

# Satellites in Emergency Management: A Bibliometric Analysis

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## Research Article

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# Abstract

Spatial data have proven to be crucial for supporting decision-making in emergency management. In this study, we conduct a bibliometric analysis of 2,833 papers about the application of satellites in emergency management from Web of Science Core Collection between 1991 and 2021. In the descriptive statistics analysis, overall growth trend and geographical distribution are provided, and top-10 influential journals, institutions, and highly cited articles are identified. Co-citation network of authors, keywords and articles are presented based on a data-driven bibliometric analysis, as well as a burst analysis, and the trends and hotspots in different 5-year periods are captured. According to the papers in 13 highlighted research clusters, popular problems and methods in this field are analyzed. Owing to the research topic belongs to an interdisciplinary subject, the clustering results contain a degree of dispersion. Satellites support different phases of emergency management, and future directions are concluded from the perspectives of disaster monitor, vulnerability and risk assessment, damage evaluation, emergency rescue and scheduling. The bibliometric analysis can provide meaningful insights of influential studies, emerging trends, and new developments of satellites applications in emergency management.

## Highlights

- A descriptive statistics analysis is presented to identify the overall growth trend and influential studies of satellites in emergency management from 2,833 articles for last three decades.
- Visualized analyses including co-citation analysis, cluster analysis and burst analysis are provided to capture the hot topics and developing trends.
- Future directions are concluded from disaster monitor, vulnerability and risk assessment, damage evaluation, emergency rescue and scheduling.
- The bibliometric analysis can provide meaningful insights of influential studies, emerging trends, and new developments of satellites applications in emergency management.

## 1. Introduction

In recent years, there is a dramatic development and popularity about space-based satellite technologies, including satellite remote sensing, navigation and communication system, with massive applications in different fields, such as, disaster response, carbon neutrality, smart city, peace and security (Avtar et al. 2021) and so on. Due to the development of satellite technologies, more applications of satellites in emergency management are explored.

Some countries have organized space platforms to collect information. The Landsat program of remote sensing of Earth from space has been started in July, 1972 with launch of the first Landsat satellite in USA. Earth Observing System of National Aeronautics and Space Administration (NASA) developed since the early 1990s, which a coordinated series of satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans (NASA 2020). The Systeme Probatoire d'Observation dela Tarre satellite series is a commercial high-resolution Earth observation satellite system

that was initiated by the French Space Agency Centre National d'Etudes Spatiales in 1986 (CNES 2020). China launched a major science and technology project to build high-resolution Earth observation systems in 2010, which has launched 14 high-resolution satellites, thus enabling quick and effective response in commercial and military applications, such as aerial exploration, environment monitoring, and surveillance (CHEOS Office 2020). Global Positioning System (GPS) is a real-time three-dimensional navigation and positioning system in the sea, land and air based on artificial Earth satellites, which was constructed by USA in 1994. It can provide accurate geographical location, vehicle speed and accurate time information anywhere in the world, as well as military purposes such as nuclear explosion monitoring and emergency communications. BeiDou Navigation Satellite System-3 was completed by China in 2020, which integrates navigation and communication capabilities, serving for short message communication, international rescue and others (CBDS Office 2022).

Natural disasters are causing immense losses to human life, property and environment every year. According to the World Disaster Report 2020, 2,850 natural disasters (which have killed 10 or more people and/or affected 100 or more people) occurred from 2010 to 2019 worldwide, and affected close to 1.8 billion people (IFRC 2021). Multiple disasters may happen at the same time, with a kind of compounding shock. For example, the dangers of cyclones, flooding, droughts, or fires did not decrease in the context of COVID-19 (Corona Virus Disease 2019) pandemic. The availability of spatial data based on remote-sensing, Geographic Information System (GIS) and Global Navigation Satellite System is valuable for disaster management (Manfre et al. 2012), and data analytic techniques (e.g., data mining, machine learning and deep learning) can promote the extraction and identification of geospatial information to support rapid emergency response (Cumbane and Gidofalvi 2019).

In 1973, the flood monitoring of Mississippi River in the United States opened the prelude to the satellite emergency observation of natural disasters (Rango, Anderson and Directorate 1974). There have been a number of spaceborne satellites that have changed the way to assess and predict natural hazards. These satellites are able to quantify physical geographic phenomena associated with the movements of the Earth's surface (earthquakes, mass movements), water (floods, tsunamis, storms), and fire (wildfires) (Gillespie et al. 2007). Some studies have reviewed the satellite-based technologies in disaster management (Higuchi 2021), emergency mapping (Voigt et al. 2016), flood management (Klemas 2015; Wang and Xie 2018), tropical cyclone (Hoque et al. 2017) and forest fires (Sakellariou et al. 2017), which are mainly about remote sensing satellites. The literatures also review the use of satellite communications (Kose, Koytak and Hascicek 2012) and satellite navigation (Hascicek, Kose and Koytak 2014) for disaster management. Shen et al. (2018) provide a visualized analysis of developing trends and hot topics in natural disaster research. Kumar et al. (2021) review the monitoring methods for assessing the performance of nature-based solutions against natural hazards.

However, there is a lack of systematic reviews or analyses for the application of satellites in emergency management. The bibliometric method allows users to conduct scientific analysis on a huge number of literatures without authors' judgement(Chen 2006). This study aims to review the current status of related literatures based on the bibliometric method, to detect and visualize emerging trends and transient

patterns regarding this theme. And 2,833 related literatures are collected, which are published on international peer-reviewed journals between 1991 and 2021. The remainder of this study is organized as follows: Section 2 shows the methodology of data collection and co-citation analysis. Section 3 provides a descriptive statistical analysis of growth trend, geographical distribution, influential journals, institutions, and articles. Section 4 focuses on co-citation analysis of authors, dynamic evolution of hot topics, cluster analysis and burst analysis of co-cited articles. The summary and future directions are concluded in Section 5.

## 2. Methodology

Emergency management focuses on unusual and hazardous events, and consists of four basic phases: 1) plan and preparedness, 2) direction and response, 3) recovery and restoration, and 4) prevention and mitigation (Iqbal, Perez and Barthelemy 2021). Satellites, especially remote sensing satellites, play a role not only in providing information for disaster risk assessment and damage evaluation, but also in pre-disaster warning and monitor, different from the traditional prediction. Navigation and communication satellites are also essential in the whole process of emergency response.

The concept of knowledge graph was introduced by Google in 2012, using a series of graphs to describe the relationship between the development and structure of knowledge in a given domain. Visualization technologies are designed for knowledge resources and their carriers, by mining, analyzing, constructing, and mapping the interrelationships. Data-driven bibliometric analysis is an analytical tool of knowledge graph, to discover the current pattern and possible trends in the future based on a number of relevant literatures. In the study, the bibliometric analysis is based on a visualization software, CiteSpace.5.8.R3c, proposed by Chen (2006) and based on Kleinberg's burst detection algorithm (Kleinberg 2003). In the software, the terms are collected from titles, abstracts, and descriptors of citing articles in a dataset, and the burst terms are used as labels of clusters in networks of articles.

In this study, the related literatures are searched from ISI Web of Science™ Core Collection, which is a leading citation database in the world, containing 12,000 high-impact journals and more than 160,000 conference proceedings. To get a full-scale relative result, we search the database using Topic for further analysis. The searching criteria is: (TS=(satellite)) AND (TS=(emergency) OR TS=(disaster) OR TS=(natural hazard)) without time limit, permitting imprecise search. And only "Article" type is considered, which means meeting papers, patents, letters and books being excluded. This resulted in a total of 3,772 relevant articles.

According to the titles, abstracts, and keywords of each record, irrelevant or repeated articles are excluded through a manual screening process. For example, the "satellite" means an immediate depot in the studies about logistics; some literatures only mention satellites in the background. Such papers do not belong to the research scope in this paper. Therefore, we collect a sample which contains 2,833 articles from 1991 to 2021 (downloaded on January 6, 2022).

### **3. Descriptive Statistics Analysis**

#### **3.1. Overall growth trend**

The last three decades have witnessed the increasing use of satellites in emergency management. The numbers of annual publications and citations are shown (Fig. 1). Before 2009, the publications and citations showed a slow growth, and the number of annual publications was less than 50. Since 2016, the publications and citations have been increasing in a crazy manner. During 2021, the number of publications equals to 367, and the number of citations equals to 8,353. Until January 6, 2022, these literatures have been cited 50,843 times.

We further use exponential functions to fit the growth. The model expression is  $N = \alpha e^{\beta Y}$ . Here, N represents the number of publications or citations, Y is the year, and  $\alpha$ ,  $\beta$  are two parameters of model. Then two exponential functions are obtained, as shown by the two dotted lines in Fig. 1, both with  $R^2 > 98\%$ . The exponential growth of studies illustrates the development of the research domain.

#### **3.2. Geographical distribution**

The research topic has drawn the attention of scholars from 128 countries and regions. Scholars from China, United States and Italy are playing the leading role in the relative research, with 26.86%, 20.58%, and 10.10% respectively (Table 1). Many countries in the list have their own Earth observation system to support relative studies. A collaboration network of countries is provided (Fig. 2), where the size of nodes reflects the number of publications, and the purple circles and connecting lines reflect the degree of cooperation. Top-three countries that pay much attention to cooperate with other countries are United States, England, and Netherlands. Although China has the largest number of publications, it mainly cooperates with scholars from United States, Canada, Australia and South Korea. More international cooperation of studies in this field is expected.

Table 1  
Geographical distribution

Num.	Country	Publications	Proportion (%)
1	China	761	26.86
2	United States	583	20.58
3	Italy	286	10.10
4	India	272	9.60
5	Japan	201	7.10
6	Germany	162	5.72
7	England	145	5.12
8	South Korea	96	3.39
9	France	93	3.28
10	Netherlands	89	3.14

### 3.3. Influential journals

The list of top-10 influential journals is provided (Table 2), according to the total number of publications in the collected sample. Among them, six journals have an impact factor of higher than 4, indicating that these journals have great academic influence, and *Remote Sensing of Environment* has the highest impact factor, 10.163. In *Remote Sensing*, with the highest number of publications, the papers focus on topics in forests, geomatics, fire, buildings, land, sustainability, smart cities, and so on. In *Natural Hazards*, the papers consider the forecasting of catastrophic events (Li et al. 2009), risk management (Mueller 2013), and the nature of precursors of natural and technological hazards (Mishra 2019). Based on a holistic Earth system science approach, papers in *Natural Hazards and Earth System Sciences* consider the detection of natural hazards, monitoring and modelling (Domenikiotis, Loukas and Dalezios 2003), vulnerability and risk assessment (Taubenboeck et al. 2011), and the design and implementation of mitigation and adaptation strategies from economical, societal, and educational aspects. The *International Journal of Applied Earth Observation and Geoinformation* publishes papers that apply Earth observation data to the inventory and management of natural resources and the environment, and the data are obtained from remote sensing mainly (Pitts and So 2017).

In summary, satellite-related technologies for mitigation, preparation, response, and recovery of natural disasters have drawn much attention of scholars, as well as bringing opportunities and challenges.

Table 2  
Top-10 Influential Journals

Num.	Journal	TP	Proportion (%)	IF	Country
1	Remote Sensing	297	10.48	4.848	Switzerland
2	Natural Hazards	109	3.85	3.102	Netherlands
3	International Journal of Remote Sensing	76	2.68	3.151	England
4	Natural Hazards and Earth System Sciences	54	1.91	4.345	Germany
5	IEEE Journal of selected Topics in Applied Earth Observations and Remote Sensing	53	1.87	3.784	United States
6	Remote Sensing of Environment	43	1.52	10.163	United States
7	Landslides	39	1.38	6.578	Germany
8	Acta Astronautica	38	1.34	2.413	United States
9	Sensors	37	1.31	3.576	Switzerland
10	International Journal of Applied Earth Observation and Geoinformation	35	1.24	5.933	Netherlands
10	IEEE Transactions on Geoscience and Remote Sensing	35	1.24	5.600	United States

Note: "TP" means the total number of publications; "IF" represents the impact factor in 2020

### 3.4. Influential institutions

The top-10 influential institutions are provided (Table 3), according to the number of publications, and a collaboration network of institutions is shown (Fig. 3), where the size of nodes reflects the number of publications by institutions. The top three institutions of publications are Chinese Academy of Sciences, NASA, and University of Chinese Academy of Sciences, with publications reaching 161, 78 and 71, respectively, and they also focus on collaborating with other institutions on data and technologies. The cooperation between agencies from different countries needs to be further strengthened.

Table 3  
Top-10 Influential Institutions

Num.	Institutions	Publications	Year (mean)	Country
1	Chinese Academy of Sciences	163	2003	China
2	NASA	79	1995	United States
3	University of Chinese Academy of Sciences	75	2012	China
4	Wuhan University	64	2012	China
5	Beijing Normal University	40	2000	China
5	Consiglio Nazionale delle Ricerche (CNR)	40	2009	Italy
7	National Oceanic and Atmospheric Administration (NOAA)	35	1998	United States
8	Tohoku University	33	2012	United States
9	University of Maryland	31	2007	United States
10	University of Twente	29	2012	Netherlands

### 3.5. Highly cited articles

Owing to the number of citations embodies the influence of an article, a citation analysis is provided in the section, and the information of top-10 influential articles are presented (Table 4) based on times cited in all databases. By reading the contents of highly cited literatures, it can be found that multiple specific research fields are involved in the use of satellites in emergency management. Some literatures focus on the construction, performance and application of satellite systems to support disaster response (Entekhabi et al. 2010; Drusch et al. 2012), and other literature analyses satellites applications in relation to specific disasters, such as fires (Siegert et al. 2001), droughts (Kogan 1995), landslides (Metternicht, Hurni and Gogu 2005), and earthquake(Brunner, Lemoine and Bruzzone 2010). Since natural hazards may originate in different sources and systems, it warrants a close interaction between different scientific and operational disciplines, aimed at enhancing the mitigation of hazards.

Global Monitoring for Environment and Security (GMES) is the European programme to establish a European capacity for Earth observation. Satellites Sentinel-1, Sentinel-2, and Sentinel-3 are designed for GMES, which contribute to the emergency response support, marine surveillance, ice monitoring and interferometric applications, and ensure the long-term collection and operational delivery of high-quality measurements to GMES ocean, land, and atmospheric services(Drusch et al. 2012; Torres et al. 2012; Donlon et al. 2012). A number of related articles are based on the data from these satellites.

Tralli et al. (2005) analyze satellite remote sensing systems and integrated observational and modeling approaches that are used to assess risks due to earthquakes, volcanoes, floods, landslides and coastal inundation. The paper points out the contributions of satellite remote sensing to understanding underlying phenomena and providing critical information for decision support by emergency managers. Entekhabi et al. (2010) focus on the Soil Moisture Active Passive (SMAP) mission, which is one of the first Earth observation satellites developed by NASA, and soil moisture measurements are directly applicable to flood assessment and drought monitoring. SMAP observations can help monitor these natural hazards, resulting in potentially great economic and social benefits. Hou et al. (2014) consider the global precipitation measurement mission, an international satellite mission to unify and advance precipitation measurements from space for scientific research and societal applications.

Table 4  
Top-10 influential articles

Num.	Title	Authors	Year	Citations
1	The Soil Moisture Active Passive (SMAP) mission	Entekhabi et al.	2010	1870
2	Sentinel-2: ESA's optical high-resolution mission for GMES operational services	Drusch et al.	2012	1449
3	The global precipitation measurement mission	Hou et al.	2014	1295
4	GMES Sentinel-1 mission	Torres et al.	2012	759
5	Increased damage from fires in logged forests during droughts caused by El Nino	Siegert et al.	2001	437
6	Droughts of the late 1980s in the united-states as derived from NOAA polar-orbiting satellite data	Kogan et al.	1995	437
7	The Global Monitoring for Environment and Security (GMES) Sentinel-3 mission	Donlon et al.	2012	367
8	Remote sensing of landslides: An analysis of the potential contribution to geo-spatial systems for hazard assessment in mountainous environments	Metternicht et al.	2005	333
9	Earthquake damage assessment of buildings using VHR optical and SAR imagery	Brunner et al.	2010	313
10	Satellite remote sensing of earthquake, volcano, flood, landslide and coastal inundation hazards	Tralli et al.	2005	291

## 4. Co-citation Analysis

Co-citation analysis is an important content of bibliometric analysis, employed to identify emerging trends and hot topics from a number of papers. Co-cited articles are considered to have similarities in contents commonly, identified by the clusters of co-cited references which means creating a link between

two or more references when they appear simultaneously in the reference lists of citing articles (Raghuram, Tuertscher and Garud 2010).

## 4.1. Co-citation analysis of authors

Scholars from the same community have been cited together, and authors with high citations also pay attention to the collaboration with authors from other institutions. A co-citation network about authors is shown (Fig. 4). Top-6 most cited authors are Guzzetti(131), Huffman(111), Ferretti(105), Wang(92), Zhang(88), and Voigt(86). The citation frequency is the total citation by our 2,833 papers dataset. It can be found that influential authors with high frequency also put emphasis on the collaboration with others.

A typical article of Guzzetti (Guzzetti et al. 2012) presents satellite-based technologies for landslide mapping, which considers the exploitation of very-high resolution digital elevation models to analyze surface morphology, and the visual interpretation and semi-automatic analysis of different types of satellite images, including panchromatic, multispectral, and synthetic aperture radar images. A typical article of Voigt (Voigt et al. 2011) talks about the activity of the Center for Satellite based Crisis Information of the German Aerospace Center after a devastating Haiti earthquake in 2010. A specific approach including preprocessing procedures and visual interpretation on a grid-basis for damage maps is proposed, to avoid problems generated from the large number and inconsistency of satellite maps internationally.

## 4.2. Dynamic evolution of co-cited keywords

Keywords are clear symbols of the critical content of research. Before the co-cited keywords analysis, technology-related words, but unrelated to a management issue, have been excluded artificially, such as lidar, persistent scatterer, synthetic aperture radar etc., and some synonyms and abbreviations are merged, such as forecast and prediction, vulnerability and susceptibility, analytic hierarchy process and AHP etc. And then, a co-occurrence network of keywords is obtained by CiteSpace (Fig. 5). The 10 most frequent words are: model, GI (Geographic Information), imagery, classification, area, climate, earthquake, impact, algorithm, vulnerability.

Moreover, a time-zone map of keywords is generated (Fig. 6), taking five-year period as a slice, and the whole interval is divided into six parts. For clarity, only keywords with high node centrality or high frequency are reserved. Through the time-zone analysis, hot issues in recent years and future directions are analyzed. The graph is a collection of nodes with the similar occurrence time in the same time zone. If there are less keywords in a time zone, fewer influential results exist in the period. And the connection of nodes between time zones indicates the inheritance of research. The evolution trend of hotspots in each period are summarized (Table 5), reflecting the main problems and influential methods.

Table 5  
Evolution of research trends.

Year	Main keywords
1991–1996	Imagery, dynamics, vegetation, identification
1997–2001	GI (Geographic Information), system, model, NDVI (Normalized Difference Vegetation Index), temperature, rainfall
2002–2006	Prediction, classification, vulnerability, deformation, accuracy, earthquake
2007–2011	Risk, damage, recovery, segmentation, simulation, logistic regression, landslide
2012–2016	Map, optimization, time series, support vector machine, AHP (Analytical Hierarchy Process)
2017–2021	Uncertainty, urbanization, ocean, UAV (Unmanned Aerial Vehicle), extreme, CNN (Convolutional Neural Network)

Over 30 years, the main methods involved in applications of satellites in emergency management are: model, system, simulation, logistic regression, optimization, time series, support vector machine, AHP, and CNN. Satellite-based technologies are applied in the problems of identification, classification, segmentation of satellite images, as well as risk assessment. The key stages in emergency management of discussions have gradually shifted from disaster identification to prediction and vulnerability assessment, further to damage evaluation and recovery.

From the view of the type of disaster, literatures about satellite monitoring for the rainfall and temperature occur early, in 1997–2001, as well as researches on flood and fire management. During 2002–2006, the focus on earthquake enhances rapidly, and 2008 Wenchuan earthquake and 2010 Haiti earthquake are extensively studied by scholars. After that, the landslide gets more attention of scholars. In recent years, disasters related to extreme weather conditions such as extreme precipitation, or disasters occurring on the ocean become the hotspots, and management problems considering uncertainty or urbanization are discussed, worthy of further study.

### 4.3. Cluster analysis of co-cited articles

In order to visualize the co-citation relationship of sample literatures, CiteSpace is used to conduct a cluster analysis on cited literatures. According to the topic of cited reference, several clusters are generated, whose labels are produced based on the text analysis of titles, keywords and abstracts of cluster members, reflecting the most frequent contents. Therefore, the cluster labels represent hot topics of relevant research.

The sample articles are arranged into 13 highlighted research clusters (Table 6), and the top five hot topics are Sentinel-1, deep learning, landslide, Analytical Hierarchy Process/AHP and earthquake, with cluster size 80, 55, 55, 53, and 51 respectively, and year labels of these clusters are 2016, 2016, 2015,

2017, and 2008 respectively. The representative articles of each cluster are also provided in the software (Fig. 7). As the cluster labels are produced by CiteSpace automatically, a careful check for the papers that be clustered into each label is conducted. Owing to the research topic belongs to an interdisciplinary subject, the clustering results of co-cited articles contain a degree of dispersion. To get more effective and rapid emergency management, an integrated methodology or framework needs to be established. Also, there may be overlaps between different cluster labels that focus on disaster issues, technologies, or both.

Table 6  
Summary of cluster analysis of co-cited articles

Cluster ID	Cluster label	Cluster size	Silhouette <sup>a</sup>	Year(mean)
#0	Sentinel-1	80	0.815	2016
#1	Deep learning	55	0.971	2016
#2	Landslide	55	0.960	2015
#3	AHP (Analytical Hierarchy Process)	53	0.955	2017
#4	Earthquake	51	0.981	2008
#5	ANFIS (Adaptive Neuro-Fuzzy Inference System) model	44	0.974	2011
#7	Fuzzy Logic	28	0.997	2011
#8	GPM (Global Precipitation Measurement)	28	0.932	2015
#10	Normalized difference vegetation index	26	0.950	2003
#11	Climate change	26	0.987	2003
#14	GIS	16	0.961	2010
#15	Landslide's susceptibility	12	0.982	2012
#21	Satellite communication	8	0.975	2008

a: Silhouette coefficient represents an appreciation of the relative quality of clusters.

The interest for satellite imagery can be explained by the availability of many open-source data with high-resolution images and regular information updates (Lissak et al. 2020). And GMES Sentinel-1 mission (Cluster #0), NASA GPM (Cluster #8), GIS (Cluster #14) provide abundant integrated information from satellites for disaster response and related studies. GIS integrates digital elevation models, satellite images, hazard maps and vector data on natural and artificial features (energy supply lines, strategic buildings, roads, railways, etc.). Dieu Tien et al. (2019) propose a hybrid approach based on Extreme Learning Machine and Particle Swarm Optimization for flash flood susceptibility mapping. A geospatial database is constructed with 654 flash flood locations and 12 factors.

The most concerned natural disasters include landslide (Cluster #2 and #15), earthquake (Cluster #4), and flood. Flood mapping or flood monitoring occur many times in keywords of literatures in Cluster #0, as well as flood risk management in cluster #7. Ostir et al. (2003) review the remote sensing applications in natural hazard monitoring, and take Mount Mangart landslide as a case study. Lissak et al. (2020) review the spaceborne, aerial and terrestrial remote-sensing methods employed for landslide assessment and processing, and point out that the key for understanding landslides is the complementarity of methods and the automation of the data processing. Building damage detection after natural hazards, especially earthquake, would help to rapid relief and response of disaster, always combined with technologies of image segmentation, and Haiti earthquake (2010 Port-au-Prince) provides a classical database for the related research. Cooner, Shao and Campbell (2016) evaluate the effectiveness of multilayer feedforward neural networks, radial basis neural networks, and random forests in detecting earthquake damage caused by Haiti earthquake. The pre- and post-flood satellite images, coupled with hydrological (river water level) and meteorological (rainfall) data, are contributive for risk management. For emergency response to floods, access to timely and accurate data is essential, and satellite imagery offers a rich source of information which can be analyzed to help determine regions affected by a disaster (Nemni et al. 2020).

AHP (cluster #3) for vulnerability assessment, ANFIS model (cluster #5) for automatic detection, and Fuzzy Logic (cluster #7) for disaster mitigation are the popular methods in emergency management. In recent years, more articles focus on deep learning (cluster #1) to implement automatic detection (including disaster prediction, monitoring and rescue), by dealing with numbers of images or other forms of data obtained from satellites. Ji, Liu and Buchroithner (2018) use the CNN to identify collapsed buildings from post-event satellite imagery. Producer accuracy, user accuracy, and overall accuracy are used as evaluation metrics, and the network performs well in classifying collapsed and non-collapsed buildings. Bai et al. (2021) present new deep learning algorithms and a multi-source data fusion driven flood inundation mapping approach by leveraging a large-scale publicly available Sen1Flood11 dataset consisting of roughly 4,831 labelled Sentinel-1 SAR and Sentinel-2 optical imagery gathered from flood events worldwide. Ahmed et al. (2021) attempt to assess flood susceptibility of the Brahmaputra floodplain of Bangladesh using Deep Boost, Deep Learning Neural Network, and Artificial Neural Network.

Satellite communication (Cluster #21) also plays an important role in the emergency management, to replace or support terrestrial infrastructures due to the facility damage or the lack of power supply (Asuquo et al. 2018; Tani et al. 2020).

## 4.4. Burst analysis of co-cited articles

Burst analysis is used to detect sudden changes in topics, authors or references of sample articles, based on citation or word frequency. A citation burst of references is conducted to detect a surge of citations, representing an active research area in a given period. The information of top-10 references with strongest citation bursts are listed in Table 7. The burst period of each reference is highlighted in red in the timeline from 1991 to 2021. Among these 10 references, 6 papers are published in the journals about remote sensing to detect the damage of natural disasters, and the earthquake has the most attention in

different types of disasters. 2 papers are published in the journals about Earth science, which focus on the semi-automatic detection and inventory maps of landslide. Another 2 papers are published in conferences associated with computer science, studying the convolutional networks. Guzzetti et al. (2012) present satellite-based technologies for landslide mapping, with the highest burst strength, 10.37. Gorelick et al. (2017) become more popular recently, summarizing the databases, system architecture, data distribution models and applications of Google Earth Engine, to help monitor, track and manage the Earth's environment and resources. And this paper receives citation bursts from 2019 to 2021.

**Table 7** Top-10 references with strongest citation bursts

Authors	Title	Journal/Conference	Year	Strength <sup>a</sup>	Begin	End	Burst period: 1991-2021
Stramondo et al.	Satellite radar and optical remote sensing for earthquake damage detection: results from different case studies	International Journal of Remote Sensing	2006	6.86	2009	2012	
Brunner et al.	Earthquake damage assessment of buildings using VHR optical and SAR imagery	IEEE Transactions on Geoscience and Remote Sensing	2010	9.33	2011	2016	
Martha et al.	Characterising spectral, spatial and morphometric properties of landslides for semi-automatic detection using object-oriented methods	Geomorphology	2010	6.73	2011	2016	
Guzzetti et al.	Landslide inventory maps: new tools for an old problem	Earth-Science Reviews	2012	10.37	2013	2018	
Voigt et al.	Rapid damage assessment and situation mapping: learning from the 2010 haiti earthquake	Photogrammetric Engineering & Remote Sensing	2011	6.76	2013	2016	
Dong and Jie	A comprehensive review of earthquake-induced building damage detection with remote sensing techniques	ISPRS Journal of Photogrammetry and Remote Sensing	2013	10.06	2015	2018	
Tofani et al.	Persistent Scatterer Interferometry (PSI) technique for landslide characterization and monitoring	Remote Sensing	2013	6.67	2017	2018	
Szegedy et al.	Going deeper with convolutions	2015 IEEE Conference on Computer Vision and Pattern Recognition	2014	7.27	2017	2020	
Ronneberger et al.	U-Net: convolutional networks for biomedical image segmentation	Medical Image Computing and Computer-Assisted Intervention – MICCAI 2015	2015	7.55	2019	2020	
Gorelick et al.	Google Earth Engine: planetary-scale geospatial analysis for everyone	Remote Sensing of Environment	2017	9.48	2019	2021	

a: The strength represents the change in the word frequency that triggered the burst, presented by Kleinberg (2003).

## 5. Conclusions

### 5.1. Summary

Satellites provide a great deal of valuable information support for decision-making in emergency management. In this study, a bibliometric analysis is implemented to depict 2,833 articles, by both descriptive statistics analysis and co-citation analysis. The last three decades have witnessed the increasing use of satellites in disaster response. Scholars from 128 countries and regions pay attention to this topic, and those from China, United States and Italy are in the majority. And top-10 influential journals, institutions and articles are analyzed.

In the co-citation analysis, a collaboration network of authors, emerging trends based on co-cited keywords, cluster analysis and burst analysis of co-cited articles are provided. An integrated knowledge graph of the field is presented, and hot topics in different 5-year periods are captured. It can be found that “uncertainty”, “urbanization”, “ocean”, “convolutional neural network” are the popular keywords in recent years. According to the papers in 13 highlighted research clusters, popular problems and methods in this field are analyzed. Owing to the research topic belongs to an interdisciplinary subject, an integrated methodology or framework needs to be established. There are new research hotspots in the field emerging constantly, but also with some limitations. In the next 10 years, substantial scientific, technological, and operational development will handle mass data from different satellite constellations, to support the effective emergency management and rapid disaster response.

## 5.2. Future directions

Satellites have already been used in each phase of emergency management, including mitigation, preparation, response, and recovery. Through the above analysis, future research directions of this field are concluded on the following four perspectives:

**(1) Disaster monitor.** Early forecasts and warnings make it possible to transfer populations and property timely, and the monitor of various disasters through satellites is extensively studied. However, there are some limitations in disaster detection and forecasting due to the visual interpretation and semi-automatic analysis of satellite images, and early warning systems rarely include real-time components to assess potential impacts generated by forecasted natural hazards. Different to monitor landslide, earthquake and flood, recent literatures pay more attention on disasters related to extreme weather conditions, or disasters occurring on the ocean. Also, 5G communication combined with the monitoring and early warning need to be investigated (Li et al. 2021), to further improve the reliability and response speed of large-scale disaster monitoring.

**(2) Vulnerability and risk assessment.** The analysis of risk and its causes is a crucial prerequisite for the risk prevention and mitigation measures, which can be defined by physiographical sensitivity and vulnerability associated with socio-economic, demographic and infrastructure aspects (Skakun et al. 2014; Narendr et al. 2021). Risk assessment indexes of different disasters are established (Jaman, Dharanirajan and Sharma 2021). With the global urbanization process, new multidisciplinary approaches need to be designed to characterize exposure and vulnerability models, to further assess stability and quantify probably affected people. With the development of smart city, the impact of accidents about electronic infrastructures increases, such as circuit interruption, mobile signal fault, etc., however, satellite-based risk assessment of urban emergency response is scarce.

**(3) Damage evaluation.** Rapid damage evaluation after natural disasters (e. g., earthquake, flood) is crucial for initiating effective emergency response actions. Remote-sensing satellites can provide vital information to map the affected areas with high geometric precision and in an uncensored manner, combined with remote sensing, GIS and GPS to assess the damage (Dong and Jie 2013; Stanley and Kirschbaum 2017; Galanis et al. 2021). Techniques such as neural networks, machine learning, random forests, and CNN are used to analyze post-event satellite imagery, to identify collapsed buildings or

determine the regions affected (Cooner et al. 2016; Cao and Choe 2020). Satellite-based damage evaluation on economic and social impacts of natural disasters are studied, especially nighttime light data in recent years (Skoufias, Strobl and Tveit 2020; Fang et al. 2021; Sarkar 2021). It is worth studying to evaluate the influence of public health events, such as COVID-19 based on satellites. Besides satellite data, real-time text, graphics, video and other types of social media data will help us better monitor and assess the impact of disasters (Ahmad et al. 2019; Hao and Wang 2020; Tavra, Racetin and Peros 2021).

**(4) Emergency rescue and scheduling.** Satellites can support emergency rescue, that is, to direct the emergency movement of materials and ground rescue teams (such as law enforcement, firemen, healthcare personnel. After natural disasters, satellites support the relief logistics from the following aspects: communications, imagery and mapping, GPS positioning devices, and GPS vehicle tracking (Delmonteil and Rancourt 2017). Satellite big data analytics help build over real-time weather information, geospatial data and deploy over a cloud-computing platform to improve the coordination and collaboration between rescue teams for humanitarian relief operations (Nagendra, Narayananurthy and Moser 2020). Satellite communications play an important role in replacing or supporting terrestrial infrastructures due to the facility damage or the lack of power supply (Asuquo et al. 2018; Tani et al. 2020). It requires an optimal deployment to balance responders' needs and financial costs and an emergency rescue information system based on navigation satellites, even without network signal for the mobile phone (Hao et al. 2018). The scheduling optimization of multiple satellites for emergency response is also of great significance (Nin, Tang and Wu 2018; Chen et al. 2020; Deng et al. 2021), but the depth of research is insufficient. Different to traditional satellite scheduling tasks, emergency tasks have the independent arrival time and execution deadline, and different task priority needs to be considered (Wu et al. 2019). To deal with the environmental uncertainties, autonomous satellite system with distributed and coordinated functions is an important development direction (He et al. 2017), which adapts to various situations such as satellite faults, cloud obscuration and emergencies without human intervention. The efficiency and reliability of satellite missions need to be further improved, ensuring real-time online planning.

## Declarations

## Ethical statements

The authors have read *Committee on Publication Ethics (COPE) guidelines*, and certify that this manuscript is original and has not been published and will not be submitted elsewhere for publication while being considered by *Natural Hazards*. And the study is not split up into several parts to increase the quantity of submissions and submitted to various journals or to one journal over time. No data have been fabricated or manipulated (including images) to support the conclusions. No data, text, or theories by others are presented as if they were our own.

The authors declare no competing interests. The submission has been received explicitly from all co-authors. And authors whose names appear on the submission have contributed sufficiently to the

scientific work and therefore share collective responsibility and accountability for the results. Dengyuhui Li wrote the draft manuscript. Guanghui Zhou conceived, organized, and revised the manuscript. Shouyang Wang supervised and instructed on the manuscript. Jianbin Jiao provided valuable comments on the manuscript. All authors discussed and approved the final manuscript.

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## Figures

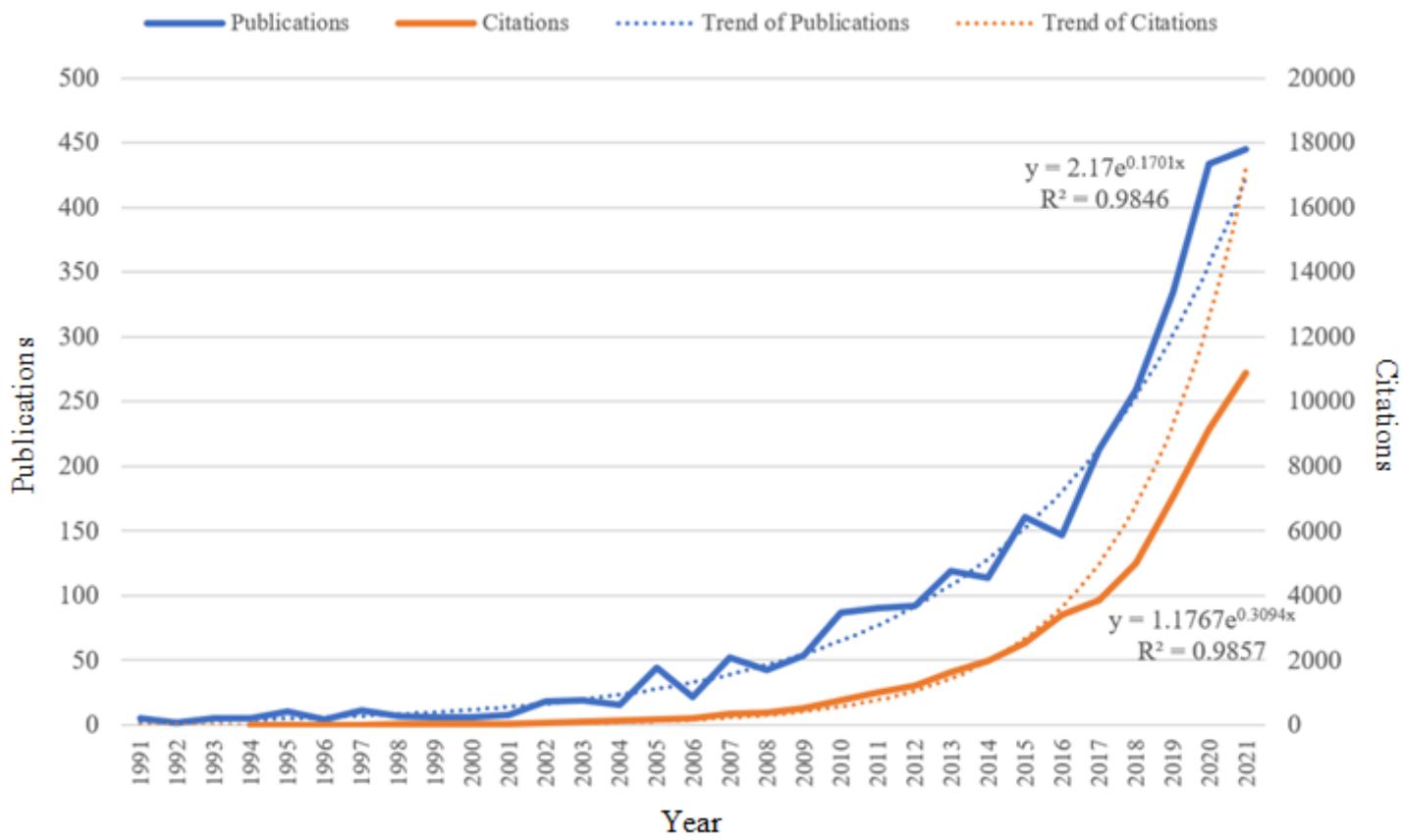


Figure 1

Numbers of annual publications and citations

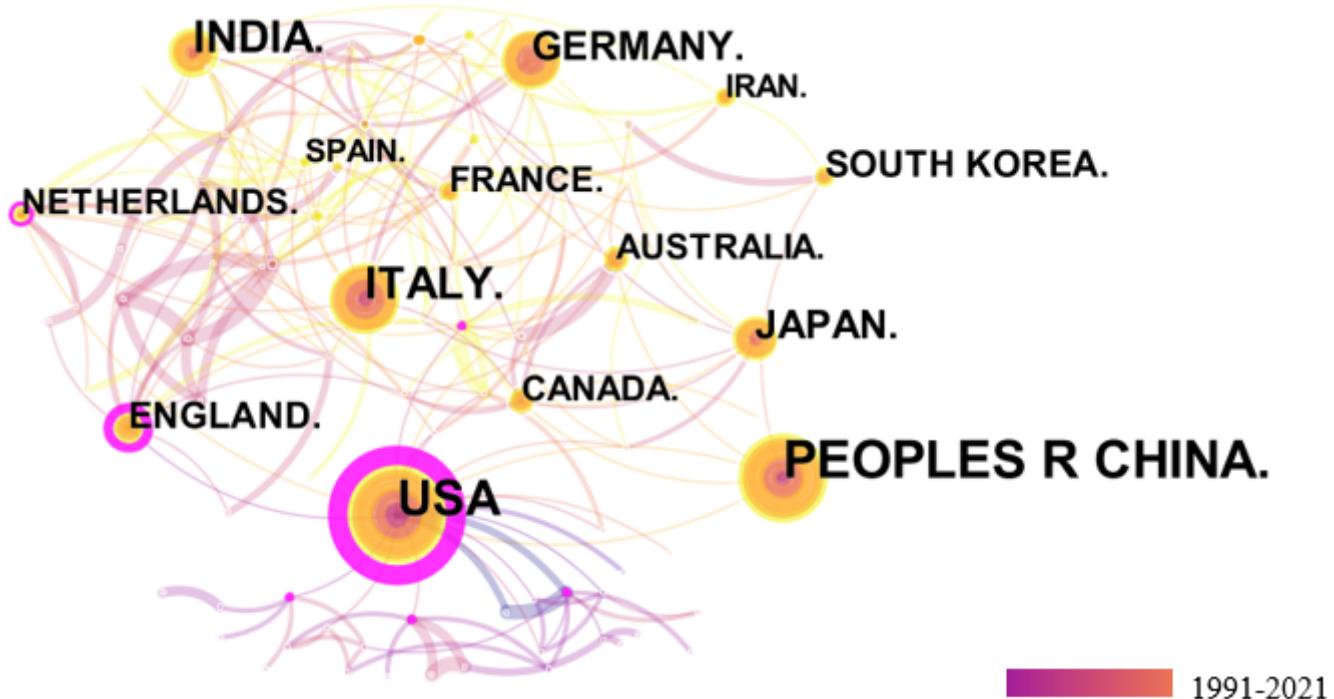


Figure 2

## Collaboration network of countries

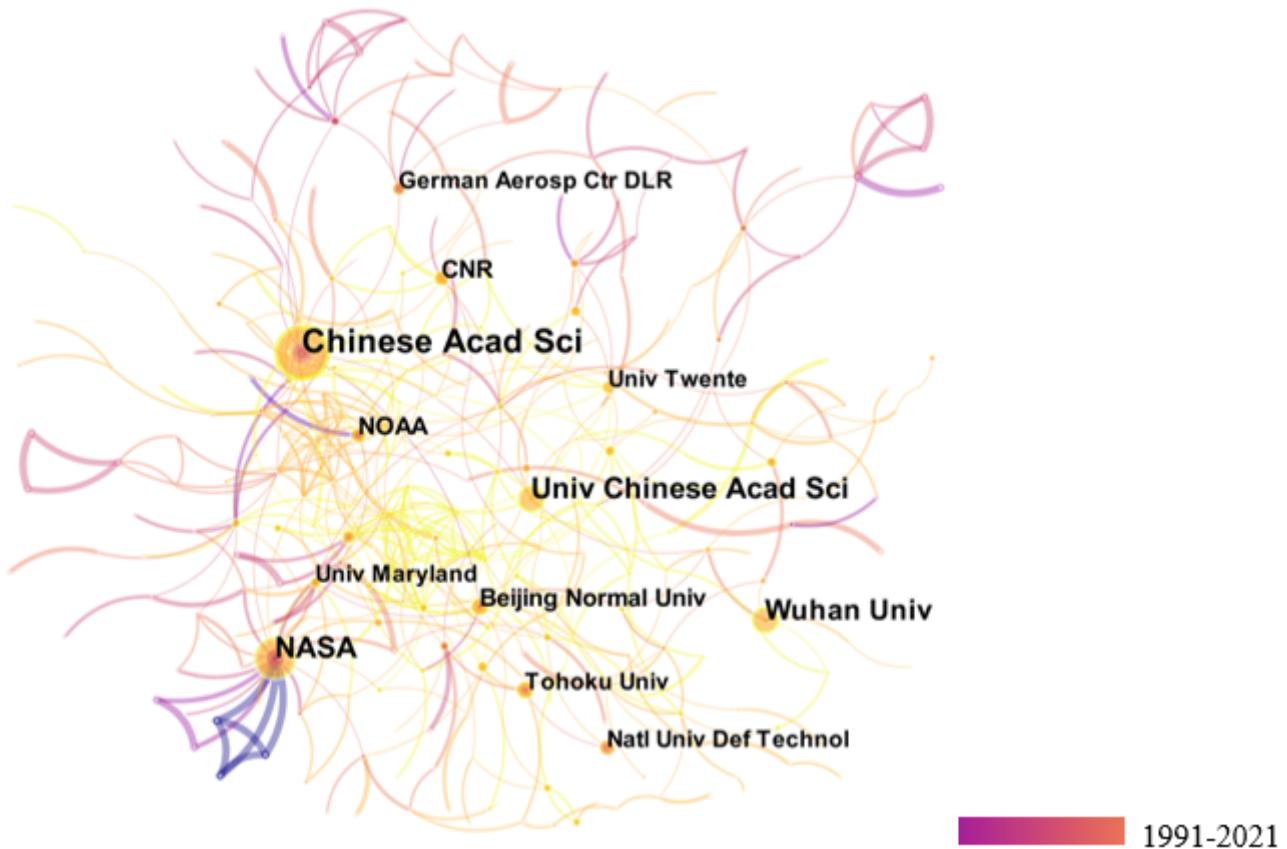
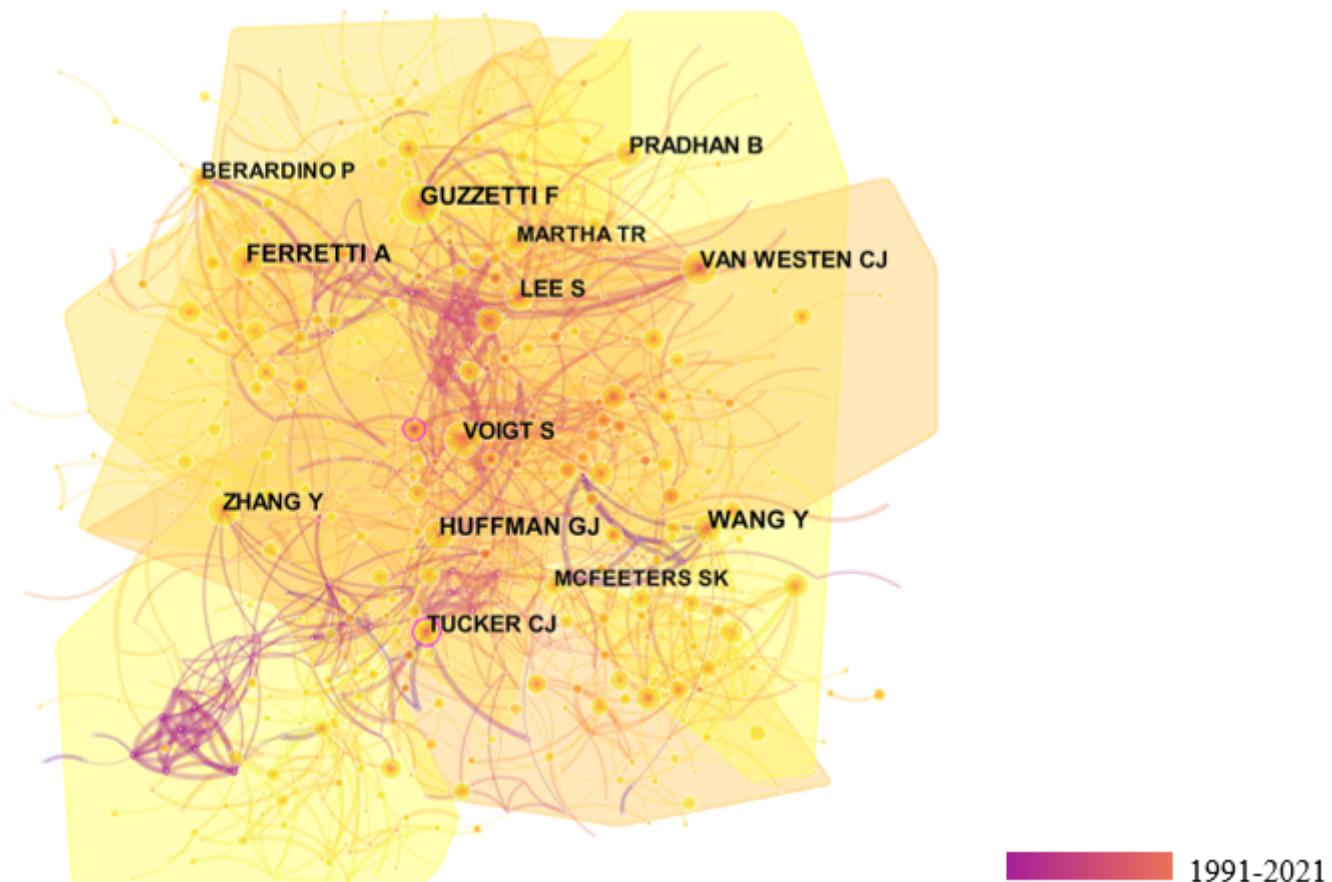


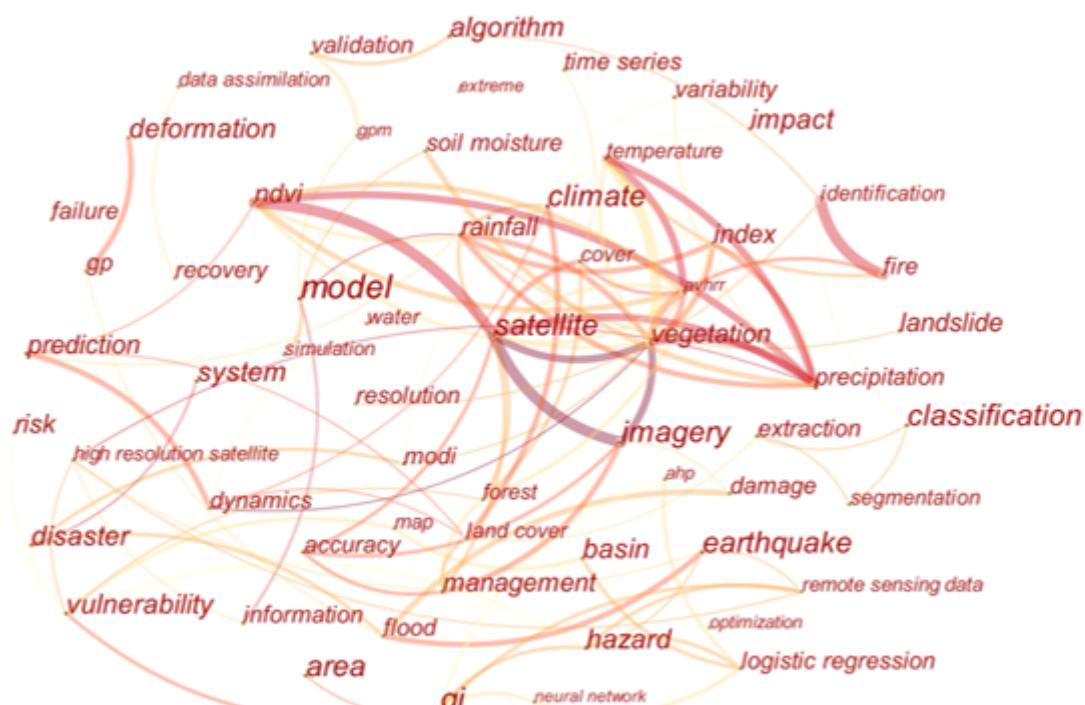
Figure 3

## Collaboration network of institutions



**Figure 4**

### Co-citation network of authors



1991-2021

Figure 5

Co-occurrence network of keywords

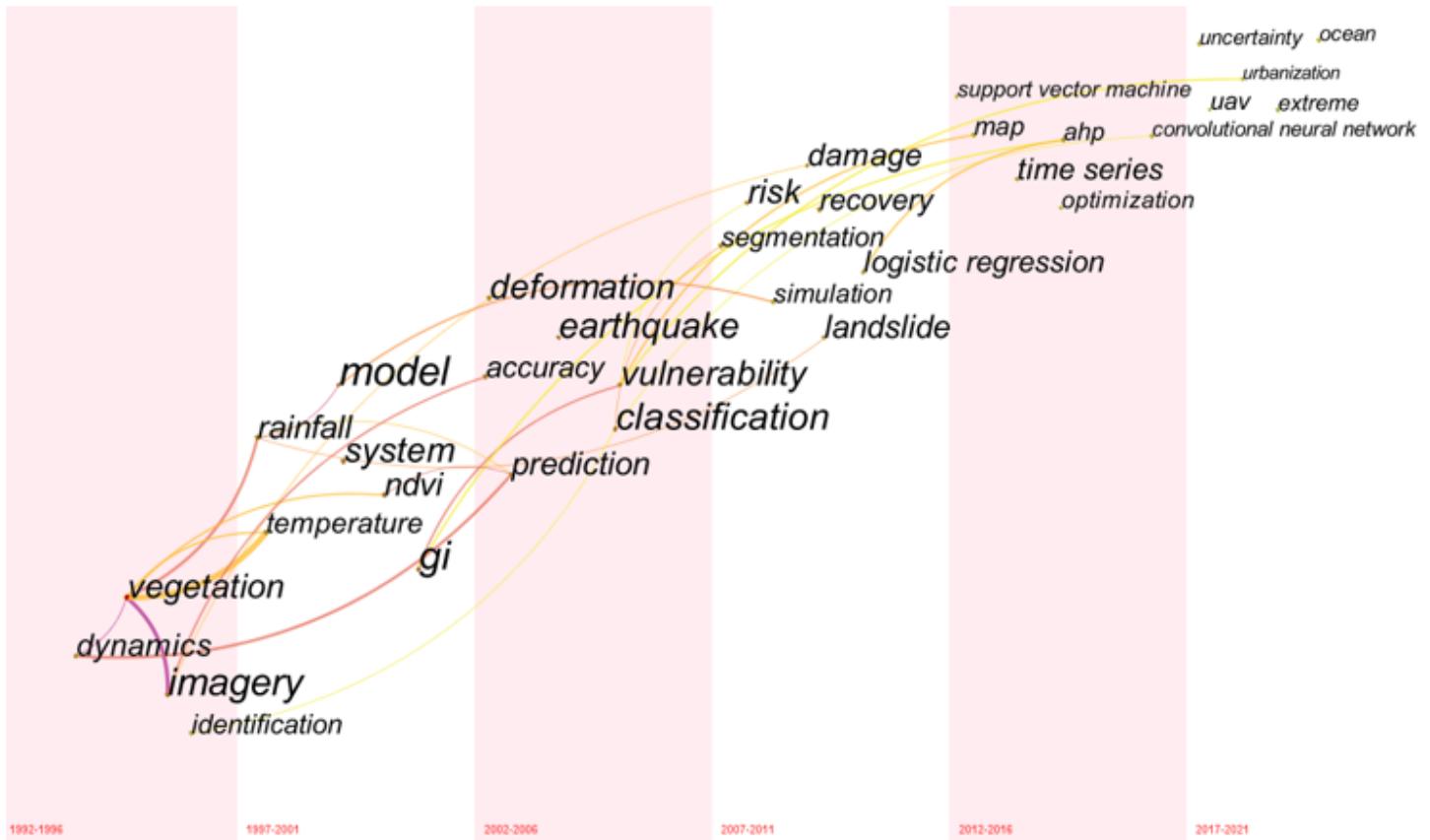


Figure 6

Time-zone map of keywords



Figure 7

### Clusters of co-cited articles and representative articles