in global publications still needs to be strengthened. The identification of these influential authors can help new researchers choose the direction of collaboration, develop publication strategies, and understand the dominant research trends in a particular subdomain. In addition, this information can also be used by educational institutions to strengthen cross-border research cooperation.

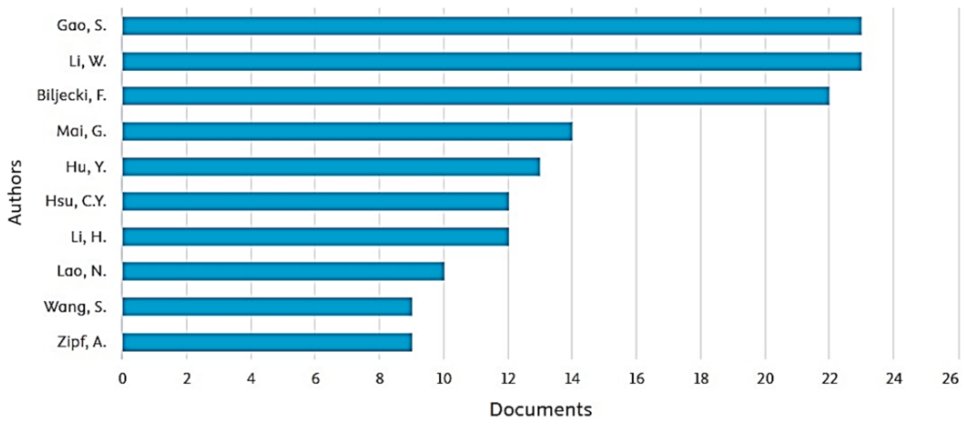

Figure 5. Document by authors

Figure 6 shows that the largest publication contributions come from countries such as the United States, China, Germany, United Kingdom, Singapore, and Australia. These countries have well-established research ecosystems, advanced computing facilities and research policies that support the integration of spatial technologies and data. This reflects the global dominance in knowledge production by developed countries with high capacity in artificial intelligence and geospatial research. The United States is the most productive country in terms of publications, in line with the role of government agencies, private sector, and top universities active in spatial-based artificial intelligence research. China follows as an aggressive emerging research force in developing artificial intelligence applications for regional planning, disaster mitigation, and environmental management. Collaboration between national research institutes and the industrial sector strengthens both countries' position on the global stage. European countries such as the United Kingdom and Germany are also making significant contributions, particularly on the topics of urban sustainability, smart cities, and the use of artificial intelligence for spatial governance. Many of their projects are open access, which has a broad impact on the global scientific community.

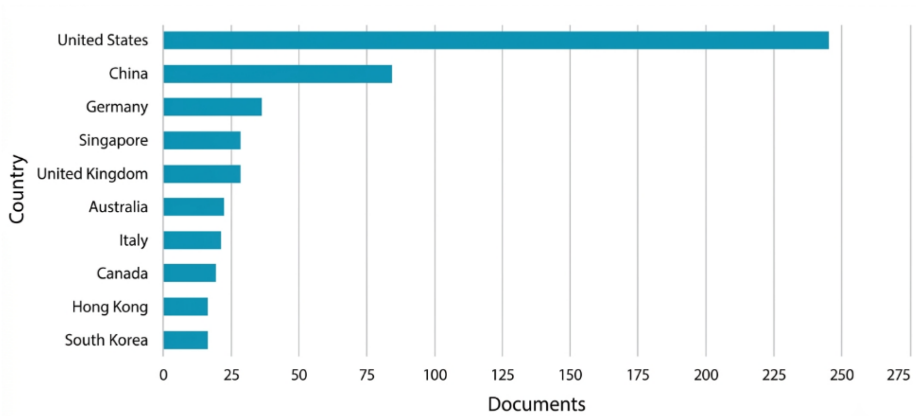

Figure 6. Document by territory

On the other hand, developing countries still show relatively small contributions despite their high demand for spatially intelligent technologies. Low access to research infrastructure and funding are the main obstacles limiting their scientific productivity. However, the potential for growth remains open, especially with more international collaborations and open funding programs. This geo-mapping shows that artificial intelligence in geospatial is not only a scientific trend, but also an indicator of inequality in access and research capacity between countries. An inclusive global strategy is needed so that this growing body of knowledge can be harnessed equitably, including by countries with high vulnerability to spatial issues such as disasters, climate change, and rapid urbanization.

As shown in Figure 7, the majority of documents analyzed in this study are scientific journal articles, followed by conference proceedings and review papers. This composition suggests that the development of artificial intelligence-geospatial topics has entered the realm of formal scientific discourse and undergone a consistent publication cycle. The significant presence of conference articles reflects that many innovations in this field are first introduced through scientific forums before being fully published in journals. This is common in technology fields that are dynamic and adaptive to the development of algorithmic and hardware trends. Meanwhile, the limited number of review articles indicates that conceptual studies and theory synthesis in this field still need to be strengthened. Bibliometric studies such as this one contribute to filling this gap by providing an intellectual map that can be used to develop theoretical frameworks and long-term research agendas. Overall, the variety of documents across formats and channels suggests that this topic has reached a certain level of maturity, but also holds great opportunities for further development, particularly in the form of critical literature reviews and collaborative publications across sectors. Figure 7 presents the distribution of publications by document type retrieved from the Scopus database. Journal articles represent the largest proportion of the dataset, followed by conference papers and review articles, indicating that peer-reviewed journal publications remain the primary channel for disseminating artificial intelligence research in geospatial and geographic intelligence.

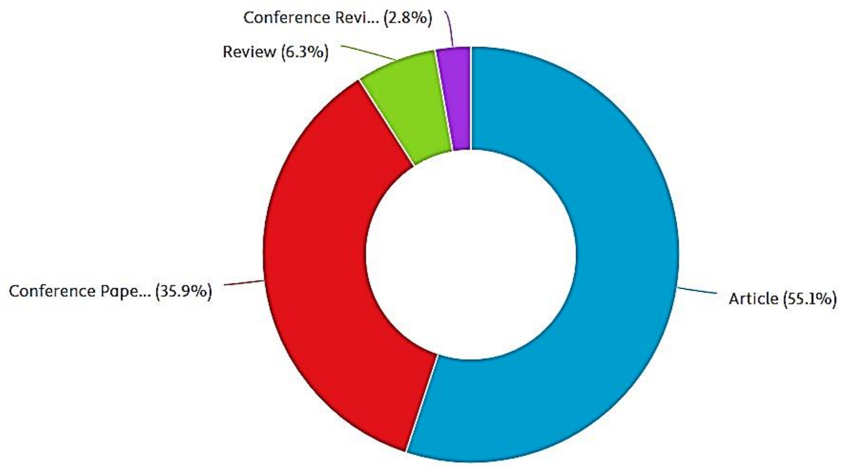

Figure 7. Document by type

3.2. Citation landscape analysis

Citation analysis is a quantitative approach in bibliometric studies used to assess the impact and scholarly influence of a publication or author in the academic community [15]. High citation indicates that the work is often referenced by other researchers and is considered to have a significant contribution to the development of knowledge in a particular field [41]. In the context of this research, citation analysis was conducted to identify leading authors in the study of artificial intelligence and its application in the field of geospatial and geographic intelligence. The visualization shown in Figure 8 shows the distribution of authors based on the number of citations they received in the documents analyzed. Authors with larger dot sizes in the visualization show higher citation rates, which indirectly indicates greater scholarly influence. Some authors also form clusters that show thematic affiliation or methodological relatedness. These results show findings that contain authors researching the use of artificial intelligence in high-resolution satellite image processing, and then evolve into findings of authors focusing on the integration of artificial intelligence and geographic information systems in the context of smart cities and spatial planning.

Artificial intelligence findings have opened up significant opportunities in the processing of high-resolution satellite imagery for various applications. Li *et al.* [42] shows the advancement of artificial intelligence and deep learning in Arctic sea ice monitoring, while Rezvani *et al.* [43] demonstrate the use of machine learning for flood prone point detection. Liu and Song [44] shows how GeoAI integrates computer vision with socioenvironmental patterns for property development mapping, meanwhile, Kang *et al.* [45] presents a comprehensive review of artificial intelligence methods and applications in the cartography. Zhang *et al.* [46] introduced MapGPT, a framework that integrates large language models with cartographic tools, and Akinboyewa *et al.* [47] developed an automated flood water depth estimation method for rapid flood mapping. The authors began to develop artificial intelligence research by integrating geographic information systems as regional planning, population, and urbanization. The integration of artificial intelligence with geographic information systems has brought significant advances in regional planning and smart city development. Wang *et al.* [8] developed a position-aware graph-CNN fusion network that integrates geospatial information with graph attention network for multiclass change detection, providing an advanced approach to monitor land use change and urbanization.

On the environmental aspect, Termeh *et al.* [48] applied an explainable GeoAI approach to assess noise pollution-prone areas, providing valuable insights for regional planning that considers the health and comfort of residents. Although such developments are promising, Marasinghe *et al.* [49] emphasized the importance of a responsible approach in the application of urban GeoAI, taking into account the ethical and social implications of this technology in an urban context. Their study of white and gray literature highlights the need for a strong ethical framework in the application of GeoAI for urban planning. Complementing this, Mansourihanis *et al.* [50] demonstrated the integration of geospatial intelligence with spatio-temporal modeling to monitor tourism-related carbon emissions in the United States, demonstrating the potential of artificial intelligence and geographic information systems in supporting environmental sustainability and managing the impacts of urbanization. Overall, the integration of artificial intelligence with geographic information systems opens up new opportunities for analyzing population patterns, managing urbanization, optimizing regional planning, and realizing the vision of a more inclusive, efficient, and sustainable smart city, although it still requires comprehensive ethical and social considerations in its implementation.

What is interesting about this finding is that there are researchers with a small number of publications, but a high citation rate. This suggests that the quality and relevance of research to scientific and practical needs have a huge influence. Articles that address actual challenges in spatial disaster mitigation, urban planning, or artificial intelligence-based resource management tend to receive more attention and citations. Some of the authors at the center of the cluster act as knowledge hubs, connecting researchers between different subfields. They often bridge technical research with policy applications or spatial operations. Their role is crucial in broadening the scope of research impact and promoting multidisciplinary integration within the scientific community. Overall, the results of this citation landscape analysis provide important insights into the key actors in the field of artificial intelligence for geospatial. This mapping not only helps in identifying thought leaders, but also provides strategic directions for new researchers to situate their contributions within the larger scholarly ecosystem. The findings confirm that citations are not just a number, but a representation of the strength of ideas, relevance of methodology, and ability to meet the challenges of the times.

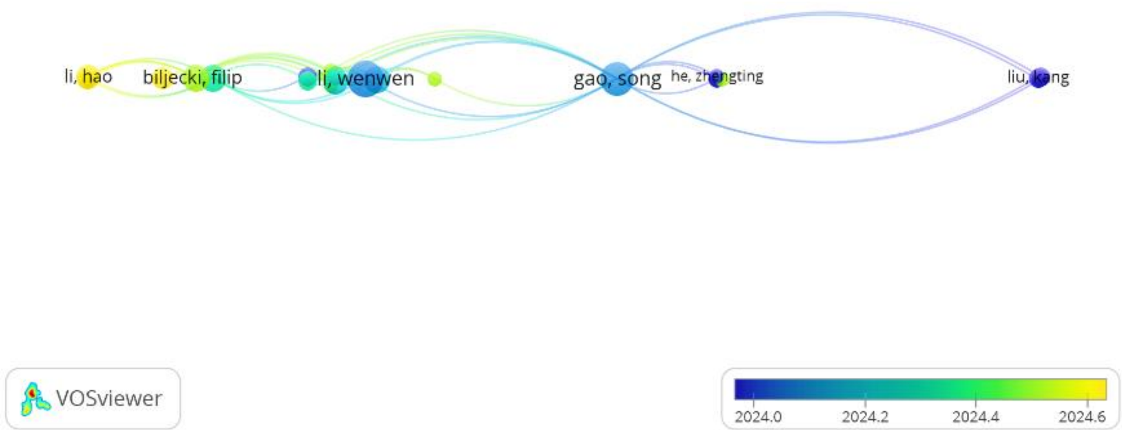

Figure 8. Citation analysis by author

3.3. Intellectual structure through co-citation analysis

Co-citation analysis is one of the techniques in bibliometric studies used to map the intellectual structure of a field of science based on the frequency of two authors or documents being cited simultaneously by other articles [51]. The more often two authors or scholarly works are cited together, the more likely it is that the two works have thematic or methodological affinities [34]. In the context of this research, co-citation analysis was conducted to understand how the scientific map is formed and grouped in the development of artificial intelligence research in the field of geospatial and geographic intelligence. Figure 9 presents the visualization of the co-citation network between authors. Each node in the graph represents one frequently cited author, while the connecting lines show the frequency of co-citation. The thickness of the line indicates the strength of the co-citation relationship between the authors. This visualization shows the formation of intellectual clusters, which are groups of authors that are closely connected through co-citation, reflecting the existence of a scientific community that has a common research focus. Table 2 shows the interpretation of the clusters formed.

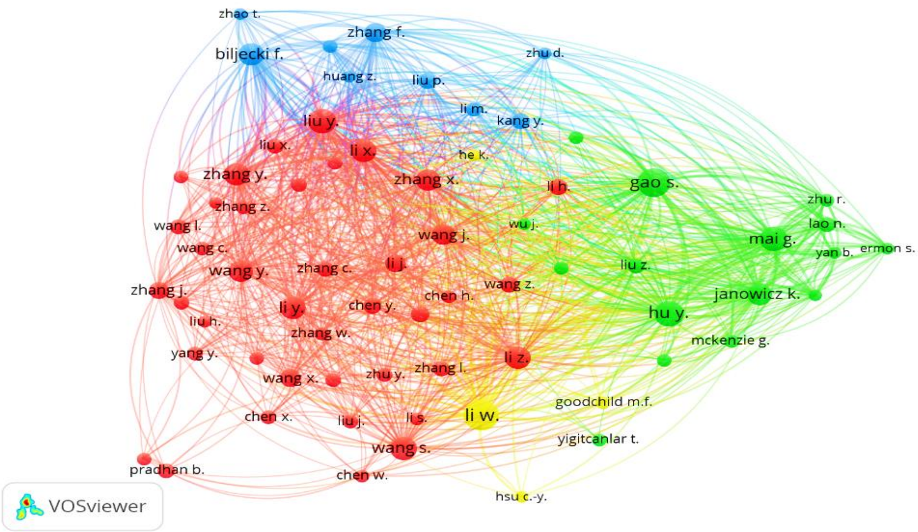

Figure 9. Co-citation analysis by author

Table 2. Interpretation of co-citation analysis clusters displayed

Cluster	Color	Label
1	Red	Chen H; Chen J; Chen W; Chen X; Chen Y; Chen Z; Huang X; Lee S; Li H; Li J; Li Q; Li S; Li X; Li Y; Li Z; Liu H; Liu J; Liu X; Liu Y; Pradhan B; Song y; Wang C; Wang h; Wang J; Wang L; Wang S; Wang X; Wang Y; Wang Z; Yang Y; Zhang C; Zhang H; Zhang J; Zhang L; Zhang W; Zhang X; Zhang Y; Zhang Z; Zhou Y; and Zhu Y
2	Green	Bengio Y; Bhaduri B; Cai L; Ermon; Gao S; Hu Y; Huang W; Janowicz K; Lao n; Liu Z; Mai G; Mckenzie G; Wu J; Yan B; Yigitcanlar T; and Zhu R
3	Blue	Biljecki F; Huang Z; Kang Y; Li M; Liu P; Ratti C; Zhang F; Zhao T; and Zhu D
4	Yellow	Goodchild M F; He k; Hsu C; and Li W

Cluster 1, for example, consists of authors who focus on development of deep learning algorithms in satellite image classification and remote sensing. This cluster is generally rooted in the fields of computer vision and machine learning, with strong methodological contributions. Cluster 2 includes authors who focus more on the application of artificial intelligence in area management, early warning systems, and spatial disaster risk mapping. Meanwhile, cluster 3 leads to researchers developing integrative approaches between artificial intelligence and smart city planning, including the use of geoinformation to support spatial decision-making. Cluster 4 emphasizes more on theoretical and conceptual aspects, including debates on ethics and sustainability in the use of artificial intelligence for spatial data. The existence of these clusters demonstrates the complexity of the field and the many approaches used by the global scientific community. The findings show that the intellectual structure of the field is multidimensional. Although the focus of studies varies, most authors remain connected through intersection of artificial intelligence and spatial data. For example, authors from the technical cluster and the applications cluster have indirect connections through citations to the same frameworks, such as CNNs or decision trees in spatial decision-making [8], [9]. The corresponding authors have work relevant to more than one research theme, and are often the connecting point between researchers who focus on technical aspects and researchers who focus on policy implementation.

This role is important in promoting interdisciplinary integration and strengthening scholarly cohesion in this emerging field. The fact that most clusters involve authors from different countries suggests that the intellectual structure in this topic is global and collaborative. Thus, co-citation analysis also helps in mapping conceptual collaborations that transcend geographical boundaries. In addition, co-citation analysis also provides a basis for designing theoretical frameworks in future research. Researchers can use information from these clusters to trace strong theoretical foundations and understand the key literature used by the scientific community in building their arguments. Co-citation not only serves as a mapping, but also as a literature guide in further research. Overall, the intellectual structure mapped through the co-citation analysis provides a comprehensive picture of the theoretical development, the relationship between ideas, as well as the centers of gravity of scholarship in this field. The results of this analysis show that the topic of artificial intelligence in geospatial is a very rich field in terms of concepts and approaches, and is open to further development through cross-disciplinary synthesis and integration of new approaches. To facilitate the interpretation of the co-citation network presented in Figure 9, the major clusters formed in the co-citation analysis are summarized and explained in Table 2. This table describes the thematic orientation of each cluster based on frequently co-cited authors, highlighting the intellectual structure underlying artificial intelligence applications in geospatial and geographic intelligence research.

3.4. Thematic evolution through bibliographic coupling

Bibliographic coupling analysis is a method in bibliometrics used to identify relationships between documents based on the similarity of the references they use [52]. Two documents are considered bibliographically linked if they cite the same source, indicating thematic affinity or similar methodological approaches [34]. In the context of this study, bibliographic coupling analysis was conducted to understand how research themes in artificial intelligence and geospatial fields evolve and form patterns of interrelationships between countries. Figure 10 presents a visualization of bibliographic coupling by country entity, showing the relationship between scientific literature from each geographic region. The size of the dot represents the number of documents produced by that country, while the connecting line indicates the strength of the bibliographic coupling. Countries that have a strong relationship indicate that they develop research with similar reference bases, which can be assumed to have a similar thematic focus. Table 3 shows the interpretation of the clusters formed through this analysis. The first cluster, for example, consists of countries such as the United States, Argentina, and Canada that focus on utilizing artificial intelligence in smart city planning and risk mitigation due to climate change. This cluster is characterized by a strong applicative and policy-oriented approach. Meanwhile, the second cluster involves countries such as Brazil, South Korea, and Germany that emphasize technical development, such as algorithm optimization and automation of satellite image classification. The third cluster consists of countries such as Malaysia, Saudi Arabia, and Poland. They tend to focus their research on environmental management, forest cover, and spatially-based disaster mitigation. The findings show that bibliographic coupling does not only reflect bibliographic relationships, but also the geographical context, national policies and research priorities of each country. Countries with rapid urbanization challenges tend to focus on smart city research, while countries with high disaster risk tend to develop artificial intelligence for spatial monitoring and mitigation through the integration of geographic information systems.

Bibliographic coupling also helps identify countries at the center of clusters, serving as a driver in directing regional and global research directions. Artificial intelligence research is best integrated with geographic information systems for regional planning in some countries [49]. The development of artificial intelligence with the integration of geographic information systems developed and utilized for disaster mitigation and mapping of areas with high disaster vulnerability [50]. Differences in the strength of connections between countries are also an indicator of the level of focus and thematic clarity of a national literature. Countries with well-directed national research strategies and funding support tend to produce documents that are strongly interconnected bibliographically. In contrast, countries with dispersed or less consolidated research systems tend to have weak connections in the coupling network.

The overall results of this bibliographic coupling analysis emphasize the importance of a global perspective in mapping the evolution of research themes. The connections between documents across countries reflect how spatial challenges are universal, but approaches and solutions are strongly influenced by local contexts. By understanding the coupling structure, researchers can identify new collaboration avenues, expand their reference range, and build a more contextually and globally relevant research framework. To support the interpretation of the bibliographic coupling network shown in Figure 10, the major country-based clusters identified in the analysis are summarized in Table 3. This table explains the thematic orientation of each cluster based on shared reference patterns, providing insight into how national research priorities and methodological similarities shape the development of artificial intelligence applications in geospatial and geographic intelligence.

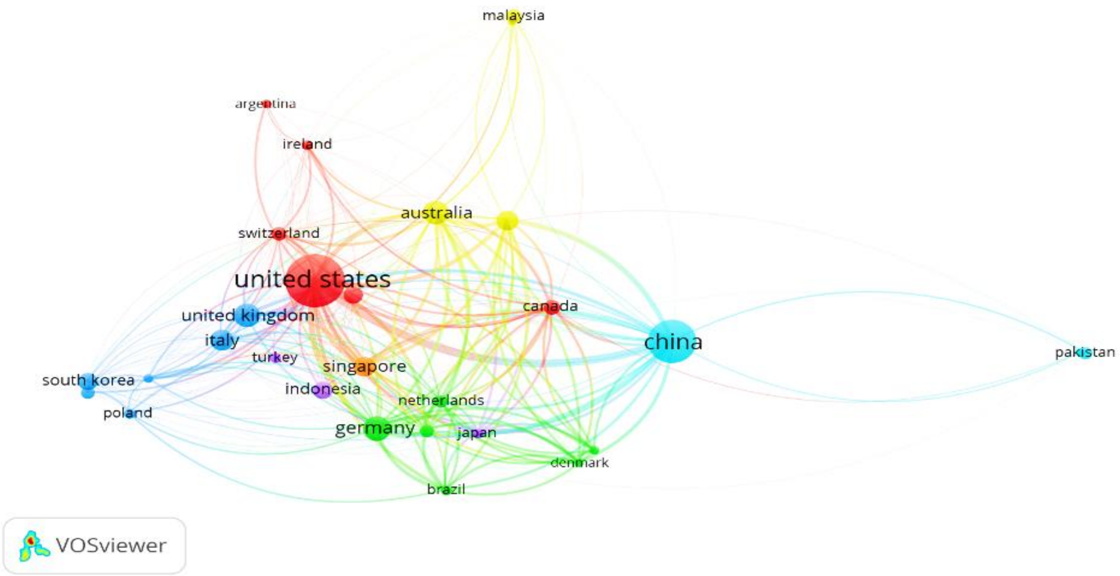

Figure 10. Bibliographic coupling by country

Table 3. Interpretation of bibliographic coupling analysis clusters displayed

Cluster	Color	Label
1	Red	Argentina, Canada, India, Ireland, Switzerland, and United States
2	Green	Austria, Brazil, Denmark, Egypt, Germany, and Netherlands
3	Blue	Italy, Poland, Saudia Arabia, South Korea, Spain, and United Kingdom
4	Yellow	Australia, Hong Kong, Malaysia, and Sweden

3.5. Conceptual framework from keywords co-occurrence

Keyword co-occurrence analysis is a bibliometric technique used to identify key concepts in a field of science through the frequency of co-occurrence of keywords in scientific documents [53]. The more often two or more keywords appear together in a document, the stronger the thematic relationship between the terms [35]. In the context of this research, co-occurrence analysis was used to map the conceptual framework developed in the literature on artificial intelligence in geospatial and geographic intelligence. Figure 11 presents a visualization of the keyword network map that forms several major clusters. These clusters are represented in different colors, each signifying a cluster of related themes. Table 4 summarizes the interpretation of each cluster based on the dominant keywords. The existence of these clusters reflects the direction of concept development and the approach used by the scientific community in studying this topic.

The first cluster consists of keywords such as ChatGPT, climate change, disaster response, GeoAI, geospatial, information retrieval, large language models, and social media. This cluster reflects the thematic focus on the utilization of remote sensing technology for area classification and spatial mapping with CNN-based approaches or advanced classification algorithms based on spatial data [8]. This cluster provides the foundation for various artificial intelligence applications in environmental ecosystems, especially for disaster, land monitoring, deforestation, and land cover conversion.

The second cluster features terms such as explainable AI, explainable artificial intelligence, GeoAI, graph neural networks, location encoding, spatial prediction, spatial representation learning, and urban analytics. This shows the focus on the use of artificial intelligence for large-scale spatial analysis in the context of smart city planning. It shows a focus on the use of artificial intelligence for large-scale spatial analysis in the context of smart city planning and spatial data-driven territory management. This cluster indicates a shift from manual approaches to more automated systems, based on the integration of spatial data with smart technologies.

The third cluster emphasizes the relationship between data fusion, geospatial analysis, geospatial intelligence, machine learning, random forest, spatial data, and urban planning. This cluster represents the application of artificial intelligence in spatial data integration, with a focus on spatial modeling for early detection, vulnerability mapping, and location-based decision-making. It is particularly relevant in the context of climate change adaptation and disaster management capacity building.

The fourth cluster includes keywords such as smart city, spatial decision, IoT, and urban monitoring. This theme emphasizes the integration of artificial intelligence with digital infrastructure and geographic information systems to support decision-making in cities based on real-time data. This cluster shows how artificial intelligence is positioned as a key driver in realizing efficient city governance that is responsive to spatial dynamics.

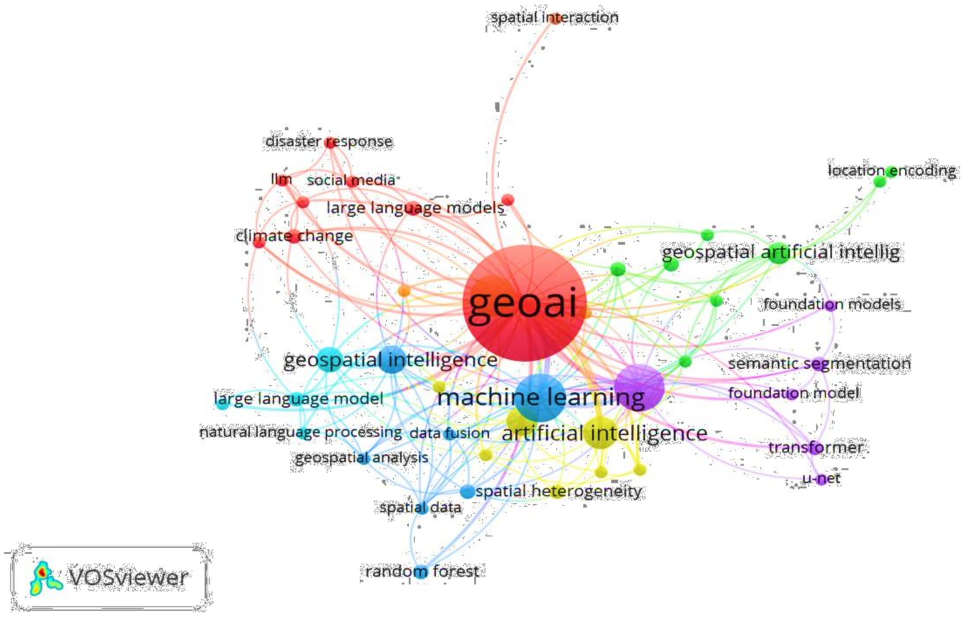

Figure 11. Co-occurrence analysis by keywords

Table 4. Interpretation of co-occurrence analysis clusters displayed

Cluster	Color	Label
1	Red	ChatGPT, climate change, disaster response, GeoAI, geospatial, information retrieval, large language models, and social media
2	Green	Explainable AI, explainable artificial intelligence, GeoAI, graph neural networks, location encoding, spatial prediction, spatial representation learning, and urban analytics
3	Blue	Data fusion, geospatial analysis, geospatial intelligence, machine learning, random forest, spatial data, and urban planning
4	Yellow	Artificial intelligence, cartography, ethics, GeoAI, responsible artificial intelligence, smart city, and spatial heterogeneity
5	Purple	Deep learning, foundation models, semantic segmentation, transformer, and U-Net

The occurrence of several cross-cluster keywords such as machine learning, deep learning, and artificial intelligence shows that artificial intelligence methods are transdisciplinary and widely applied in various spatial contexts. This strengthens artificial intelligence's position as a general approach that is flexible and adaptive to various spatial challenges. The analysis also shows a trend of shifting keywords from technical to applied terms. Whereas initially the focus was more on methods such as support vector machine or artificial neural network, terms such as urban resilience, geospatial intelligence, or spatial planning are now used. This shows that the scientific community is increasingly placing artificial intelligence as a tool to address real-world problems in geography.

In addition, the density of keywords in some clusters indicates popularity and high frequency in the literature, indicating great focus and attention from the academic community. However, keywords with low density but still appearing, such as explainable AI or graph neural networks, may be an indicator of new themes that are emerging or have the potential to be further developed. Overall, the results of this co-occurrence analysis provide an overview of the conceptual landscape that makes up the artificial intelligence-geospatial field. This keyword map can be used as a basis for designing theoretical frameworks, identifying mature research areas that are still open for exploration, and understanding the dynamics of scientific discourse within the global research community. By understanding how keywords are interconnected and form thematic clusters, researchers can map the position of their research within the broader knowledge ecosystem, while designing relevant and impactful scientific contributions. This analysis is an important capstone in understanding the direction of topic development and formulating conceptual and strategic implications of the overall bibliometric findings. To clarify the thematic structure derived from the keyword co-occurrence network shown in Figure 11, the main conceptual clusters and their dominant keywords are summarized in Table 4. This table provides a concise interpretation of each cluster, highlighting the core research themes and conceptual directions that characterize artificial intelligence applications in geospatial and geographic intelligence.

4. CONCLUSION

This study provides a comprehensive bibliometric overview of artificial intelligence applications in geospatial and geographic intelligence using Scopus data and science mapping techniques. The results reveal a rapid growth in publications after 2020, dominated by contributions from countries with strong research infrastructures such as the United States, China, and United Kingdom. Core intellectual clusters are formed around remote sensing, spatial prediction, smart cities, disaster management, and responsible GeoAI. Citation, co-citation, bibliographic coupling, and keyword co-occurrence analyses collectively illustrate the intellectual structure, thematic evolution, and collaboration patterns within the field. Despite these contributions, this study is limited by the use of single bibliographic database and reliance on metadata-based analysis. Future research may expand the dataset by incorporating additional databases and applying content-based or longitudinal analyses to capture deeper thematic evolution and methodological advances in artificial intelligence-driven geospatial research.

ACKNOWLEDGMENTS

The authors would like to thank Universitas Sebelas Maret for supporting and funding this research through a fundamental grant.

FUNDING INFORMATION

This research was funded by the Universitas Sebelas Maret Annual Work Plan and Budget (RKAT) for fiscal year 2025 through the Fundamental Research B (PFB-UNS) program, under research assignment agreement number 369/UN27.22/PT.01.03/2025.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Chatarina Muryani	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Singgih Prihadi	✓			✓	✓				✓	✓		✓		
Gentur Adi Tjahjono	✓			✓	✓					✓	✓	✓		
Albertus Erico Jerry Krisna Nugroho		✓	✓		✓	✓	✓	✓	✓	✓	✓			
Fitria Dewi Kartika					✓		✓		✓	✓	✓		✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY

Due to ethical/privacy concerns, the data are not publicly available. However, anonymized datasets are available from the corresponding author, [CM], upon reasonable request.

REFERENCES

[1] Y. Lu, "Artificial intelligence: a survey on evolution, models, applications and future trends," *Journal of Management Analytics*, vol. 6, no. 1, pp. 1–29, Jan. 2019, doi: 10.1080/23270012.2019.1570365.

[2] S. Makridakis, "The forthcoming artificial intelligence (AI) revolution: Its impact on society and firms," *Futures*, vol. 90, pp. 46–60, Jun. 2017, doi: 10.1016/j.futures.2017.03.006.

[3] S. Scheider and K.-F. Richter, "GeoAI," *KI - Künstliche Intelligenz*, vol. 37, no. 1, pp. 5–9, 2023, doi: 10.1007/s13218-022-00797-z.

[4] W. Li and C.-Y. Hsu, "GeoAI for large-scale image analysis and machine vision: recent progress of artificial intelligence in geography," *ISPRS International Journal of Geo-Information*, vol. 11, no. 7, Jul. 2022, doi: 10.3390/ijgi11070385.

[5] K. Janowicz, S. Gao, G. McKenzie, Y. Hu, and B. Bhaduri, "GeoAI: spatially explicit artificial intelligence techniques for geographic knowledge discovery and beyond," *International Journal of Geographical Information Science*, vol. 34, no. 4, pp. 625–636, Apr. 2020, doi: 10.1080/13658816.2019.1684500.

[6] T. Zhou, "Application of artificial intelligence in geography," in *International Conference on Software Engineering and Machine Learning*, Dec. 2023, doi: 10.1088/1742-6596/2646/1/012006.

[7] A. Lavallin and J. A. Downs, "Machine learning in geography–past, present, and future," *Geography Compass*, vol. 15, no. 5, May 2021, doi: 10.1111/gec3.12563.

[8] M. Wang, X. Li, K. Tan, J. Mango, C. Pan, and D. Zhang, "Position-aware graph-CNN fusion network: an integrated approach combining geospatial information and graph attention network for multiclass change detection," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 62, pp. 1–16, 2024, doi: 10.1109/TGRS.2024.3350573.

[9] K. Nagaiah, K. Kalaivani, R. Palamalai, K. Suresh, V. Sethuraman, and V. Karuppiah, "A logical remote sensing based disaster management and alert system using ai-assisted internet of things technology," *Remote Sensing in Earth Systems Sciences*, vol. 7, no. 4, pp. 457–471, Dec. 2024, doi: 10.1007/s41976-024-00139-7.

[10] Y. Choi, "GeoAI: integration of artificial intelligence, machine learning, and deep learning with GIS," *Applied Sciences*, vol. 13, no. 6, Mar. 2023, doi: 10.3390/app13063895.

[11] S. D. Sabbata, A. Ballatore, H. J. Miller, R. Sieber, I. Tyukin, and G. Yeboah, "GeoAI in urban analytics," *International Journal of Geographical Information Science*, vol. 37, no. 12, pp. 2455–2463, Dec. 2023, doi: 10.1080/13658816.2023.2279978.

[12] W. Utami, C. Sugiyanto, and N. Rahardjo, "Artificial intelligence in land use prediction modeling: a review," *IAES International Journal of Artificial Intelligence*, vol. 13, no. 3, pp. 2514–2523, Sep. 2024, doi: 10.11591/ijai.v13.i3.pp2514-2523.

[13] A. Amiran, B. Behnam, and S. Seyedin, "AI-based model for site-selecting earthquake emergency shelters," *Scientific Reports*, vol. 14, no. 1, Nov. 2024, doi: 10.1038/s41598-024-80586-w.

[14] I. Molenaar, "Towards hybrid human-AI learning technologies," *European Journal of Education*, vol. 57, no. 4, pp. 632–645, Dec. 2022, doi: 10.1111/ejed.12527.

[15] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. M. Lim, "How to conduct a bibliometric analysis: an overview and guidelines," *Journal of Business Research*, vol. 133, pp. 285–296, Sep. 2021, doi: 10.1016/j.jbusres.2021.04.070.

[16] O. Ellegaard, "The application of bibliometric analysis: disciplinary and user aspects," *Scientometrics*, vol. 116, no. 1, pp. 181–202, Jul. 2018, doi: 10.1007/s11192-018-2765-z.

[17] P. Duan, Y. Wang, and P. Yin, "Remote sensing applications in monitoring of protected areas: a bibliometric analysis," *Remote Sensing*, vol. 12, no. 5, Feb. 2020, doi: 10.3390/rs12050772.

[18] T. Xu, F. Wang, Q. Yi, L. Xie, and X. Yao, "A bibliometric and visualized analysis of research progress and trends in rice remote sensing over the past 42 years (1980–2021)," *Remote Sensing*, vol. 14, no. 15, Jul. 2022, doi: 10.3390/rs14153607.

[19] D. M. Marchiori, S. Popadiuk, E. W. Mainardes, and R. G. Rodrigues, "Innovativeness: a bibliometric vision of the conceptual and intellectual structures and the past and future research directions," *Scientometrics*, vol. 126, no. 1, pp. 55–92, Jan. 2021, doi: 10.1007/s11192-020-03753-6.

[20] A. E. J. K. Nugroho, S. Sugiyanto, and S. Prihadi, "Implementation of geography curriculum and learning methods : a bibliometric analysis," *Jurnal Eduscience*, vol. 12, no. 4, pp. 967–987, Aug. 2025, doi: 10.36987/jes.v12i4.7033.

[21] A. Kalantari *et al.*, "A bibliometric approach to tracking big data research trends," *Journal of Big Data*, vol. 4, no. 1, Dec. 2017, doi: 10.1186/s40537-017-0088-1.

[22] O. Öztürk, R. Kocaman, and D. K. Kanbach, "How to design bibliometric research: an overview and a framework proposal," *Review of Managerial Science*, vol. 18, no. 11, pp. 3333–3361, 2024, doi: 10.1007/s11846-024-00738-0.

[23] J. P. Romanelli, M. C. P. Gonçalves, L. F. de A. Pestana, J. A. H. Soares, R. S. Boschi, and D. F. Andrade, "Four challenges when conducting bibliometric reviews and how to deal with them," *Environmental Science and Pollution Research*, vol. 28, no. 43, pp. 60448–60458, 2021, doi: 10.1007/s11356-021-16420-x.

[24] J. Zhu and W. Liu, "A tale of two databases: the use of Web of Science and Scopus in academic papers," *Scientometrics*, vol. 123, no. 1, pp. 321–335, Apr. 2020, doi: 10.1007/s11192-020-03387-8.

[25] A. Shukla, A. Biere, L. Pulina, and M. Seidl, "A survey on applications of quantified Boolean formulas," in *2019 IEEE 31st International Conference on Tools with Artificial Intelligence (ICTAI)*, Nov. 2019, pp. 78–84, doi: 10.1109/ICTAI.2019.00020.

[26] N. R. Haddaway, M. J. Page, C. C. Pritchard, and L. A. McGuinness, "PRISMA2020 : an R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis," *Campbell Systematic Reviews*, vol. 18, no. 2, Jun. 2022, doi: 10.1002/cl2.1230.

[27] Y. Shi, S. Blainey, C. Sun, and P. Jing, "A literature review on accessibility using bibliometric analysis techniques," *Journal of Transport Geography*, vol. 87, Jul. 2020, doi: 10.1016/j.jtrangeo.2020.102810.

[28] W. Kappers, "Through the lens of the reviewer: information literacy, an LMS, and peer review," in *2016 ASEE Annual Conference & Exposition Proceedings*, 2016, doi: 10.18260/p.27040.

[29] M. Frické, “Boolean logic,” *Knowledge Organization*, vol. 48, no. 2, pp. 177–191, 2021, doi: 10.5771/0943-7444-2021-2-177.

[30] T. A. Rocha, A. T. Martins, and F. M. Ferreira, “Synthesis of a DNF formula from a sample of strings,” in *2018 7th Brazilian Conference on Intelligent Systems (BRACIS)*, Oct. 2018, pp. 534–539, doi: 10.1109/BRACIS.2018.00098.

[31] A. Lohia, K. D. Kadam, R. R. Joshi, and A. M. Bongale, “Bibliometric analysis of one-stage and two-stage object detection,” *Library Philosophy and Practice*, vol. 2021, pp. 1–33, 2021.

[32] W. M. Lim and S. Kumar, “Guidelines for interpreting the results of bibliometric analysis: a sensemaking approach,” *Global Business and Organizational Excellence*, vol. 43, no. 2, pp. 17–26, Jan. 2024, doi: 10.1002/joe.22229.

[33] M. J. Page *et al.*, “The PRISMA 2020 statement: an updated guideline for reporting systematic reviews,” *BMJ*, vol. 372, no. 1, pp. 1–9, Mar. 2021, doi: 10.1136/bmj.n71.

[34] R. Zhang and J. Yuan, “Improving bibliographic coupling and co-citation: a study evaluating the effects of various full-text citation features,” *Journal of Information Science*, Mar. 2025, doi: 10.1177/01655515251322483.

[35] A. C. Vargas, M. E. -Mina, D. L. Alvarez, and J. N. Espinosa, “Bibliometric software: the most commonly used in research,” in *ICAIW 2022: Workshops at the 5th International Conference on Applied Informatics*, 2022, pp. 47–65.

[36] M. Sharp, R. Ak, and T. Hedberg, “A survey of the advancing use and development of machine learning in smart manufacturing,” *Journal of Manufacturing Systems*, vol. 48, pp. 170–179, Jul. 2018, doi: 10.1016/j.jmsy.2018.02.004.

[37] D. Li, Z. Shao, and R. Zhang, “Advances of geo-spatial intelligence at LIESMARS,” *Geo-spatial Information Science*, vol. 23, no. 1, pp. 40–51, Jan. 2020, doi: 10.1080/10095020.2020.1718001.

[38] S. Dananjayan and G. M. Raj, “Artificial intelligence during a pandemic: the COVID-19 example,” *The International Journal of Health Planning and Management*, vol. 35, no. 5, pp. 1260–1262, Sep. 2020, doi: 10.1002/hpm.2987.

[39] C. Lv *et al.*, “Innovative applications of artificial intelligence during the COVID-19 pandemic,” *Infectious Medicine*, vol. 3, no. 1, Mar. 2024, doi: 10.1016/j.imj.2024.100095.

[40] T. V. Pham, J. E. Hart, F. Laden, and Y.-Y. Chiang, “Emerging trends in geospatial artificial intelligence (geoAI): potential applications for environmental epidemiology,” *Environmental Health*, vol. 17, no. 1, Dec. 2018, doi: 10.1186/s12940-018-0386-x.

[41] I. Passas, “Bibliometric analysis: the main steps,” *Encyclopedia*, vol. 4, no. 2, pp. 1014–1025, Jun. 2024, doi: 10.3390/encyclopedia4020065.

[42] W. Li, C. Hsu, and M. Tedesco, “Advancing arctic sea ice remote sensing with AI and deep learning: opportunities and challenges,” *Remote Sensing*, vol. 16, no. 20, Oct. 2024, doi: 10.3390/rs16203764.

[43] S. M. Rezvani, A. Gonçalves, M. J. F. Silva, and N. M. de Almeida, “Smart hotspot detection using geospatial artificial intelligence: a machine learning approach to reduce flood risk,” *Sustainable Cities and Society*, vol. 115, Nov. 2024, doi: 10.1016/j.scs.2024.105873.

[44] C. Liu and W. Song, “Mapping property redevelopment via GeoAI: integrating computer vision and socioenvironmental patterns and processes,” *Cities*, vol. 144, Jan. 2024, doi: 10.1016/j.cities.2023.104644.

[45] Y. Kang, S. Gao, and R. E. Roth, “Artificial intelligence studies in cartography: a review and synthesis of methods, applications, and ethics,” *Cartography and Geographic Information Science*, vol. 51, no. 4, pp. 599–630, Jul. 2024, doi: 10.1080/15230406.2023.2295943.

[46] Y. Zhang, Z. He, J. Li, J. Lin, Q. Guan, and W. Yu, “MapGPT: an autonomous framework for mapping by integrating large language model and cartographic tools,” *Cartography and Geographic Information Science*, vol. 51, no. 6, pp. 717–743, Nov. 2024, doi: 10.1080/15230406.2024.2404868.

[47] T. Akinboyewa, H. Ning, M. N. Lessani, and Z. Li, “Automated floodwater depth estimation using large multimodal model for rapid flood mapping,” *Computational Urban Science*, vol. 4, no. 1, May 2024, doi: 10.1007/s43762-024-00123-3.

[48] S. V. R. -Termeh, A. S. -Niaraki, X. A. Yao, R. A. Naqvi, and S.-M. Choi, “Assessment of noise pollution-prone areas using an explainable geospatial artificial intelligence approach,” *Journal of Environmental Management*, vol. 370, Nov. 2024, doi: 10.1016/j.jenvman.2024.122361.

[49] R. Marasinghe, T. Yigitcanlar, S. Mayere, T. Washington, and M. Limb, “Towards responsible urban geospatial AI: insights from the white and grey literatures,” *Journal of Geovisualization and Spatial Analysis*, vol. 8, no. 2, Dec. 2024, doi: 10.1007/s41651-024-00184-2.

[50] O. Mansourihanis, M. J. M. Tilaki, T. Kookhaei, A. Zaroujtaghi, S. Sheikhfarshi, and N. Abdoli, “Integrating geospatial intelligence and spatio-temporal modeling for monitoring tourism-related carbon emissions in the United States,” *Management of Environmental Quality: An International Journal*, vol. 36, no. 1, pp. 107–129, Jan. 2025, doi: 10.1108/MEQ-04-2024-0156.

[51] F. A. F. Ferreira, “Mapping the field of arts-based management: bibliographic coupling and co-citation analyses,” *Journal of Business Research*, vol. 85, pp. 348–357, Apr. 2018, doi: 10.1016/j.jbusres.2017.03.026.

[52] S. H. H. Shah, S. Lei, M. Ali, D. Doronin, and S. T. Hussain, “Prosumption: bibliometric analysis using HistCite and VOSviewer,” *Kybernetes*, vol. 49, no. 3, pp. 1020–1045, Aug. 2019, doi: 10.1108/K-12-2018-0696.

[53] R. Kleminski, P. Kazienko, and T. Kajdanowicz, “Analysis of direct citation, co-citation and bibliographic coupling in scientific topic identification,” *Journal of Information Science*, vol. 48, no. 3, pp. 349–373, Jun. 2022, doi: 10.1177/0165551520962775.

BIOGRAPHIES OF AUTHORS

Chatarina Muryani is a senior lecturer in the Department of Geography Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, Indonesia. She holds a doctoral degree in Geography Education and has published many scientific papers in the field of environmental education, curriculum development, and spatial thinking in schools. Her research interests include geography literacy, sustainability education, and technology integration in geography teaching to disaster. In this article, she contributed to the conceptual framework, manuscript supervision, and critical review. She has received national grants from the Indonesian Ministry of Education for curriculum innovation and has been a reviewer and editor for several accredited journals in education and geography in Indonesia. She can be contacted at email: chatarinamuryani@staff.uns.ac.id.

Singgih Prihadi is a lecturer and researcher at the Department of Geography Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret. His expertise includes educational technology, geography education and learning as well as geography learning models. He has actively participated in academic research and has published articles on geography learning and education. In this research, he contributed to the methodological design and provided analytical direction, particularly in the bibliometric framework. He has been involved in several national and regional development research projects, and is a member of the Indonesian Geographers Association (IGI). He can be contacted at email: singgihprihadi@staff.uns.ac.id.

Gentur Adi Tjahjono is a lecturer at the Department of Geography Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret. His academic background focuses on environmental geography, remote sensing, and sustainable development education. He has authored and co-authored papers in indexed journals and has experience integrating geospatial analysis in educational research. His role in this research includes co-developing data visualizations and interpreting thematic clusters. She is a recipient of national research grants and a frequent speaker in workshops on geospatial and sustainability education. He can be contacted at email: genturadi@staff.uns.ac.id.

Albertus Erico Jerry Krisna Nugroho is a graduate student of Geography Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret, specializing in geography education. Having experience as a geography teacher and vice principal for public relations provides additional contributions in modern geography education. His research interests include geography and environmental education. As an author, he assisted the first author responsible for designing the research, conducting bibliometric data analysis using VOSviewer, preparing visualizations, and drafting the manuscript. He can be contacted at email: albertusericojerry@student.uns.ac.id.

Fitria Dewi Kartika graduated from Geography Education master program at Department of Geography Education, Faculty of Teacher Training and Education, Universitas Sebelas Maret. Her academic focus includes geography learning media, educational technology, and physical geography. She contributes in critical review of manuscripts and alignment with current geography education trends. Her contributions are particularly relevant in linking bibliometric insights. She has been actively involved in the disaster training and development program of the Institute of Research and Community Service. She can be contacted at email: fitriadewi27@student.uns.ac.id.