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Article

The Development Trend and Research Frontiers of Distributed Hydrological Models—Visual Bibliometric Analysis Based on Citespace

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Abstract: Based on the bibliometric and data visualization analysis software Citespace, this study carried out document statistics and information mining on the Web of Science database and characterized the distributed hydrological model knowledge system from 1986 to 2019. The results show a few things: (1) from 1986 to 2019, the United States and China accounted for 41% of the total amount of publications, and they were the main force in the field of distributed hydrological model research; (2) field research involves multiple disciplines, mainly covering water resources, geology, earth sciences, environmental sciences, ecology and engineering; (3) the frontier of field research has shifted from using distributed hydrological models in order to simulate runoff and nonpoint source environmental responses to the coupling of technologies and products that can obtain high-precision, high-resolution data with distributed hydrological models. (4) Affected by climate warming, the melting of glaciers has accelerated, and the spatial distribution of permafrost and water resources have changed, which has caused a non-negligible impact on the hydrological process. Therefore, the development of distributed hydrological models suitable for alpine regions and the response of hydrological processes to climate change have also become important research directions at present.

Keywords: distributed hydrological model; bibliometric; Citespace; research frontier; development trend; visual analysis

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1. Introduction

Water resources are important natural resources that maintain ecological balance and promote the economic development of modern society. In the past two decades, the emergence of problems such as population expansion, water shortage, environmental pollution and climate change [1–3] have made rational planning of water-resource allocation and sustainable use of water resources become a top priority. Driven by research needs, the development and application of distributed hydrological models has also become a hot spot in the field of hydrological research.

The distributed hydrological model is an important tool for understanding the hydrological cycle and planning the sustainable use of water resources to meet various needs [4]. Currently, distributed hydrological models are widely used to the major scientific issues like the hydrological response under climate change [5,6], nonpoint source pollution [7], integrated water resources management [8], hydrological response to land use/cover change [9], etc. In addition to applying models to solve problems, research in the field of distributed hydrological models also includes the development, continuous updating and improvement of many models, as well as coupling with other technologies or products (such as GIS, remote sensing technology, precipitation products, etc.) [10–13] to obtain more accurate simulation results. It can be seen that the research field of distributed hydrological model research is multifaceted.

The focus of scientific research changes over time. In a complex research field, it is difficult for many scholars to directly understand the overall knowledge structure of the field, research progress, research frontiers and hot spots and so on. This study was based on a visual analysis software—Citespace. It describes the core research strength, development trajectory, research frontiers and emerging trends in the field of distributed hydrological model research through statistical analysis of 3079 documents using scientometrics. The results will provide valuable reference information for scholars and related researchers.

2. Data Collection and Method

2.1. Data Collection

The documents for analysis used in this study were derived from the SCI-E database, the core collection of Web of Science. The search conditions were "Distributed Hydrological Model", "Not Semi-distributed Hydrological Model", and "And article", and the time span was 1920–2019 by basic search. Under such search conditions, a total of 3079 documents were retrieved. The searched documents first appeared in 1986; therefore, the time span of the retrieved documents was from 1986 to 2019, and 3079 documents remained after deduplication. In addition, because the relevant data of the documents published in 2020 is not complete, this article separately analyzes the keyword co-occurrence of 226 documents with a time span from January 2020 to October 2020.

2.2. Method

Bibliometrics is a branch of informatics used to analyze quantitative scientific documents to be able to see the knowledge structure of the field and emerging research trends [14]. As a software for bibliometrics visualization and analysis, Citespace was developed based on Java by Dr. Chen Chaomei from Drexel University. Citespace is used to analyze the co-occurrence network of disciplines in the field, evaluate the research status and reveal the main research forces, research frontiers and emerging trends in the field [15–17]. So far, Citespace has been used in psychology [18], nonpoint source pollution research [19], stormwater management [20], information science [21] and other fields. This study used the 5.7.R1 version of Citespace to analyze 3079 documents retrieved in the field of distributed hydrological model research. The content of the analysis includes co-occurrence network analysis of country/region, institutional, co-citation analysis of author, document, keywords co-occurrence and burst word analysis. Network nodes used a single node. The nodes usually represent authors, countries, institutions, keywords, etc. Each node is described as a series of tree rings with different colors (corresponding to different years), and the surrounding purple rings indicate good concentration: the higher the citation and centrality of a node, the greater the influence of the node in the co-citation map [22]. The link represents the common reference or common occurrence between these nodes, and the color of the link represents the year when the two nodes co-occur [23]. The time slice in this study was one year, and the data selection criterion was the top 50.

3. Results and Discussion

3.1. Time Analysis of Post Volume

In order to summarize the research situation of distributed hydrological models, this article counted the circulation of documents related to distributed hydrological models in the core collection of Web of Science from 1986 to 2019 (Figure 1). The total number of documents was 3079. Around the 1990s, a number of distributed hydrological models emerged in the context of the promotion of research needs such as the sustainable use of water resources, nonpoint source pollution, the impact of global changes on the hydrological cycle and the rapid development of computer technology [24]. In 1986, three documents were published, two of which were introductions of the SHE model of the distributed water collection model system based on physics developed in Europe [25,26]. No related documents were published in the core collection of Web of Science in 1988 and 1989. From 1986 to 1993, no more than 10 documents were published each year. Since then, the number of annual publications had increased significantly, from 15 in 1994 to 298 in 2019. Distributed hydrological models have shown a significant increase overall since 1994, which means that scholars had been paying more and more attention to distributed hydrological models, that research investment had gradually increased since 1994, and that the field of distributed hydrological model shows a trend of rapid development. So far, distributed hydrological models have become an indispensable application tool in related research fields.

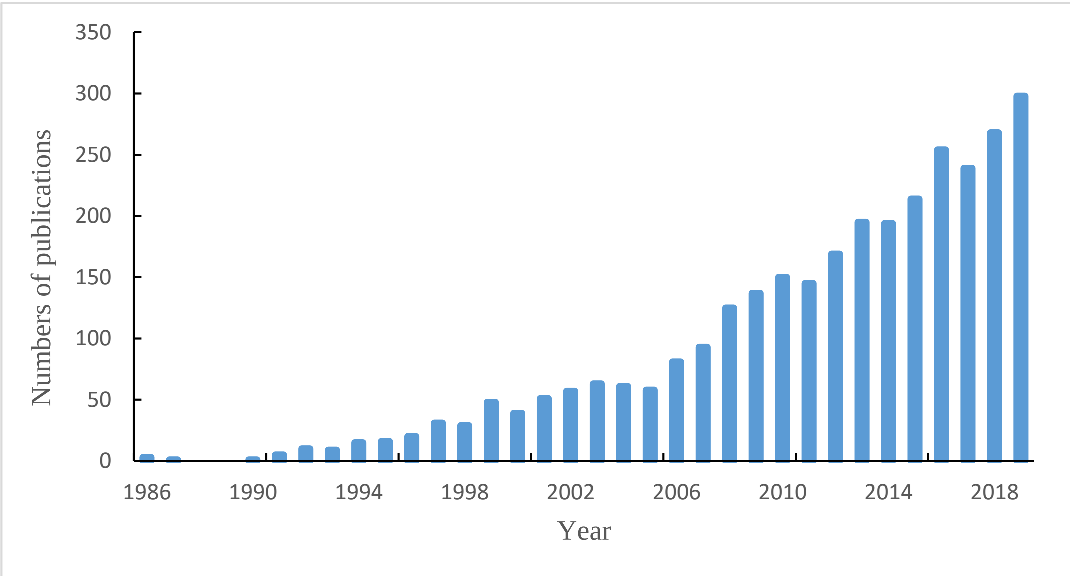

Figure 1. Documents publication performance from 1986 to 2019. Search term by "Basic search": "Distributed Hydrological Model" and "Not Semi-distributed Hydrological Model". The type of documents is "And article".

3.2. Cooperation Network Analysis

The analysis of cooperation networks in this article includes the analysis of cooperation networks between countries/regions and between institutions. The analysis of the cooperation network can reveal the cooperation network between the issuing countries and institutions and can explore the main research force of distributed hydrological models. It can also help different research units to establish cooperative relations. Running Citespace, we obtained a country/region cooperation network map with 59 nodes and 280 links (Figure 2) and an institution cooperation network map with 394 nodes and 775 links (Figure 3). A node in the figure represents a country/region (Figure 2) or research institution (Figure 3), that is, 59 countries and 394 institutions have published research results on this topic. The size of the node represents the amount of posts. The countries/regions and institutions connected by lines indicate cooperative relations, and the thickness of the line indicates the closeness of the partnership [27].

Research on distributed hydrological models was distributed in 59 countries/regions. Figure 2 shows that among 59 countries, the United States, China and some European countries (including Germany, France, Italy, England, Canada, The Netherlands, Australia, Switzerland, etc.) (top ten documents published) have more research on distributed hydrological models, which means the distributed hydrological models were widely used on a global scale. There were cooperative relations between multiple countries, among which China and France were the hubs of the cooperative network. The United States and China ranked first and second with 649 and 615 documents, respectively, accounting for 41% of the total number of documents. Therefore, the United States and China are the main research forces of distributed hydrological models. The top ten countries accounted for 96% of all publications, suggesting that these countries dominate the development of the field of distributed hydrological modeling.

The number of articles published in a country has a considerable relationship with the population base. The top 5 countries with the number of articles published are USA, China, Germany, France and Italy. The number of articles published in these five countries is related to the population (population quantity unit is one million). The ratios are 1.98, 0.44, 3.66, 3.76, 4.10, respectively, which shows that Italy has invested a lot in the field of distributed hydrological models, while the number of people active in the field of distributed hydrological models in China accounted for the total proportion is small. Figure 3 shows the changes in the number of posts issued by the top five countries from 1986 to 2019. Figure 3 shows the overall increase in the number of posts in these five countries. The annual number of articles published in the United States has accounted for a relatively large proportion for many years. China has only published a record of articles since 2003, but the growth trend has been the most obvious from 2003 to 2019.

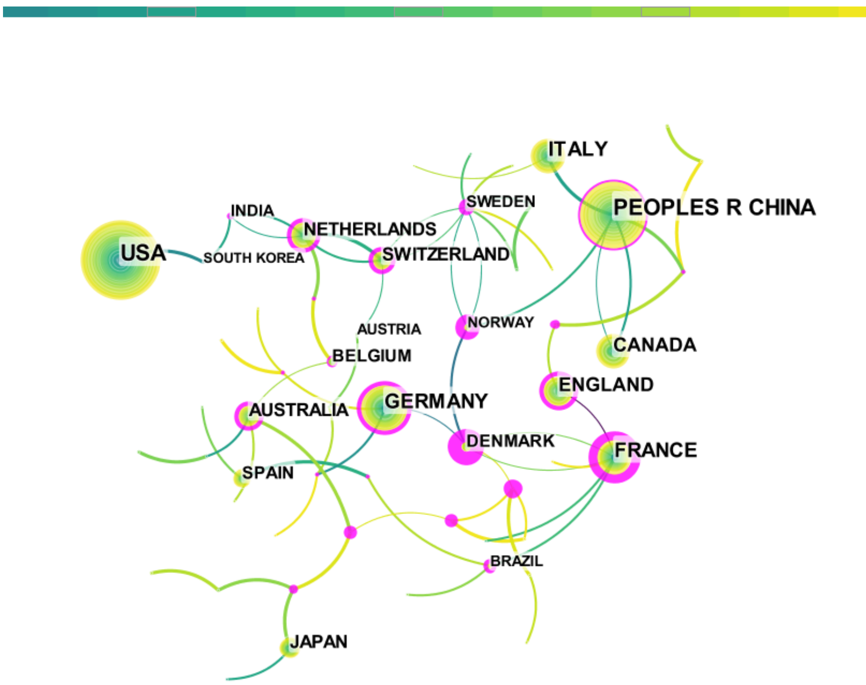

Figure 2. Country/territory cooperation network map. The colored line at the top in Figure 2 represents the years from old to new from left to right. A node represents a country/region. The size of the node is directly proportional to the number of articles published, each node is described as a series of tree rings with different colors (corresponding to different years), and the surrounding purple rings indicate good concentration. The link represents the common reference or common occurrence between these nodes; the color of the link represents the year when the two nodes co-occur; the thickness of the line indicates the closeness of the partnership.

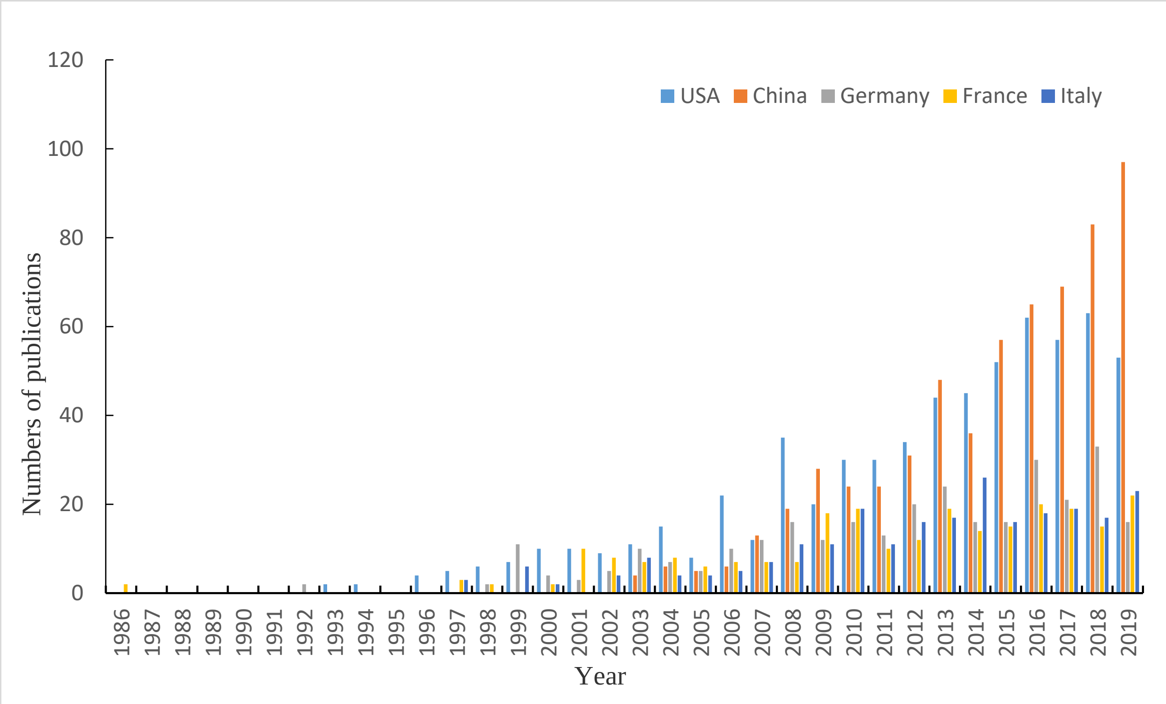

Figure 3. Trends in the number of published articles in the top 5 countries from 1986 to 2019.

Figure 4 shows that the Chinese Academy of Sciences, Beijing Normal University, Hohai University, China Institute of Water Resources and Hydropower Research and Tsinghua University have more research results. The top ten institutions in terms of publication volume are listed in Table 1, and seven of them are Chinese institutions. It shows that China has invested more in the research of distributed hydrological models. However, the cooperation of the seven Chinese institutions is not very close. Among them, only the Chinese Academy of Sciences and Wuhan University, as well as the China Institute of Water Resources and Hydropower Research and Tsinghua University have a cooperative relationship. On the whole, the top ten institutions have few exchanges and little cooperation, so it is necessary to strengthen China's domestic and international cooperation.

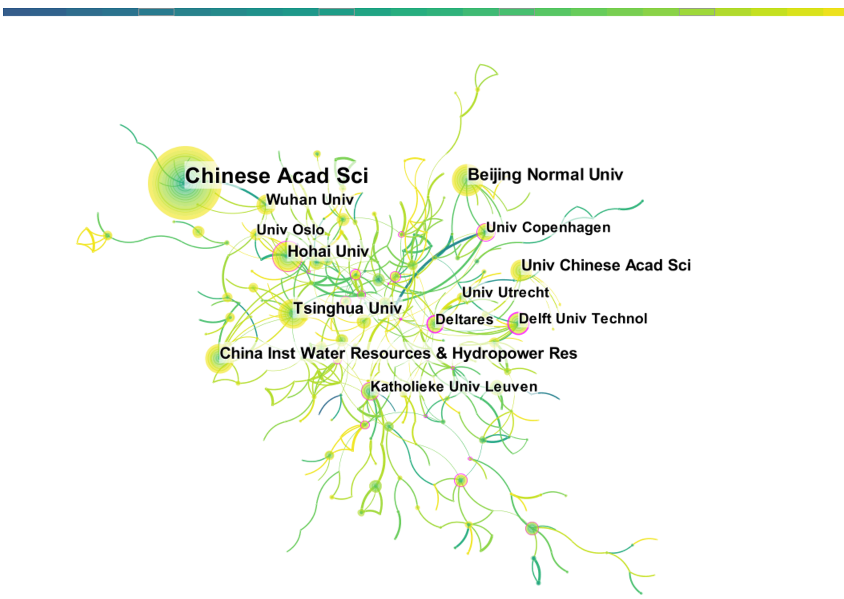

Figure 4. Institutional cooperation network map.

Table 1. Top 10 research institutions in terms of publication volume.

Ranking	Number of Articles Published	Institution
1	197	Chinese Acad Sci
2	63	Beijing Normal Univ
3	56	Hohai Univ
4	54	China Inst Water Resources & Hydropower Res
5	54	Tsinghua Univ
6	52	Univ Chinese Acad Sci
7	38	Wuhan Univ
8	36	Delft Univ Technol
9	34	Univ Copenhagen
10	34	Katholieke Univ Leuven

3.3. Co-Occurrence of Discipline Categories

Based on the co-occurrence analysis of discipline categories, disciplines involving distributed hydrological models can be detected, running Citespace to get 65 nodes and 255 links. A node represents a discipline category. The link linking two nodes means the co-occurrence of two discipline categories. It can be seen from Figure 5 that the research and application of distributed hydrological models involve multiple discipline categories. Figure 4 shows eleven disciplines. The top five popular research disciplines are water resources, geology, earth science, engineering and environmental science and ecology. In the field of water resources, distributed hydrological models were used to calculate snowmelt [28], evaluate water quality [4,29], observe and simulate changes in river flow [30] and flood forecasting [31], etc., to realize the rational allocation and sustainable use of water resources. When the research area is located in a mountainous area, it is necessary to use the knowledge of geology, earth science and engineering to explore the influence of the topography in the complex mountain on the hydrological process [28,32]. This shows that there is a phenomenon of multidisciplinary integration in the field of distributed hydrological models.

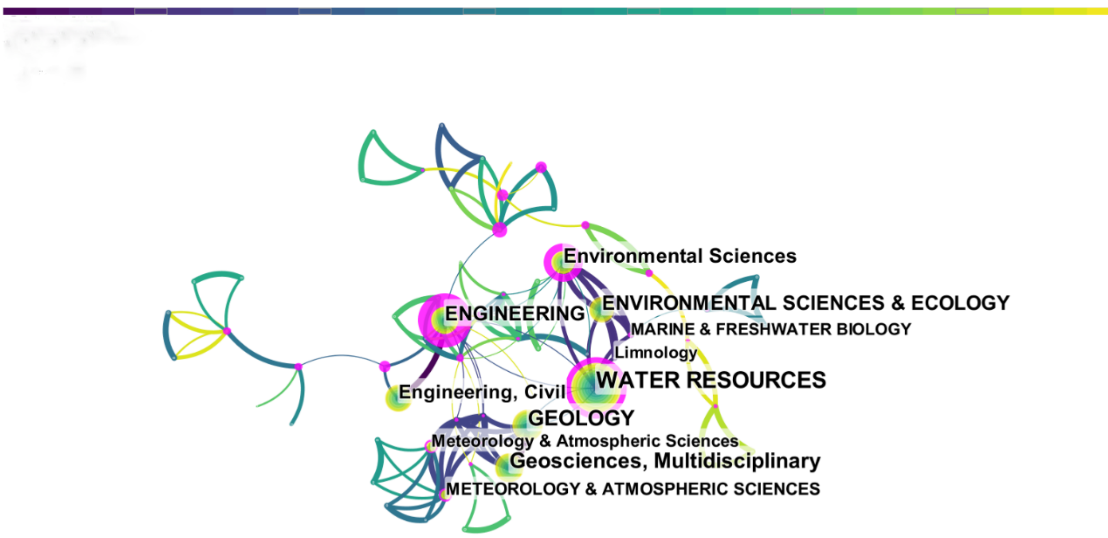

Figure 5. Disciplines co-occurrence network map involving distributed hydrological models.

3.4. Co-Citation Analysis

Co-citation analysis includes author co-citation analysis and document co-citation analysis, which means that two authors or two documents are cited by a third party at the same time. The concept of author co-citation was first proposed by White and McCain [33]; it reflects the proximity of research directions and the importance of the author and has been widely used to assess the relevance of scientific research. High-frequency co-cited documents usually have breakthroughs and innovations in the corresponding research areas; at the same time, high-frequency co-cited references form the knowledge base of the current analyzed field, which is of great significance to the development of the field.

Figure 6 shows the author co-citation map created by Citespace, with a total of 582 nodes, and each node represents a cited author. The author of the largest node in the figure was BEVEN K, whose documents have been cited 1241 times, as well as NASH JE (777), ARNOLD JG (338), ABBOTT MB (269), REFSGAARD JC (261), GUPTA HV (245), MORIASI DN (230), DUAN QY (217), BERNER LT (199), BLOSCHL G (196) and others. They represent the core people in the research and development of distributed hydrological models.

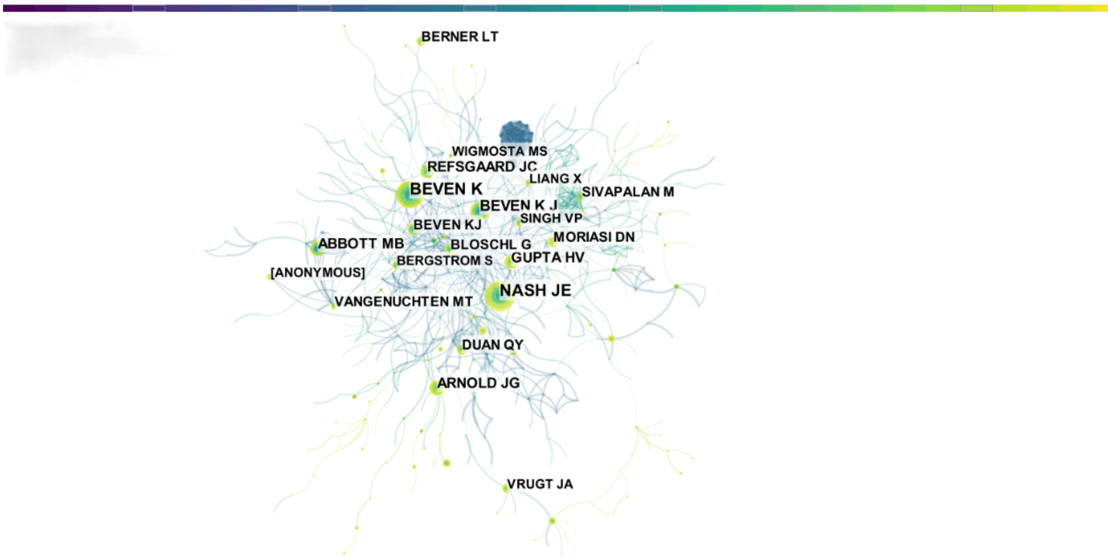

Figure 6. Author co-citation map.

Running Citespace to analyze the co-cited references, we obtained 484 nodes and 1526 links. The references co-citation map is shown in Figure 7. The co-cited references were clustered and analyzed. The top ten major clusters in terms of size are listed in Table 2. The size value indicates the size of the cluster. The larger the size, the greater the number of related documents published in the cluster, and large clusters usually represent the main research direction, that is, one cluster corresponds to one research hotspot. The silhouette value reflects the similarity of the clusters; the closer its value is to 1, the better the quality of the cluster. The silhouette values of the clusters in Table 2 are all close to 1, indicating that all the clusters are highly uniform. Mean year represents the average year of documents publication in the cluster. The larger the value, the newer the mean year of the publication in the cluster and the closer to the current research frontier. The most representative term in each cluster was detected and selected by Logarithmic Likelihood Ratio (LLR), which is used to mark corresponding cluster for discussion. In the top ten clusters (Table 2), the mean years $\geq$ 2005 were #8 (2009) and #9 (2006). The representative terms were TRMM and ensemble Kalman filter, respectively. The full name of TRMM is Tropical Rainfall Measuring Mission, which is a meteorological satellite developed by the National Aeronautics and Space Administration (NASA) and Japan Aeronautics and Space Administration (JAXA) to quantitatively measure tropical and subtropical rainfall [34]. Recently, ensemble Kalman filter has been used to solve in the inverse problem of water environment pollution source identification, effectively improving the efficiency of updating observations in the models [35].

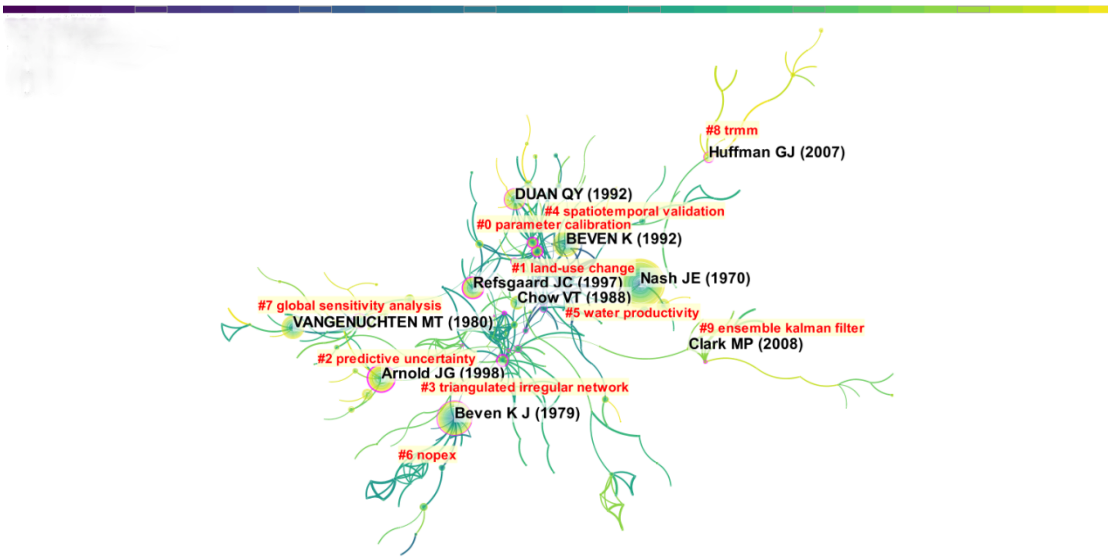

Figure 7. References co-citation map.

Table 2. Major clusters of co-cited references.

Cluster ID	Size	Silhouette	Mean Year	Representative Terms (LLR)
0	35	0.934	2000	Parameter calibration
1	35	0.889	1997	Land-use change
2	34	0.930	2002	Predictive uncertainty
3	32	0.848	1995	Triangulated irregular network
4	30	0.951	1993	Spatiotemporal validation
5	27	0.931	2000	Water productivity
6	24	0.965	1989	NOrthern hemisphere climate Processes land surface EXperiment (NOPEX)
7	22	0.899	1996	Global sensitivity analysis
8	21	1	2009	Tropical Rainfall Measuring Mission (TRMM)
9	20	0.965	2006	Ensemble Kalman filter

Highly cited documents are usually groundbreaking in the research field and are of great significance to the development of the field. The top ten most highly cited documents in the field of distributed hydrological model research are listed in Table 3. The main content involved is as follows: (1) the proposed concepts, methods, technologies and application principles of distributed hydrological models (documents 1, 5, 6 and 8) [36–39]; (2) evaluation and improvement of distributed hydrological models (documents 2, 3 and 10) [40–42]. The distributed hydrological-vegetation model described in the second document considers the impact of canopy interception, evaporation and transpiration as well as snow cover and snowmelt on runoff [40], and the tenth document solves the problem of CRR (Conceptual Rainfall-Runoff) model optimization [42]; (3) the development and introduction of new models (documents 4, 7 and 9) [25,26,43], including the SWAT model [43] and the SHE model [25,26].

Table 3. Top ten most highly cited documents in the research field of distributed hydrological models.

Ranking	Journal	First Author	Title
1	Journal of Hydrology	J.E. Nash	River flow forecasting through conceptual models, part I—A discussion of principles
2	Water Resources Research	Mark S. Wigmosta	A distributed hydrology vegetation model for complex terrain
3	Transactions of the ASABE	D.N. Moriasi	Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations
4	Journal of the American Water Resources Association	J.G. Arnold	Large Area Hydrologic Modeling and Assessment, Part I: Model Development
5	Hydrological Processes	K. Beven	The future of distributed models: Model calibration and uncertainty prediction
6	Biogeosciences	L.T. Berner	Cajander larch (Larix cajanderi) biomass distribution, fire regime and post-fire recovery in northeastern Siberia
7	Journal of Hydrology	M.B. Abbott	An introduction to the European Hydrological System—Système Hydrologique Européen, "SHE", 2: Structure of a physically-based, distributed modelling system
8	Soil Science Society of America Journal	M. Th. van Genuchten	A Closed form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils
9	Journal of Hydrology	M.B. Abbott	An introduction to the European Hydrological System—Système Hydrologique Européen, "SHE", 1: History and philosophy of a physically-based, distributed modelling system
10	Water Resources Research	Qingyun Duan	Effective and efficient global optimization for conceptual rainfall-runoff models

3.5. Keywords Co-Occurrence and Burst

Keywords can highly condense and summarize the research content of the documents, which is an effective method to determine the overall structure and research theme of a research field. The higher the frequency of the keywords, the more representative the research hotspots in the field. Running Citespace to get the keyword co-occurrence network, with a total of 398 nodes and 1138 links, we performed cluster analysis on the co-occurring keywords and obtained 18 clusters. The result is shown in Figure 8. The high-frequency keywords include "distributed hydrological model", "climate change", "SWAT", "evapotranspiration", "uncertainty", "remote sensing", "runoff", "water balance", "soil moisture", "GIS", etc., which represent the focus of research in the field. The top ten clusters of size were listed in Table 4. Cluster #7 "CEQUEAU" in Table 4 is a distributed deterministic hydrological model that takes into account the physical characteristics of the watershed as well as their space-domain variation, which developed by the Institut National de la Recherche Scientifique, Québec, Canada [44]. It can be seen from the average year that clusters #0 (uncertainty analysis), #3 (Great Lakes), #6 (optimization) and #9 (GRACE (Gravity Recovery and Climate Experiment)) are clusters formed in recent years, which means that the research hotspots in recent years include uncertainty analysis and optimization of the distributed hydrological model, combined with the time-varying gravity field provided by the GRACE gravity satellite to detect changes in surface water storage, and the application of the distributed hydrological model to evaluate the water storage, water quality and ecological environment of large lakes.

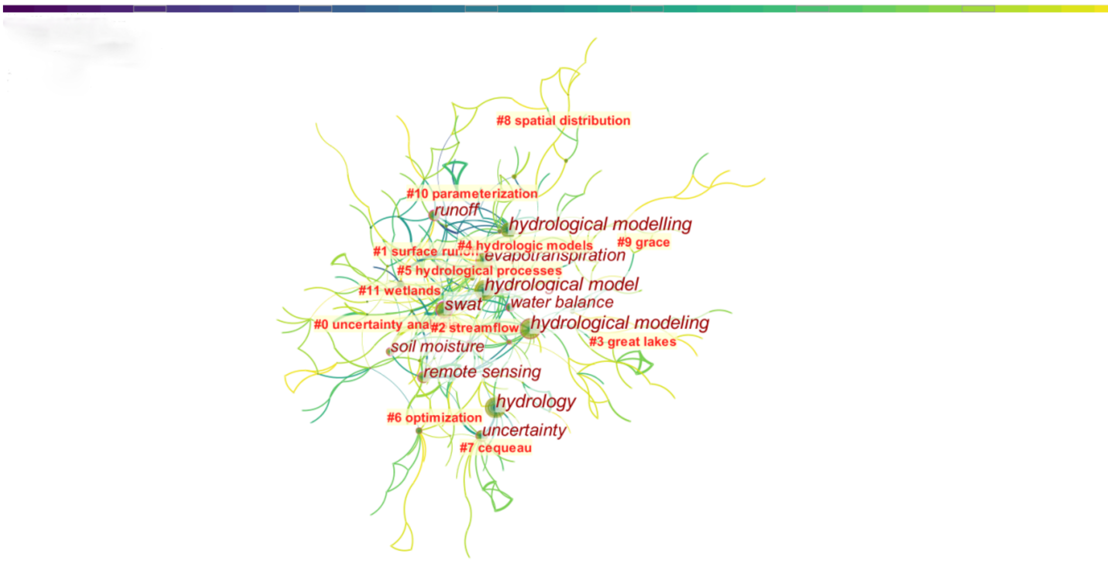

Figure 8. Keyword co-occurrence network map.

Table 4. Major clusters of keyword.

Cluster ID	Size	Silhouette	Mean Year	Lable (LLR)
0	37	0.985	2013	Uncertainty analysis
1	37	0.884	2009	Surface runoff
2	34	0.891	2009	Streamflow
3	28	0.934	2013	Great Lakes
4	26	0.929	2011	Hydrologic models
5	25	0.919	2010	Hydrological processes
6	23	0.959	2013	Optimization
7	22	0.925	2010	CEQUEAU (model)
8	20	0.934	2011	Spatial distribution
9	20	0.937	2013	Gravity Recovery and Climate Experiment

Citespace's burst terms analysis function can be used to investigate terms that appear suddenly and have a rapid increase in frequency. Burst terms often reflect the research frontiers in the field. The top 52 burst terms in strength are listed in Table 5. According to the time axis in Table 5, the time of the appearance and disappearance of the research front can be judged, and the time axis can intuitively reflect the historical length of the mutation word outbreak. The statistical burst terms first appeared in 1995. The earliest research front was the application of distributed hydrological models to simulate runoff and nonpoint source environmental response. The TOPMODEL [45] was a model that scholars studied and used more in the early stage. The scale problems of distributed hydrological model modeling and the aggregation and disaggregation method in hydrological modeling have also attracted the attention of scholars [46]. In 1999, the impact of evapotranspiration on the surface water cycle process began to receive attention [47], and complex hydrological models for mountain basins were also developed [48]. From 2001 to 2005, the research front shifted to the sensitivity analysis of distributed hydrological model parameters and the automatic calibration of the models. At the same time, the integration of GIS technology with distributed hydrological models provides powerful data storage, display, description and analysis capabilities for distributed hydrological models [49,50]. In terms of application, distributed hydrological models have begun to be widely used to calculate snowmelt, simulate flood processes, and predict the hydrological characteristics of floods in the basin. The rainfall-runoff model was used to simulate the impact of spatial changes in rainfall on the outlet runoff of the basin [51,52]. From 2006 to 2010, the water balance problem caused by climate change and its impact on wetland hydrological conditions began to attract people's attention. Regional climate models were used to simulate climate change. Weather radar and PCRaster GIS systems were combined with hydrological models to give the model the function of spatial data analysis [53,54]. In 2011, climate change became the research frontier, but the historical period as the research frontier was relatively short. The same situation of burst terms include "spatially distributed water balance model", "spatial discretization", "China", "copula" and "Distributed Hydrology Soil Vegetation Model (DHSVM)". The history of words as the research front lasted for about one year, and the "distributed model" and "hydrological model" appeared as burst terms several times in different time nodes. It can be seen that the research front is not continuous. When scholars shift their attention from one problem to another, there will be a sudden stop of frontier research and a sudden emergence of another frontier of research.

Table 5. Top 52 keywords with the strongest citation bursts.

Keywords	Year	Strength	Begin	End	1986–2019
distributed modeling	1986	3.5443	1995	2005	
hydrological model	1986	3.0914	1995	2000	
aggregation	1986	4.2414	1995	2004	
topmodel	1986	4.7137	1997	2004	
runoff	1986	6.1307	1997	2008	
simulation	1986	2.8983	1999	2007	
disaggregation	1986	2.7104	1999	2000	
evapotranspiration	1986	3.0497	1999	2000	
mountain hydrology	1986	3.1009	1999	2008	
distributed modelling	1986	3.5973	1999	2007	
distributed hydrological modelling	1986	4.0156	2001	2004	
hydrology	1986	4.6525	2001	2005	
distributedmodel	1986	2.5531	2001	2007	
sensitivity analysis	1986	2.3495	2002	2005	
hydrological modelling	1986	3.5999	2002	2007	
distributed model	1986	7.5845	2002	2012	
flood	1986	2.9424	2002	2004	
runoff generation	1986	3.863	2003	2004	
gis	1986	5.6917	2003	2010	
distributed hydrological model	1986	3.3624	2004	2007	
automatic calibration	1986	2.3024	2004	2008	
digital elevation model	1986	3.0792	2004	2009	
snowmelt	1986	5.3009	2004	2008	
rainfall-runoff model	1986	3.0973	2005	2011	
flood prediction	1986	2.5032	2005	2007	
water balance	1986	2.6727	2006	2008	
modelling	1986	4.8293	2006	2008	
calibration	1986	2.2889	2007	2008	
regional climate model	1986	2.158	2007	2009	
wetland	1986	3.6104	2009	2011	
groundwater recharge	1986	4.1903	2009	2013	
weather radar	1986	2.1681	2009	2015	
pcraster	1986	2.3827	2009	2010	
hydraulic model	1986	2.3684	2011	2012	
climate change	1986	4.2772	2011	2012	
river basin	1986	3.3518	2012	2013	
wetspa	1986	2.9464	2012	2013	
spatial discretization	1986	2.1936	2013	2014	

Table 5. *Cont.*

Keywords	Year	Strength	Begin	End	1986–2019
surface runoff	1986	2.4468	2013	2016	
china	1986	3.5548	2013	2014	
copula	1986	2.1884	2014	2015	
flash flood	1986	2.6689	2014	2016	
hydrologic model	1986	4.2868	2014	2015	
data assimilation	1986	3.1799	2014	2017	
uncertainty analysis	1986	3.1744	2014	2016	
swat model	1986	2.4835	2015	2019	
trmm	1986	2.3384	2016	2019	
downscaling	1986	2.4475	2016	2019	
dhsvm	1986	4.1772	2016	2017	
hydrologicalmodelling	1986	2.9837	2016	2019	
precipitation	1986	3.7723	2017	2019	
bias correction	1986	2.3754	2017	2019	

It is worth noting that as the research frontier, the burst terms lasted until 2019. They represent the current research hotspots in the field of distributed hydrological model research. The SWAT model is usually used to evaluate water volume and water quality and to simulate runoff and nonpoint source pollution. It has attracted the attention of scholars in 2015 and has been widely used until now. It shows that the SWAT model has been rapidly developed and widely used, with good simulation effects and practicality [55]. The meteorological data provided by TRMM is used as driving data in hydrological simulations, which solves the problem of lack of precipitation data in tropical areas to a certain extent. Through continuous updating, the characteristics of the product data set have evolved from the original spatiotemporal resolution to a high spatiotemporal resolution [56]. In order to improve the regional resolution and model simulation accuracy, the research of downscaling and bias calibration methods [57,58] and their application in hydrological simulation have also attracted much attention in recent years.

Because 2020 is not over, the situation of annual published documents is not complete. Here is a phased summary of the co-occurrence of keywords in the 226 documents published in the Web of Science core collection in 2020. Figure 9 shows the co-occurrence of keywords from January to October 2020. The most frequently occurring word was "climate change", followed by "evapotranspiration", "SWAT", "remote sensing", "soil moisture", "uncertainty", "TRMM" etc. This shows that (1) in the context of global warming, the impact of climate change on the environment has aroused people's attention; (2) the current SWAT model is still a distributed hydrological model favored by scholars after many updates; (3) coupling products with high-resolution data into hydrological models is currently an important means to improve simulation accuracy.

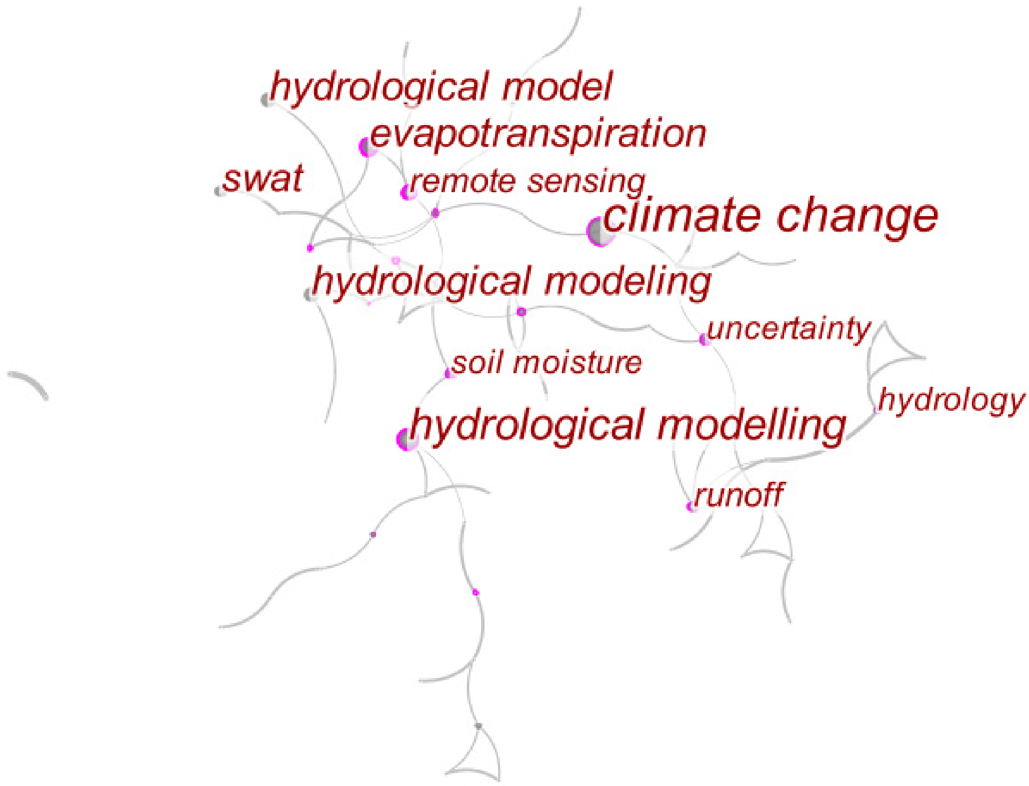

Figure 9. Keyword co-occurrence map from January to October 2020.

4. Conclusions

4.1. Summary

Based on the documents in the core collection of Web of Science, this paper conducts a comprehensive scientific statistical review of the distributed hydrological model research. From 1986 to 2019, a total of 3079 documents related to the field of distributed hydrological modeling were published, and a total of 226 documents were published from January to October 2020. Since 1994, the number of annual publications has been on the rise as a whole, indicating that scholars have continued enthusiasm in the field of distributed hydrological models, and the development of this field is an urgent need for global development.

From 1986 to 2019, the United States and China accounted for 41% of the total. They were the main force in the field of distributed hydrological model research. Field research involves multiple disciplines, including water resources, geology, earth science and engineering. Through the author's co-citation analysis, this article has excavated the core power representatives in the field of distributed hydrological models. The core figures include BEVEN K (1241), NASH JE (777), ARNOLD JG (338), ABBOTT MB (269), REFSGAARD JC (261), GUPTA HV (245), MORIASI DN (230), DUAN QY (217), BERNER LT (199), BLOSCHL G (196) and others. At the same time, this article listed ten groundbreaking and highly cited documents based on the results of the co-citation analysis of the documents. After clustering the co-cited documents, we found that the representative terms were "parameter calibration", "land-use change", "predictive uncertainty", "triangulated irregular network", "spatiotemporal validation", etc.

This article reviews the changes in the historical time research frontier through the analysis of keywords and burst terms. The SWAT model is still popular among scholars. In mountainous and alpine regions, the integration of related technologies, methods and products with distributed hydrological models has become an important means to obtain high-precision simulation results.

Based on visual statistical analysis, we provide valuable information for researchers in the field of distributed hydrological models, which will help scholars to have a deep understanding of knowledge structure, research frontiers and hotspots in the field of distributed hydrological models, strengthen cooperation and promote the further development of the field.

4.2. Outlook

In response to this point of strengthening cooperation and exchanges, we propose the following idea:

Set up cooperation project funds between universities or research institutions. Universities or research institutes often have a competitive relationship in project funds and scientific research results. This may be one of the main reasons for the lack of cooperation between universities and research institutions. The establishment of cooperative project funds can weaken the competitive relationship between universities and research institutions in project funding, and the holding of domestic and international large-scale academic exchange conferences is more conducive to the discovery of teams that match their own research and facilitate their cooperation. International academic exchange conferences can provide researchers with insight into the frontier hotspots of the subject and can inspire their thinking. Therefore, strengthening international cooperation is also an important means to promote scientific and technological development.

Regarding the research hotspots and trends in the field of distributed hydrological models, we propose the following prospects:

(1) Obtain high-precision and high-resolution data. Hydrological phenomena exhibit different hydrological characteristics at different spatial scales. Improving the accuracy and resolution of hydrological data is an effective method to reveal hydrological processes at different scales. With the continuous deepening of hydrological simulation in mountainous and alpine regions, there is an urgent need for high-resolution rainfall data as driving data for distributed hydrological models. At present, the integration of related technologies (such as GIS, remote sensing technology) and products with distributed hydrological models has become an important means to obtain high-precision data and to improve the accuracy of hydrological models to simulate hydrological processes. Therefore, in order to improve the accuracy of simulation of hydrological processes, it is an inevitable trend in the field to develop new technologies and products and improve the degree of coupling with distributed hydrological models.

(2) Development of distributed hydrological models suitable for alpine regions. As the cumulative effect of climate warming has continued in the past ten years, the global cryosphere has shown a trend of accelerated change. Climate change has led to the melting of glaciers, and changes in the vertical distribution of permafrost and vegetation which inevitably have an impact on the hydrological processes of the basin [59]. Therefore, the study of hydrological processes in the global cryosphere and alpine regions has become more and more important. At present, most of the research and development of hydrological models is for large and medium-sized noncryosphere basins. These models are not easily applied to alpine regions. Therefore, the development of models suitable for alpine regions is very important to further explore the hydrological processes in alpine regions, and it is also a trend in the field of hydrological model research.

(3) The response of hydrological processes to climate change. Sohoulande et al. (2020) stated that under climate change, most predictions show that the terrestrial hydrological cycle has been severely disturbed, which affects the availability of freshwater resources [60]. Therefore, under the continuous influence of climate warming, the response of hydrological processes to climate change will become an important research direction in the field, and the coupling of meteorological models and hydrological models has also become an important means to explore the response of hydrological processes to climate change.

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Abbreviations

Logarithmic Likelihood Ratio (LLR); Tropical Rainfall Measuring Mission (TRMM); National Aeronautics and Space Administration (NASA); Japan Aeronautics and Space Administration (JAXA); NOrthern hemisphere climate Processes land surface EXperiment (NOPEX); Conceptual Rainfall-Runoff (CRR); Gravity Recovery and Climate Experiment (GRACE); Distributed Hydrology Soil Vegetation Model (DHSVM); Geographic Information System(GIS); Soil and Water Assessment Tool (SWAT).

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