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Review Article

Bibliometric Analysis of Interferometric Synthetic Aperture Radar (InSAR) Application in Land Subsidence from 2000 to 2021

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Land subsidence is one of the serious natural disasters which can cause heavy casualties and economic losses. As a vital method, Interferometric Synthetic Aperture Radar (InSAR) can provide quick and efficient solutions for analysis. Currently, most reviews on InSAR application in land subsidence only focused on single types of land areas, such as the land around groundwater and land of the mining area. There is a lack of discussion on all types of land areas. This study thus aims at conducting a bibliometric literature analysis of the existing literature from 2000 to 2021 to fill this gap. The authors used scientific mapping methods to analyze the InSAR applications in land subsidence so that researchers and practitioners can comprehend the procedure. Then, the authors identified the major research areas, development milestones, evolutionary stages, and the transaction dynamics of evolutionary stages. Knowledge maps of five aspects were applied and analyzed in this research, including temporal development analysis, countries and institutions, major research disciplines, high-frequency terms, and cocitation of high-citation papers. The results reveal that the research of land subsidence monitoring with InSAR is in the stage of diffusion from developing many tools and techniques to integrating with other research areas. Overall, the bibliometric results combined with evolutionary stages provide a holistic picture of the status quo and future trends in InSAR application in land subsidence.

1. Introduction

Land subsidence generally refers to both the gentle subsidence of the surface and the sudden subsidence of discrete parts of the surface [1, 2]. It is believed that human activities and natural forces are two major causes of land subsidence [3]. Land subsidence caused by human activities mainly includes exploiting underground resources, such as water and minerals, which could make the subsidence rate 1-2 orders of magnitude greater than natural factors [4–6]. Land subsidence caused by natural forces mainly includes loess collapse, organic soil consolidation, karst erosion, sediment compression, volcanic eruptions, and tectonic movements [3, 4, 6]. The primary reason for land subsidence in coastal cities is groundwater extraction [7–9]. The aftermath of land subsidence is severe, such as environmental pollution, flooding, wetland loss, and shoreline erosion [6, 9, 10]. Land subsidence cannot only cause environmental damage but also damage infrastructures, such as buildings, foundations, and pile structures [2, 9, 11]. Although the risk of land subsidence to a human being is negligible in uninhabited areas, land subsidence can cause heavy losses to geological stability and safety of the built environment in inhabited areas, such as the damage to roads, bridges, cables, and sewers [3, 4, 10]. Furthermore, land subsidence may cause many casualties [2, 12, 13]. So far, more than 150 cities worldwide have experienced land subsidence, of which more than 85% are delta cities [9, 14]. Therefore, measuring and real-time monitoring of land subsidence are indispensable to minimizing casualties and property losses [1].

In the past few years, several technologies have been applied to monitor land subsidence, such as terrestrial leveling, Global Positioning System (GPS), Interferometric Synthetic Aperture Radar (InSAR), geostatistics, and integrated approaches [11, 15, 16]. In addition, with the advancement of modern technology, InSAR has been widely and effectively used to monitor various surface movements [16–18].

InSAR is an advanced electromagnetic method that combines synthetic aperture radar technology with interferometric measurement technology [9]. The recording of InSAR scattering intensity and phase information reflects the surface characteristics feature, which can be used to calculate the ground displacement [7]. The phase difference between two coregistered SAR images is called an interferogram [19]. Due to its ability to obtain millimeter-scale deformation from hundreds of kilometers away [20] and to work around the clock [21], InSAR is growingly used to indicate land subsidence by spatial and temporal in unprecedented details instead of traditional surveying and mapping methods [10, 22]. However, InSAR technology still suffers from several shortcomings in decorrelation and noise in the InSAR processing. [23, 24].

Given the interests of InSAR, many efforts were made to surround the topic of monitoring and measuring land subsidence using InSAR [25–27]. Exiting studies undoubtedly deepened the studied area's understanding, provided valuable insights, and summarized the entire area's principles and approaches. However, previous discourses were rather broad and fragmented. For instance, some authors primarily analyzed land subsidence in groundwater fields [28–30] and mining field [31–33]. Hitherto, little research has been done to conduct a bibliometrics and scientometrics review of land subsidence using InSAR from a systematic and holistic perspective to identify the research trends and interests, thereby leading to promising research directions [34].

Bibliometrics and scientometrics are quantitative tools to analyze the research topic from macro to microperspectives. Macroanalysis usually analyzes the whole subject, including papers, categories, countries, authors, and institutions, while microscopic analysis emphasizes citations and keywords [35]. Due to its advantages of integrating different disciplines, such as computer engineering and statistics, this method has been applied in more than 60 fields [36–38].

To close the research gaps, this research thus aims at conducting a bibliometrics and scientometrics analysis of land subsidence using InSAR. The specific objectives are twofold, (i) prove a comprehensive analysis of the research trend and research interests of monitoring land subsidence by InSAR technology and (ii) visualize and analyze existing studies to pinpoint the research gaps and develop possible further research directions. This research is considered imperative for understanding the key progress, application expansion, and transformation of InSAR application in land subsidence.

2. Research Methods

In this research, the scope of the literature search was determined first, including the criteria of topic and period. The results were visualized and analyzed and then determine their current stage of development. The detail will be described next.

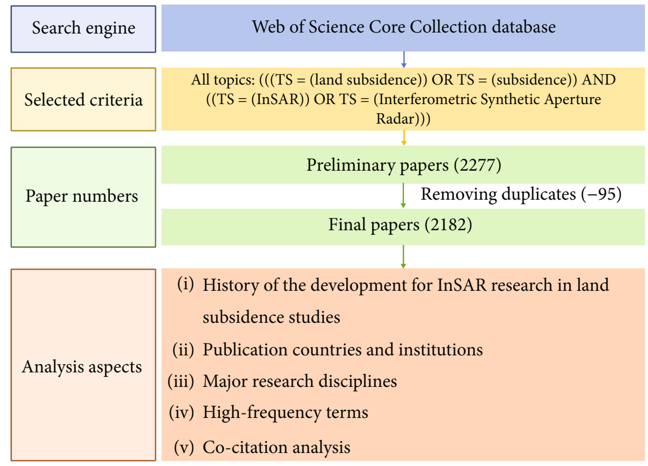

Figure 1: Data processing flow chart.

2.1. Data Collection. Data used for a comprehensive scientometrics analysis was first collected on monitoring and predicting land subsidence by InSAR technology. As the land subsidence application for InSAR has been fast developing since 2000, the research period was selected from 2000 to 2021. The data retrieval source was downloaded from the Web of Science Core Collection (WoSCC) database, which is one of the most common and popular academic search engines and includes the world's leading journals of remote sensing [39, 40]. Although Scopus and Google scholar covers a wider journal range [41], the data overlap rate of Scopus is high, and the result of them is no significant difference [42]. The search was performed from January 2000 to December 2021, with the search criteria of "All topics: (((TS=(land subsidence)) OR TS=(subsidence)) AND ((TS=(InSAR)) OR TS=(Interferometric Synthetic Aperture Radar)))." Articles, reviews, and conference papers were selected as the document types to ensure authenticity and credibility [43]. As a result, a total of 2277 publications were retrieved. After removing duplicates, a total of 2182 publications were extracted. Figure 1 illustrates the paper retrieval process.

2.2. Data Analysis. CiteSpace is a Java-based software for detecting and visualizing research front and data, analyzing the intellectual bases and dynamic complex network. It allows experts to build a knowledge network map to identify the potential research trends and interests of academic literature in the studied field [44, 45]. The dynamic knowledge map can present the logical relationships between the references, get data directly from graphs and tables faster and easier, and find hotspots and research trends in a field with vast analytic data [34, 46]. Hence, this paper utilized CiteSpace as the analysis tool for InSAR application in land subsidence.

The analysis procedure of using CiteSpace generally ranges from countries and institutions, major research disciplines (macro), and high-frequency terms (micro and intuitive) to the cocitation of high-citation papers (whole) [35, 46]. CiteSpace takes a set of bibliographic records as its input and builds a series of underlying entities and their relationships then divides the integrated network into different entities, such as research countries and institutions, research disciplines, high-frequency terms in existing studies, and cited references. Structural patterns and trends are combined with temporal patterns and indicators to inform analysts of significant developments in the field of research [44]. The cluster view is the main mode of concrete visualization.

The core function of the CiteSpace software is the analysis of cocited publications. In the cocitation network view, the location of clusters and the correlation between clusters can show the domain's intellectual structure, allowing scholars to understand the overall picture of the studied field [46, 47]. The log-likelihood ratio (LLR) algorithm is usually used to extract cluster labels from related publications, and several knowledge frontiers representing the database can be summarized. Cocitation and cluster analysis of the citations of all studied publications can intuitively reflect the changes in critical areas, analytical perspectives, and research methods in different periods. Cocitation analysis expresses the relationship between publications through the frequency of simultaneous citations by other publications. In other words, two publications are simultaneously cited by other publications. The higher citation frequency means a closer relationship between the two publications. In the cocitation network, the location of clusters, the relevance, and critical nodes between clusters can reflect the intellectual structure, knowledge base, and evolutionary characteristics of InSAR research in land subsidence studies and play a vital role in the evolution process [36, 46, 48].

To assess the effect of the network structure and the cluster analysis, CiteSpace software provides two indicators: modularity (Q) and silhouette (S). Modularity (Q) is a clustering and measurement of complex network or map structures, which measures the strength of dividing the network into clusters. In a network with a high degree of modularity (Q), the nodes in each module are closely connected, but the connections between nodes in different modules are sparse. Silhouettes (S) is a graphical aid to the interpretation and validation of cluster analysis. Q is generally in the interval (0, 1), and $Q > 0.3$ means that the network structure is statistically significant. The closer the S is to 1, the higher the confidence, while an S greater than 0.7 is statistically reliable.

Another function is burst analysis, which was designed by Kleinberg and detected sharp increases from large quantities of data in a short period [49]. It is an effective way to explore research trends [35].

This paper utilized CiteSpace to analyze (i) the temporal development analysis, (ii) research countries and institutions, (iii) major research disciplines, (iv) high-frequency terms in existing studies, and (v) cocitation of high-citation papers. The justifications for selecting the above analysis areas are given below. First, the development of publications is an important index to measure the research progress of the InSAR application in land subsidence. Second, in order to analyze the cooperation network of countries and institutions, the core countries and institutions in the InSAR application in land subsidence and their cooperation relationships can be identified by using betweenness centrality as the measure, betweenness centrality is a common structural metric in social network analysis—as an indicator to analyze the number of times a node acts as the shortest bridge between two other nodes. Third, major research disciplinary analysis can macroscopically understand which subject knowledge area needs to be covered in the InSAR application in land subsidence, dual-map, and subject cooccurrence analysis can display the disciplinary directly. Fourth, investigating high-frequency terms and burst terms that appear in the InSAR application in land subsidence can indicate potential research directions. Finally, cocitation analysis is an overall analysis of this review's InSAR application in land subsidence. The cocitation analysis of references can be considered a research front related to clusters calculated by the LLR algorithm. The modularity (Q) and silhouette (S) are indicators to measure the quality of clustering [46].

By using Shneider's four-stage theory [50], the underlying connections between these results and progress in the InSAR application in land subsidence are discussed below. A field of research generally goes through the initial concept-forming stage, the first stage, in which the object of research has been identified. In the second stage, research capacity and scope begin to increase with the availability of a large number of research tools, allowing researchers to study underlying phenomena. When researchers are equipped with specialized tools, research enters the diffusion stage, the third stage. In the third stage, as the level of new technologies and tools has been greatly improved, the researchers' understanding of the research problem has also greatly improved, deriving new research directions or research specialties. Finally, it enters the fourth stage, the decay stage, which is characterized by the simplification and routinization of knowledge, which can be compiled into textbooks to convey to new members of the profession [46, 50].

3. Results

3.1. Temporal Development Analysis. Since the National Aeronautics and Space Administration launched the first successful Low-Earth orbital weather satellite on April 196—Television and Infrared Observation Satellites (TIROS-1), a new generation of earth observations has started [48]. In 1975, the working group on land subsidence was established by United Nations Educational, Scientific and Cultural Organization [1]. Since the end of the last century, the use of InSAR monitoring has gradually developed [51]. Since 2000, an average of 99.18 publications have been published each year, and each publication is cited 15.91 times on average; the number of publications increased from 6 in 2000 to 281 in 2021 (see Figure 2). The average annual growth rate of publications is 1.21, and citations is 1.36. These results indicate the rapid and high-quality development of InSAR research in land subsidence studies.

3.2. Publication Countries and Institutions. Figure 3 provides the distribution of publications for different countries. The top 10 countries contribute 2344 (103.4%) of publications. This might be because that many authors or institutions tend to cooperate in conducting research. The countries of

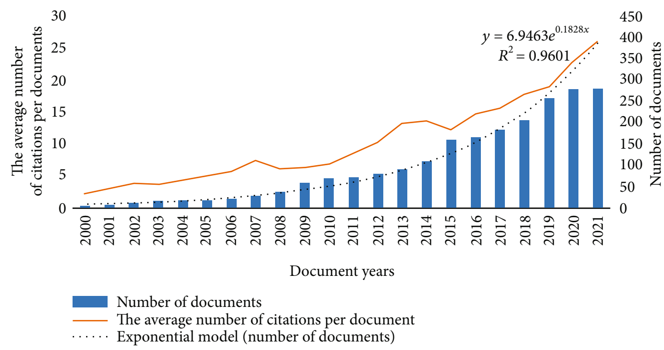

FIGURE 2: Temporal evolution of publications and times cited per year on InSAR of land subsidence monitoring in 2000-2021.

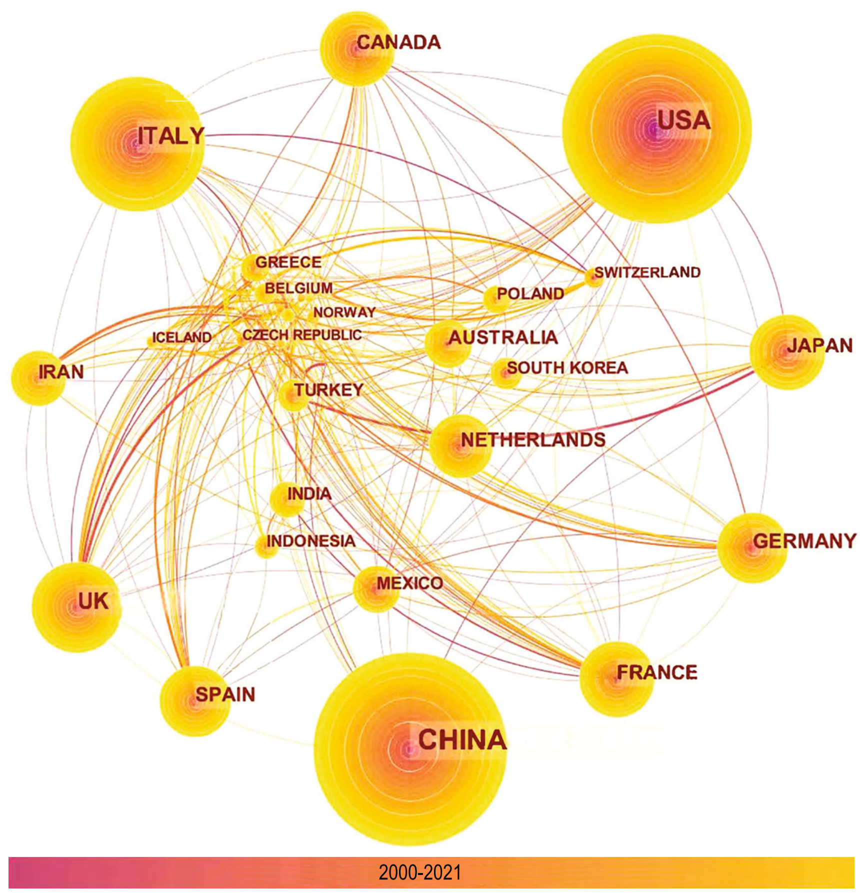

FIGURE 3: Network of coauthors' countries.

all authors in each publication are counted once. For example, if there are five authors all from different countries in an article, the five countries to which these authors belong will be counted instead of only the corresponding author or the first author. The result also indicates that InSAR research in land subsidence studies is more inclined to cross-border cooperation, with China, the USA, and Italy ranking as the top countries, accounting for 36%, 22%, and 13% of the total publications. The cooperate country network map results in 92 countries and 468 links, which means the total cooperation is 468 times. According to [46], the more a node acts as an "intermediary", the greater its betweenness centrality. In Figure 3, although 805 studies focused on China, its betweenness centrality is only 0.14. It is suggested that scholars are more inclined to conduct independent studies in China. In comparison, with only 475 publications focusing on the USA, its betweenness centrality value is 0.38, indicating that the scholars in the USA actively bridge the research collaboration between other countries (Table 1).

The publications of these countries and regions are also proportional to the number of research institutions. The result shows that around 1592 academic institutions have contributed to InSAR application in land subsidence research. Table 2 shows the developed collaboration network regarding institutions in CiteSpace. The results reveal that the top 10 institutions in terms of coauthored publications

Table 1: Count, ratio, and centrality of top 10 countries of the period from 2000 to 2021.

Countries/Regions	Publications	Percentage of 2182 (%)	Betweenness Centrality
China	805	36.893	0.14
USA	475	21.769	0.38
Italy	287	13.153	0.24
UK	168	7.699	0.26
Spain	117	5.362	0.1
Germany	110	5.041	0.11
Japan	101	4.629	0.07
Canada	97	4.445	0.06
France	95	4.354	0.19
Netherlands	89	4.079	0.06

have participated in the most research. The Chinese Academy of Sciences ranked first and published 162 papers, followed by the China University of Mining Technology, which published 124 papers. Ranking as the fourth largest number of publications, the UK had only one institution in the top 10 of the total number of publications. In addition to the number of publications, the betweenness centrality of national cooperation can also be used to measure a country's research strength [35]. The betweenness centrality values in Table 2 show that Chinese institutions tend to conduct independent research rather than cooperate with other institutions. Figure 4 illustrates the network of coauthors' institutions. The color of the nodes of the institutions on the right of Figure 4 (all Chinese institutions) is brighter than the color on the left institutions. This again suggests that Chinese institutions tend to cooperate more than other institutions in recent years. Moreover, the bright-colored links are mainly concentrated on the right side in Figure 4. This result thus shows that Chinese institutions are more inclined to communicate with other Chinese institutions and do independent research than other countries. Analyzing the betweenness centrality in Table 2 and the number of links in Figure 4 can also show the same result as above.

From Figures 3 and 4, the bright yellow color occupies the vast majority of most nodes. This means that the main publications of various countries and institutions experienced a substantial increase after about 2010. In Figures 3 and 4, the color of the line connecting the nodes has a lot red, which shows that researchers have tended to cooperate in research since the first stage.

3.3. Major Research Disciplines. According to the Web of Science analysis results of the category field, the number of disciplines of InSAR applications in land subsidence has increased from 11 in 2000 to 77 in 2021.

Figure 5 presents a dual-map overlay of citing publications and cited publications, which depicts the major disciplinary areas of the analyzed publications. The left of the figure illustrates the distribution of the citing articles and covers 11 major research areas, such as "3. Ecology, earth, marine" in the upper left corner. On the other end, the right side of the figure depicts the cited articles and covers 16 major research areas, such as "10. Plant, ecology, geophysics" in the upper right corner. The former can be regarded as the domain application of the research contents of this review, and the latter can be regarded as the research foundation of the research contents of this review. Using CiteSpace to extract and analyze subject words from the data retrieved, the results show that Geology (941 articles), Geosciences (921 articles), and Remote Sensing (857 articles) are the top three disciplines. Figure 6 further illustrates the betweenness centrality (purple circle) of the subject words, and the results indicate that the focus of InSAR research in land subsidence studies is built around the engineering field, covering geology, earth science, geography, and geophysics [28, 34, 48]. Although the "computer science" node is relatively small, its betweenness centrality value is relatively large. Also, the links connecting to the "computer science" node are relatively thick, indicating computer science is also located in an essential position in the InSAR application in land subsidence. For example, some remote sensing data modeling [1, 9, 52], machine learning-based algorithms and the intersection of remote sensing [53, 54], and electrical and electronic disciplines applications [55].

Figures 5 and 6 can also identify the current evolutionary stage of the four-stage theory. As shown in Figure 5, although most of the links of "3. Ecology, earth, marine" in the upper left corner are linked to "10. Plant, ecology, geophysics" in the upper right corner, there are still a few links connected to the lower right corner of "12. Economics, economic, political". Therefore, we can preliminarily judge that the InSAR application in land subsidence is transforming to the third stage; the tools developed by this profession are applied to other disciplines. Some nodes in Figure 6 are also confirmed, such as "Computer Science" node and "Engineering, Electrical & Electronics" node.

3.4. High-Frequency Terms. A total of 540 high-frequency terms were detected in InSAR research in land subsidence studies from 2000 to 2021, as shown in Figure 7. We divided these high-frequency terms into six groups every four years and differentiated them with various colors. The evidence in Figure 7 shows that the top 25 nodes of the most frequent high-frequency words (the largest 25 nodes) include red, yellow, green, light green, blue, and purple in order from recent to early. The two most prominent nodes are "land subsidence" and "InSAR," which exactly are the focus areas of the present research.

These terms can be divided into two main categories, research tools and methods such as permanent scatterer (PS), small baseline subset (SBAS), time series, and InSAR data; research applications such as groundwater extrication, urban area, and mining area.

Moreover, the number of links shows that related research in InSAR research in land subsidence studies is continuously expanding and developing. Due to the continuous improvement of computing power and data collection technology, various research directions and technologies have been developed rapidly, e.g., urban areas, dining areas,

Table 2: Characteristics and frequency of the top 10 cooperation institutions in the studied period from 2000 to 2021.

Institutions	Publications	Country	Betweenness Centrality
Chinese Academy of Sciences	162	China	0.16
China University of Mining and Technology	124	China	0.05
California Institute of Technology	123	USA	0.14
Wuhan University	119	China	0.12
Capital Normal University	110	China	0.04
Chang'an University	108	China	0.04
China Earthquake Administration	83	China	0.07
US Geological Survey	82	USA	0.12
Delft University of Technology	71	Netherlands	0.11
University of Leeds	68	UK	0.12

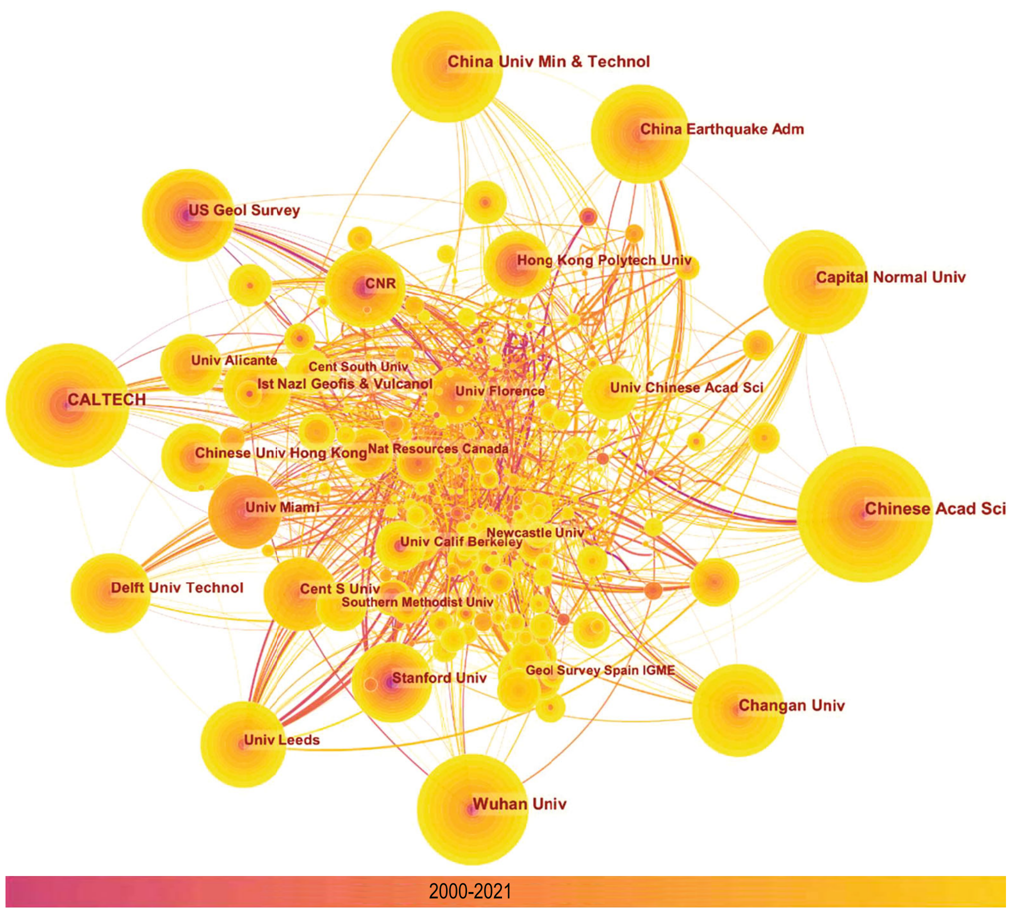

Figure 4: Network of coauthors' institutions.

and groundwater. Nowadays, time series, SBAS [56], and PS [57] are also mainstream technologies.

Furthermore, Figure 8 illustrates the results of the burst term analysis, which reveals the bursts of five key terms whose frequency has been rapidly increasing since 2019 and records the burst time of their first appearance until 2021. The red bar represents the time when the burst term begins and ends, and the blue bar represents the entire observation period. The strength of the burst terms, as shown in Figure 8, denotes a larger value than the reference bursts [46, 49]. The term "burst," in this case, means the sudden increase in the frequency of a specific term in a certain period. For example, the burst term of Sentinel-1 in 2019 means that the application frequency of the Sentinel-1 term has increased sharply in remote sensing since 2019 [57–59]. The first unit of Sentinel-1, Sentinel-1A, was launched on April 3, 2014, and the second unit, Sentinel-1B, was launched on the 25th of April, 2016. By using the search criteria: (((((TS = (land subsidence)) OR TS = (subsidence)) AND ((TS = (InSAR)) OR TS = (Interferometric

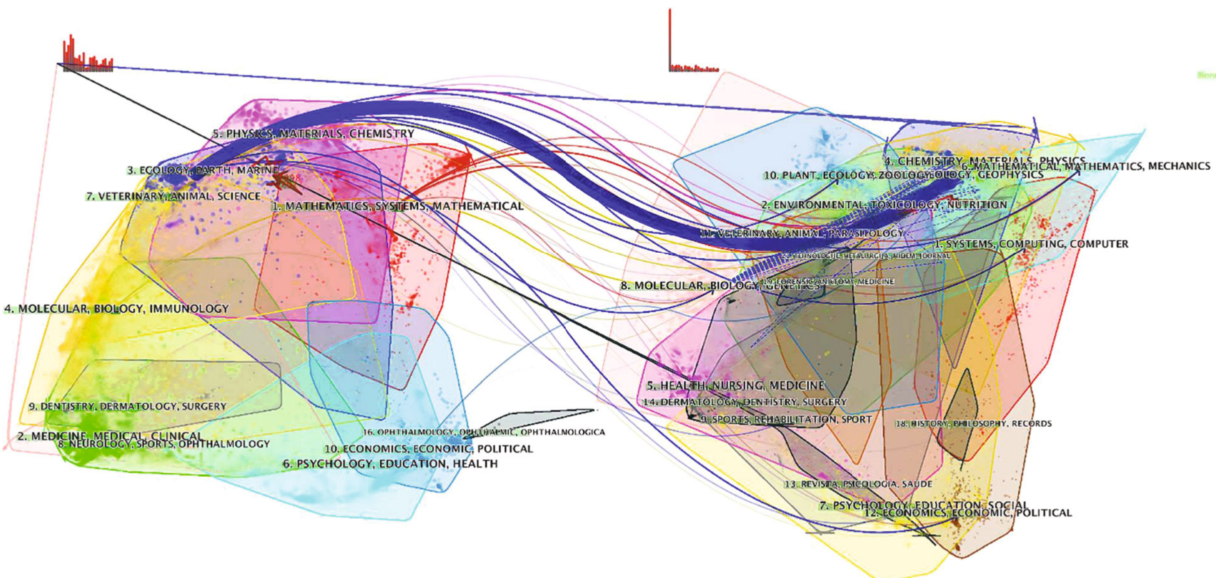

Figure 5: Dual map overlay of citing publications and cited publications.

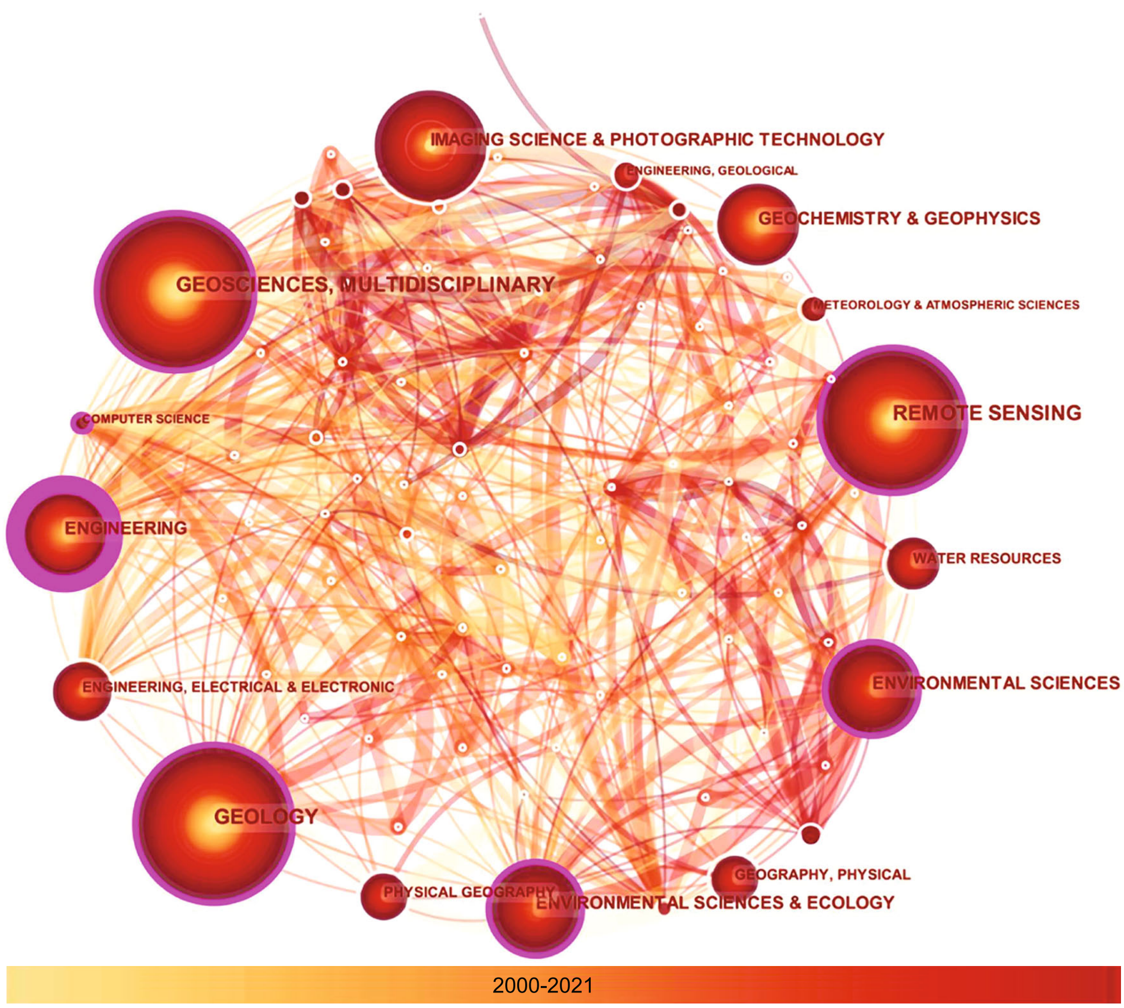

Figure 6: Subject cooccurrence map.

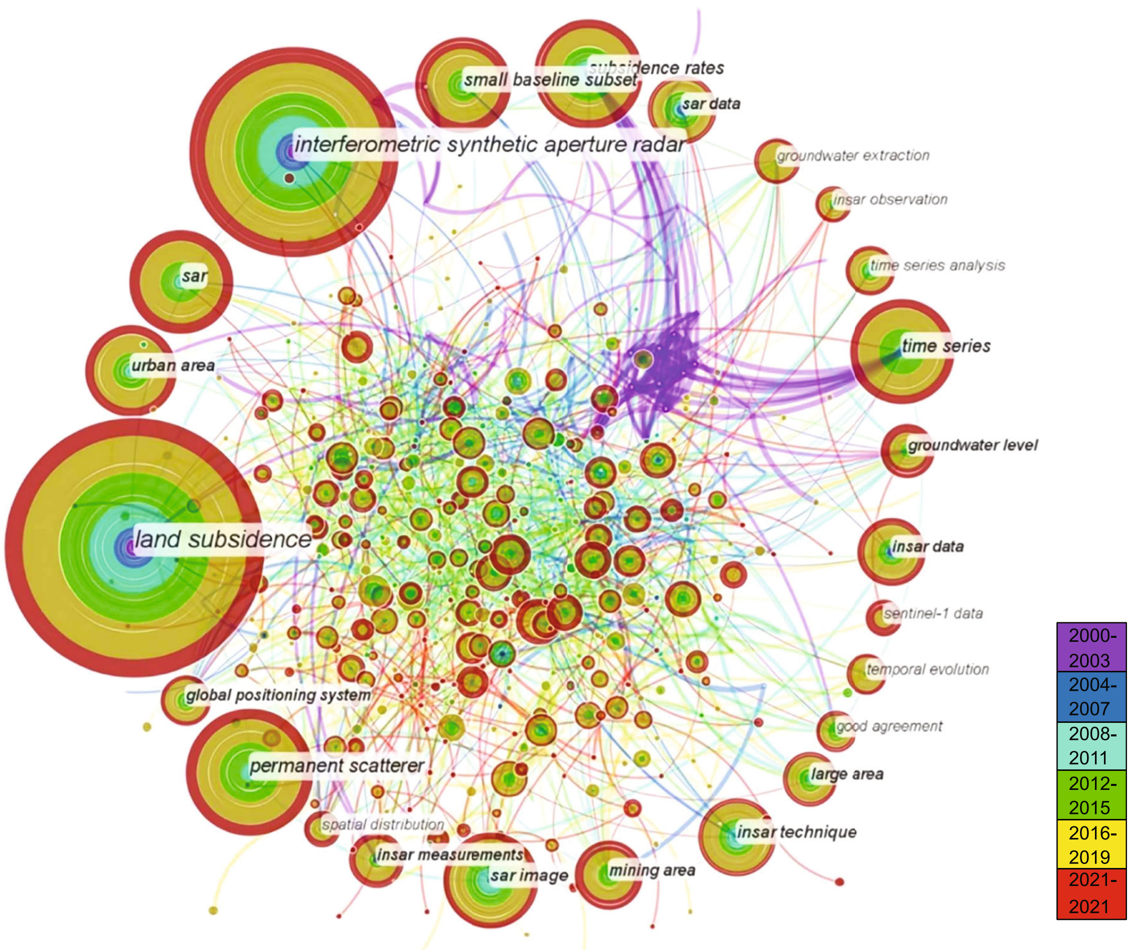

Figure 7: Network of cooperating terms.

Terms	Year	Strength	Begin	End	2000–2021
Sentinel-1 data	2000	9.03	2019	2021	
Global navigation satellite system	2000	8.27	2019	2021	
Human activity	2000	5.25	2019	2021	
Sentinel-1a image	2000	4.59	2019	2021	
Climate change	2000	4.59	2019	2021	

Figure 8: Top 5 terms in burst term analysis.

Synthetic Aperture Radar)))) AND TS = (Sentinel-1a)) NOT TS = (Sentinel-1b) from 2000 to 2021, the result is 187. In contrast, when we swap Sentinel-1a and Sentinel-1b, the result is only 6. Since Sentinel-1b was launched two years later than Sentinel-1a and there are more publications about Sentinel-1a, there is no burst term for Sentinel-1b in Figure 8. In addition, the burst terms of "human activity," such as groundwater extraction, subway development, mining, and urban construction, are also identified as the main factors leading to land subsidence [58, 60, 61]. Besides, "climate change" also reinforced the role of human activities to have a new direction in the research of land subsidence [62, 63].

As Figure 7 shows, among the terms, research tools and methods account for the vast majority; most of the terms appear from 2008 to 2015. Furthermore, the burst term in Figure 8 is "climate change," which is already covered in other disciplines. This situation can still indicate that the research has been transformed from the second stage to the third stage.

3.5. Cocitation Analysis of High-Citation Papers. Figure 9 shows the cocitation cluster map. The value of Q is 0.79, which means the cocitation cluster can clearly define the various subfields of InSAR application in land subsidence. The value of S is 0.9, indicating that the obtained cluster is very reasonable. Figure 9 highlights the top 10 most essential clusters from 2000 to 2021. Using the LLR algorithm, we further analyzed 12 articles of the respective cocited publications of

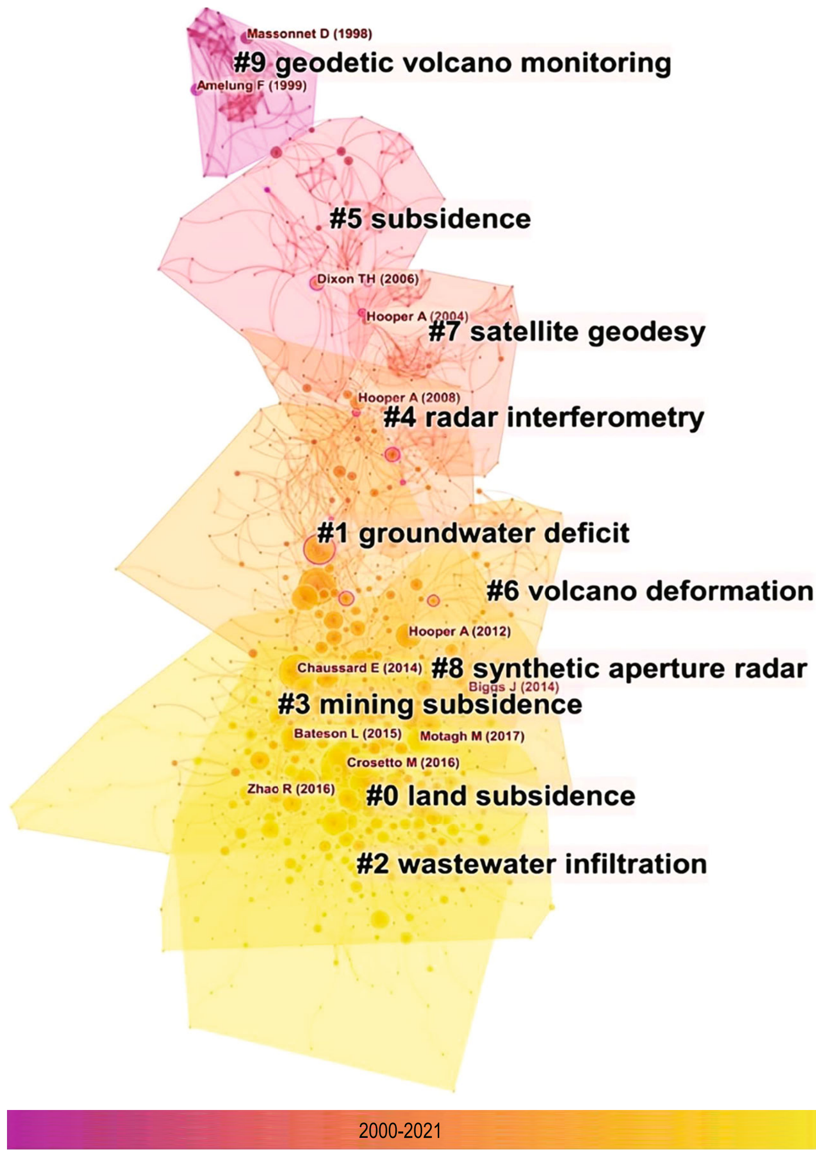

Figure 9: Cocitation cluster map.

the top-focused clusters. It can be seen that the existing studies regarding InSAR in land subsidence primarily emphasized mainly focusing on "groundwater deficit," "wastewater infiltration," "mining subsidence," and "volcano deformation."

Generally, groundwater deficit is affected by overexploitation and climate stresses closely related to human activities. The depletion of aquifers could lead to land subsidence compaction of the aquifer matrix and further cause social and economic issues, especially in the driest places. Future climate conditions and population growth are expected to exacerbate the problem [64]. This phenomenon occurs in many cities around the world, such as Las Vegas [65], Beijing [13], Shanghai [28], Bangkok [30], and Mexico City [6, 7, 66]. InSAR is thus suitable for measuring the spatial extent and magnitude of surface deformation related to the compaction of aquifer systems [1]. Since 1998, InSAR has been widely used to draw detailed land subsidence maps related to groundwater pumping, e.g., [1, 48, 51, 67–70].

To slow down the rapid land subsidence, many cities have begun to control water extraction and artificial recharge of aquifers [16, 17, 19]. However, when municipal and industrial wastewater were discharged into surface water channels and streams, infiltration events can be observed to a large extent throughout the basin. This part of sewage may affect the local groundwater recharge, but this is not included in the aquifer water budget estimate [68]. Furthermore, wastewater infiltration will also change the soil's characteristics and lead to land subsidence [71]. In this way, InSAR can monitor hydraulic head changes caused by wastewater infiltration, which is significant to groundwater management [19, 68].

Land subsidence is a common geological phenomenon in mining areas [31]. The evaluation and monitoring of mine geological disasters and mining subsidence dynamics can be realized by drawing dynamic land subsidence maps caused by underground mining [33, 72]. Traditional mining

References	Year	Strength	Begin	End	2000–2021
Amelung F, 1999, GEOLOGY, V27, P483, DOI 10.1130/0091-7613 (1999) 027<0483:STUADO>2.3.CO;2, DOI	1999	12.23	2000	2004	
Massonnet D, 1998, REV GEOPHYS, V36, P441, DOI 10.1029/97RG03139, DOI	1998	10.44	2000	2003	
Ferretti A, 2001, IEEE T GEOSCI REMOTE, V39, P8 DOI 10.1109/36.898661, DOI	2001	12.99	2003	2006	
Dixon TH, 2006, NATURE, V441, P587, DOI 10.1038/441587a, DOI	2006	12.44	2007	2010	
Hooper A, 2007, J GEOPHYS RES-SOL EA, V112, P0, DOI 10.1029/2006JB004763, DOI	2007	14.74	2009	2012	
Hooper A, 2008, GEOPHYS RES LETT, V35, P0, DOI 10.1029/2008GL034654, DOI	2008	20.31	2010	2013	
Osmanoglu B, 2011, INT J APPL EARTH OBS, V13, P1, DOI 10.1016/j.jag.2010.05.009, DOI	2011	21.97	2011	2016	
Ferretti A, 2011, IEEE T GEOSCI REMOTE, V49, P3460, DOI 10.1109/TGRS.2011.2124465, DOI	2011	37.42	2012	2016	
Cigna F, 2012, REMOTE SENS ENVIRON, V117, P146, DOI 10.1016/j.rse.2011.09.005, DOI	2012	13.88	2012	2017	
Hooper A, 2012, TECTONOPHYSICS, V514, P1, DOI 10.1016/j.tecto.2011.10.013, DOI	2012	24.07	2013	2017	
Galloway DL, 2011, HYDROGEOL J, V19, P1459, DOI 10.1007/s10040-011-0775-5, DOI	2011	13.74	2013	2016	
Chaussard E, 2013, REMOTE SENS ENVIRON, V128, P150, DOI 10.1016/j.rse.2012.10.015, DOI	2013	15.65	2014	2018	
Chaussard E, 2014, REMOTE SENS ENVIRON, V140, P94, DOI 10.1016/j.rse.2013.08.038, DOI	2014	19.48	2015	2019	
Motagh M, 2017, ENG GEOL, V218, P134, DOI 10.1016/j.enggeo.2017.01.011, DOI	2017	12.26	2018	2021	
Crosetto M, 2016, ISPRS J PHOTOGRAMM, V115, P78, DOI 10.1016/j.isprsjprs.2015.10.011, DOI	2016	20.81	2019	2021	

Figure 10: Top 15 references with the strongest citation bursts.

collapse monitoring methods (geometrics, GPS, and precision leveling) have many shortcomings, such as high cost, heavy workload, and difficulty in maintaining work for a long time. InSAR technology, such as TS-InSAR and D-InSAR, can largely improve these problems [72–74].

The process of volcanism, including magma accumulation in underground reservoirs, magma transportation, and emplacement under volcanic structures, will cause land subsidence, which can be detected by InSAR [27, 31, 75]. During volcanic eruptions, the phenomenon of ground subsidence is widespread, and the placement and cooling of the magma play a vital role during the volcanic eruption [76]. Therefore, InSAR has an extensive range of applications in earth and environmental sciences [27].

By analyzing the burst terms in the cocited publications, as shown in Figure 10, we can better understand the development and evolution of research on land subsidence of InSAR. At the end of the last century, InSAR was gradually found to have advantages in detecting subsidence in various fields (fault motion, earthquake, landslide, and underground space), such as great spatial detail, spatial sampling density, and high precision [65, 77]. Since 2001, InSAR has successfully integrated the principle of synthetic aperture imaging and interferometric measurement technology and uses the phase information of radar signals to extract high-precision 3D information on the earth's surface. It is a unique surface measurement that uses space remote sensing to obtain 3D space information on the surface and its small deformations. This means, especially the emergence of time series interferometric SAR technology represented by differential InSAR (D-InSAR), permanent scatterer InSAR (PS-InSAR), small baseline InSAR (SBAS-InSAR), and their more advanced algorithm such as multitemporal InSAR, Stanford method for persistent scatterers (StaMPS), and SqueeSAR making it widely used in the measurement of land subsidence [7, 8, 78–84]. At the same time, some articles, as bursts, also record in detail the application and development history of InSAR for land subsidence monitoring—urban construction (infrastructure, dam monitoring, cultural heritage, and reclamation) and natural disasters (mining areas, groundwater, landslides, volcanoes, and flood monitoring and forecasting) [1, 85, 86].

The comprehensive results from the publications cocitation network and burst analysis show that InSAR technology mainly has the following two application fields in land subsidence: (i) different time series algorithms of this technology and (ii) different application areas of the technology.

Since temporal and geometrical decorrelation usually interferes with the accuracy of InSAR, the appearance of PS technology in 2000 avoided the influence of temporal and geometrical decorrelation and improved the accuracy. However, the atmospheric phase estimation accuracy of PS technology is not significant, and the development of other technologies is still needed [78]. In 2007, Hopper proposed a method for PS analysis—StaMPS—that use the spatial correlation of interferogram phases to find pixels with low phase variance in all terrains, with or without buildings. Around the same period, multitemporal InSAR (MT-InSAR) was proposed by Hopper in 2008 [81]. As a combination of PS and SBAS methods, MT-InSAR can extract deformation signals at more points and has a more significant overall signal-to-noise ratio than either method alone [81]. In 2011, Ferretti et al. introduced the SqueeSAR method to jointly handle point-wise deterministic objects (i.e., PS) and distributed scatterers (DS). This method does not require major changes to the traditional PS-InSAR processing chain, nor does it need to exploit hundreds of interferograms. Hence, it can greatly increase the density of ground monitoring points and achieves millimeter-level measurement accuracy. It does not require ground monitoring points and can cover an area which artificially difficult to reach [82]. In 2016, Crosetto et al. detailed more than 20 different PSI methods in the past, affirming the development of PSI technology, e.g., advances in pixel selection, algorithm improvements, and the ability to monitor large-scale deformation. The author further stated that one of the most important components that need to be improved is phase unwrapping, and the algorithm itself also needs to be improved to cope with the increasing data throughput [85].

InSAR time series analysis results were obtained by Sentinel-1 to investigate land subsidence in the plains [84]. The result analysis is that the overexploitation of groundwater due to the development of agriculture and industry is the leading cause of land subsidence. These high subsidence rates are likely to keep the most densely populated coastal areas below relative sea level within a few decades [8, 82, 83]. There are three main approaches to mitigating subsidence caused by groundwater abstraction—reduced groundwater abstraction, constraining the distribution and connectivity of water-bearing units and artificial recharge [1, 7]. At present, the mainstream land subsidence research focuses on groundwater and human activities, while natural factors such as volcanoes and floods can also lead to land subsidence [79, 80]. More research is still needed to monitor and predict land subsidence caused by these factors in real time.

From the analysis of the cocitation clusters map (Figure 9), the development of the InSAR application in land subsidence can be more intuitive. The ten largest clusters formed are related to research tools and methods. This period is the same as the growth period for countries, institutions, and terms. Therefore, the transition time of research in the InSAR application in land subsidence from the first stage to the second stage is about 2010. This shows that the research has a tendency to spread from the technology research in the InSAR application in land subsidence to other fields. According to Shneider's four-stage theory, the InSAR application in land subsidence is in the initial transition from the second stage to the third stage.

4. Discussion

4.1. Evolution of Collaboration Networks. In recent years, many scholars, institutions, and countries have realized the importance of scientific collaboration. Scientific collaboration has become a meaningful way to promote technological, economic, and social development as a means of scientific knowledge production. This study provides a collaborative network and academic impact analysis of InSAR application in land subsidence through five collaborative network analyses provided by CiteSpace—countries, institutions, disciplines, subjects, and terms.

Regarding the number of publications published by countries, the total number of publications in the top three countries with enormous contributions accounted for 71.8% of all countries, which indicates that the distribution of publications in InSAR application in land subsidence is highly uneven. Regarding betweenness centrality, Japan, Canada, and the Netherlands have lower betweenness centrality, indicating that these countries tend to be independent research. In contrast, France, which ranks ninth in terms of publications, has higher betweenness centrality than China, indicating that France is more inclined to cooperate.

Although Chinese institutions have many publications and occupy 7 of the top 10 institutions in terms of publications, the remaining institutions, except for the Chinese Academy of Sciences and Wuhan University, do not have a high betweenness centrality. Combined with the betweenness centrality of China analyzed above, it can be concluded that China has less communication with other countries and lacks communication with its institutions. In contrast, institutions in the UK and the USA are more inclined to collaborate and communicate. It is noteworthy that the Delft University of Technology in the Netherlands has 71 publications with a betweenness centrality of 0.12, while the total number of publications in the Netherlands is only 89 with a betweenness centrality of 0.06. This means that most of the Dutch institutions, except the Delft University of Technology, are independent and have few publications, which also reflects the fact that collaborative research can be more rewarding.

Figures 5–7 show the collaborative relationships between disciplines, subjects, and terms. These three figures show the collaborative relationships in developing and applying the InSAR application in land subsidence from the macro to micro level. The analysis shows that early collaborative relationships were less frequent in InSAR application in land subsidence but increased dramatically in the last decade. The subjects "computer science", "engineering, geological", and "meteorology & atmospheric sciences", and the terms "Sentinel-1", "spatial distribution", and "groundwater level" have been more active in recent years. This indicates that InSAR application in land subsidence is more closely related to other disciplines and subjects. Therefore, the trend is to integrate more disciplines and subjects and study more research areas in InSAR application in land subsidence.

4.2. Trends and Research Stage. Using Shneider's four-stage theory, cocitation networks and cluster analysis of the literature were analyzed to define the trends in InSAR application in land subsidence. The first stage was before 2010, when the InSAR application in land subsidence was developing its first concepts, mainly in terms of the low volume of publications, infrequent cooperation between countries and institutions, and few concepts of subjects and terms. From 2010 to 2015, the second period saw the emergence of a large number of research tools and fields of InSAR application in land subsidence, which led to an increase in the number of publications, cooperation between countries and institutions, and the number and cooperation between subjects and terms. During the period from 2015 to 2021, InSAR application in land subsidence has also added many practical research tools and methods due to breakthroughs in computer technology. However, researchers have derived and collaborated on many research methods outside of research, allowing research and theory to begin to diversify gradually. Thus, according to Shneider's four-stage theory, this research field is in the second to the third stage of Shneider's four-stage theory transformation.

5. Conclusions

Real-time and accurate monitoring of land subsidence is important to facilitate remote sensing development. As an emerging technology, InSAR technology provides an indispensable means for land subsidence to provide detailed space observations. In addition to monitoring, InSAR can also make predictions and analyses to ensure subsequent land subsidence.

Land subsidence is a crucial application field of remote sensing. Many countries and institutions tend to conduct cooperation studies. It is found that InSAR technology is mainly divided into different algorithms of InSAR, such as D-InSAR, PS-InSAR, and some data resources, such as Sentinel-1. There are diversified applications of land subsidence, such as glaciers, volcanoes, groundwater, mining areas, and landslides.

Currently, the development of InSAR is primarily based on satellite imagery and computer algorithms. Compared with traditional land subsidence measurement methods, the accuracy and clarity of satellite imagery can largely be improved. InSAR technology can also realize automatic monitoring of land subsidence. Thus, it can still be used as a mainstream technology in land subsidence in the near future. With the continuous breakthrough of artificial intelligence technology and the explosive growth of InSAR data, future industrial and commercial needs will also grow synchronously. In this sense, high-resolution sensors (NInSAR-S band) are preferred among scholars, and the research tends to combine artificial intelligence, cloud computing, and InSAR technology. Meanwhile, it is necessary to combine traditional disciplines such as geology, hydrology, and meteorology to develop together.

In conclusion, the application of InSAR technology in land subsidence is still in the transition stage from the second stage to the third stage. It means that there is still potential to improve in the InSAR application in land subsidence. Possible strategies may include proving the support of proprietary technical tools, bearing the theories and methods of other disciplines, reconsidering and improving substantive and targeted research, and combining application of research techniques and tools from different sources.

This research has some limitations. Firstly, the research literature is only downloaded from the core collection of WoS, and there is no reference from other databases, such as Google Scholar. In this way, some excellent publications may be lost. Secondly, the article's topic selected when downloading publications does not contain synonyms of land subsidence, such as surface subsidence. The general literature will include both topics, and the surface may add some confusing items, such as the ocean's surface and the surface of other planets. Finally, the cocited literature analysis may lack many popular articles in recent years because of its timeliness.

Data Availability

All data, models, and code generated or used during the study appear in the submitted review.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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