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Bibliometric Analysis of Global Trends on Soil Moisture Assessment Using the Remote Sensing Research Study from 2000 to 2020

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Abstract Soil moisture assessment on production land is gaining more attention as one of the critical factors and had a remarkable impact on agriculture production, life as well as global warming. Bibliometric analysis is performed by extracting datasets from SCOPUS from 2000 to 2020 to analyse soil moisture using remote sensing study and progress in the last two decades. The outcome indicates that study on the development of soil moisture monitoring tools using remote sensing has been increasing especially for international cooperation articles. International Geoscience and Remote Sensing Symposium (IGARSS) recorded the most productive journal published articles in this field. Among the top active countries that produce most articles were the USA followed by China. The current keywords search on soil mechanism and satellite technology frequently searched in this field. Global issues that focus on the relationship between soil moisture and environmental forecast such as drought, climate change and global warming by using remote sensing technology needed more high impact research outputs in the future.

Keywords Soil moisture · Remote sensing · Bibliometric · Trend

1 Introduction

Soil moisture is an important factor in the natural ecology that provides physiological state to the plant and microorganism growth and development as well as for plant rooting (Noguchi et al. 2016). Variation in soil moisture content impacted the hydrological mechanism such as evapotranspiration, transport of water and soil solutes (Yamashita et al. 2003). Not only does soil moisture play an important role in watering plants (Sawatsky and Li, 1997), to water (Rawls et al., 2003) plant (Li et al., 2011) but it also plays an important part in agriculture (Jensen, 1982). The availability of detailed data on soil moisture is also critical for classifying habitat in relation to water gradient because plants have different relationships with water that are also associated with topographical variation in water availability (Marryanna et al., 2012). Soil moisture studies are important for irrigation management practices in parched and semi-parched land (Subbaiah, 2013; Bell et al., 2020) as well as to improve crop productivity

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(Bodner, Nakhforoosh, and Kaul, 2015; Medrano et al., 2015).

Remote sensing performed spatial scale (Cheema, 2011), which was used to collect surface hydrology and vegetation information (Chen et al., 2005). Soil moisture spatio-temporal volatility can be studied by retrieving spatio-temporal continuous soil moisture and other various data from remote sensing images (Zhang et al., 2020). Medium-resolution spectrometers and microwave radiometer satellites for soil water and seawater salinity were part of the remote sensing data image products that are widely used in soil moisture research (Petropoulos, Ireland, and Barrett, 2015; Karthikeyan et al., 2017; Reichle, 2008).

Bibliometrics or systematic analysis is a tool that provides network mapping and trends in the state of the art for a given specified fields related to scientific knowledge (Wang, 2015). This analysis can identify, interpret and classify the performance of the publications by author, keyword, country, year and others that quantitatively highlight research niche and trends (Zhang et al., 2020). Various articles with different scopes for soil moisture using remote sensing research (Cui et al., 2019; McColl et al., 2017) but only few bibliometric review that can reflect the trend has been conducted.

To understand the direction and gaps in soil moisture assessment using remote sensing as a tool in research, bibliometric analysis is conducted to find the pattern and trend from 2000 until 2020 with various perspectives to expose the variance and contemporary research method in the global trend. This study is conducted by clarifying the correlation between annual publications, keywords, source country, institutions and journals. Innovative approach was implemented, such as collaborative network analysis and keyword mapping to reveal the trend and pattern from multiple perspectives. Further studies should be conducted in the future to reduce the knowledge gap in this subject by using remote sensing in research methods that are available in global research networks and trends.

2 Material and Methods

2.1 Data Collection

Data exploitation of this research is searched and compiled from SCOPUS database over 10 years recent from 2000 to 2020. The search data keywords used are "soil moisture" AND "remote sensing" with extended search to document titles, abstracts and keywords of the entire SCOPUS database. The search queries the keywords in 2000 until 2020. The publications that matched the search keywords were 6417 articles, which were then collected for further study and analysis.

2.2 Data Analysis

Bibliometric analysis was performed to expose trends, network mapping and patterns in the soil moisture using remote sensing study research by multiple features such as annual publications, keywords, source country, institutions and journals. From the SCOPUS dataset provided from the search query, the individual data and details were downloaded in Microsoft Excel for data processing. Data network mapping was visualised using software VOSviewer (Wolfe et al., 2002). The software creates co-occurrence and frequency network from the data downloaded and presents the network mapping of each feature. The node represents the degree of centrality, while the thickness of the line represents the intensity of collaboration. The larger the nodes, the more crucial it is, while the thicker the line of the network, the stronger the relation.

3 Results and Discussion

3.1 Development of Research Activity by Quantitative Method by Article Outputs

Figure 1 shows the distribution lines of the annual number of articles and citation per article from 2000 to 2020. MODIS or shorted form of the Moderate Resolution Imaging Spectroradiometer was launched on December 1999 (Wolfe et al., 2002). MODIS is a remote sensing algorithm that derives time series globally on multiple geophysical parameters (Vermote et al., 2002). This research focusing on articles that published after MODIS was launched starting from the year 2000. The numbers of citations per article are increasing and reach its peak value (47.71) in the year 2002 and then went down and keep dropping until year 2020. This is because citation rates are highly influenced by the

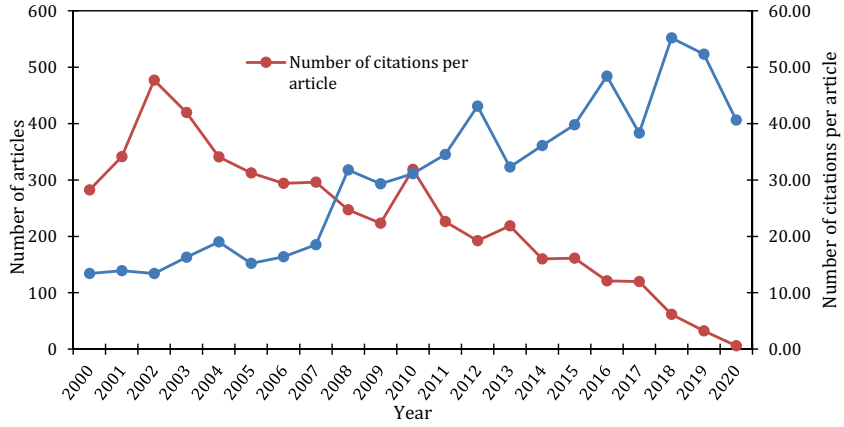

Fig. 1 The annual number of articles and citations per article from 2000 to 2020

discipline and the number of people employed in that field. For the numbers of articles, the published article keeps increasing gradually until recent year. After rapid evolution, internet became easier to access online publication that increases the number of articles. Meanwhile, it can lead to lower citations per article where researchers have large number of publications but shorter publication time.

From the total acquired 6417 articles related to soil moisture and remote sensing research, the data were sorted by annual total publications from the years 2000 until 2020. Table 1 shows the total number of articles published by year, total citations and number of citations per article. The number of articles shows a significant increase from 134 in 2000 to 185 in 2007 which represent the launching of MODIS specifically in soil moisture research. MODIS remote sensing images are generally used to evaluate ecology system and have been engaged as susceptibility model of environment (Leuven & Poudevigne, 2002; Maina et al., 2008) and build resilience indices and work structure (Ares & Bertiller, 2001; Forbes et al., 2009). In the matter of disaster readiness, remote sensing has the capability to equip essential reinforcement and monitoring during disaster and post-disaster rebuilding (Forbes et al., 2009). As a result of the fast growth of the internet, where publications and articles are simpler to access internationally, the total number of articles increased to 318 in 2008, more than double from 2007. As summary, the table illustrates the pattern of rising, except for total citations illustrating the expanding inflation of scientific knowledge in soil moisture using remote sensing research study in the past two decades.

Table 1 Article output in soil moisture using remote sensing research from 2000 to 2020

Year	TA	TC	TC/TA
2000	134	3783	28.23
2001	139	4746	34.14
2002	134	6393	47.71
2003	163	6839	41.96
2004	190	6474	34.07
2005	152	4750	31.25
2006	164	4819	29.38
2007	185	5481	29.63
2008	318	7862	24.72
2009	293	6535	22.30
2010	311	9913	31.87
2011	345	7810	22.64
2012	431	8290	19.23
2013	323	7064	21.87
2014	361	5784	16.02
2015	398	6426	16.15
2016	484	5869	12.13
2017	383	4587	11.98
2018	552	3411	6.18
2019	523	1682	3.22
2020	406	237	0.58

Abbreviations: *TA* total number of articles, *TC* total number of citations, *TC/TA* number of citations per article

3.2 Analysis of Journals and Institutions

The root of the journal with high acknowledgement can be identified based on the statistical study of the distribution of journals that publish articles in the soil moisture using remote sensing research field (Hengl et al., 2009). Table 2 shows the top 20 productive journals that publish articles in this research field along with the total number of citations and number of citations per article. *International Geoscience and Remote Sensing Symposium (IGARSS)* published the most articles (895) in the last two decades reckoning 25.8% of the total. *Remote Sensing of Environment* ranked first in terms of total citations with 19,227 accounting 25.01% compared to other journals. This figure indicates that remote sensing topic attracted a wide discussion especially in environment element on the monitoring approach with a modest amount of outputs. *The International Society for Optical Engineering* also ranked high as they published 289 articles (8.32%) and ranked third in terms of articles publications and second for total citations is IEEE Transactions on Geoscience and Remote Sensing journal which accounting for 309 articles published (8.89%) and 15,063 citations (19.60%) respectively.

Table 3 shows the top 20 productive institutions in the soil moisture study using remote sensing tools for research for the last two decades. The top institutions scattered across the USA and China and added with institutions from Austria, Belgium, Australia, France, the UK and Italy. In terms of the number of publications, US Department of Agriculture in the USA and the Chinese Academy of Sciences were relatively higher than other institutions with 297 articles (17.61%) and 213 articles (12.63%) respectively. Meanwhile, NASA Goddard Space Flight Centre recorded high number of citations (7031) followed by US Department of Agriculture (6600) and California Institute of Technology (6080). However, in terms of citation number per article, these three institutions drop to rank number

Table 2 The top 20 productive journals in remote sensing soil moisture research from 2000 to 2020

Journals	TA	TA%	TC	TC%	TC/TA
International Geoscience and Remote Sensing Symposium (IGARSS)	895	25.76	2798	3.64	3.13
The International Society for Optical Engineering	356	10.24	645	0.84	1.81
IEEE Transactions on Geoscience and Remote Sensing	309	8.89	15,063	19.60	48.75
Remote Sensing of Environment	289	8.32	19,227	25.01	66.53
Remote Sensing	261	7.51	3054	3.97	11.70
International Journal of Remote Sensing	162	4.66	3339	4.34	20.61
Journal of Hydrology	139	4.00	6082	7.91	43.76
International Archives of The Photogrammetry, Remote Sensing and Spatial Information Sciences	122	3.51	338	0.44	2.77
Water Resources Research	120	3.45	6021	7.83	50.18
IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing	116	3.34	2232	2.90	19.24
Hydrology and Earth System Sciences	108	3.11	4086	5.32	37.83
Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering	102	2.94	475	0.62	4.66
Journal of Hydrometeorology	90	2.59	3947	5.14	43.86
Iahs-Aish Publication	82	2.36	146	0.19	1.78
Agricultural Water Management	58	1.67	1392	1.81	24.00
Hydrological Processes	57	1.64	1657	2.16	29.07
Agricultural and Forest Meteorology	55	1.58	2100	2.73	38.18
European Space Agency	53	1.53	19	0.02	0.36
IEEE Geoscience and Remote Sensing Letters	53	1.53	1117	1.45	21.08
Geophysical Research Letters	48	1.38	3125	4.07	65.10

Abbreviations: *TA* total number of articles, *TC* total number of citations, *TC/TA* number of citations per article

Table 3 The top 20 productive institutions in remote sensing soil moisture research from 2000 to 2020

Institution	Country	TA	TC	TC/TA
US Department of Agriculture	USA	297	6600	22.22
Chinese Academy of Sciences	China	213	5307	24.92
California Institute of Technology	USA	160	6080	38.00
Beijing Normal University	China	154	563	3.66
NASA Goddard Space Flight Centre	USA	139	7031	50.58
University of Chinese Academy of Sciences	China	119	1168	9.82
Vienna University of Technology	Austria	73	4854	66.49
Ghent University	Belgium	66	1209	18.32
Monash University	Australia	63	1094	17.37
Massachusetts Institute of Technology	USA	53	2893	54.58
Centre D'etudes Spatiales de la Biosphère	France	48	1857	38.69
University of Maryland	USA	48	2588	53.92
Wuhan University	China	44	161	3.66
Hohai University	China	44	132	3.00
IEEE	USA	41	2645	64.51
Princeton University	USA	34	1754	51.59
Peking University	China	27	200	7.41
European Centre for Medium-Range Weather Forecasts	UK	25	2032	81.28
Research Institute for Geo-hydrological Protection	Italy	24	1269	52.88
Joint Centre for Global Change Studies	China	15	87	5.80

Abbreviations: *TA* total number of articles, *TC* total number of citations, *TC/TA* number of citations per article, *US* United States, *NASA* National Aeronautics and Space Administration, *IEEE* Institute of Electrical and Electronics Engineers

8th, 12th and 10th, respectively. This is due to high low number of published articles in those countries. The leading institutions for number of citations per article are European Centre for Medium-Range Weather Forecasts in the UK which is accounting for 81.28. Next to them is Vienna University of Technology in Austria (66.49) and IEEE in the USA (64.51).

3.3 Analysis of Productive Countries

Table 4 summarises the top 20 productive countries that contributed to soil moisture using remote sensing research with total number of articles and citations for independent and collaborative published articles. The USA and China lead the development of the study by publishing generous number of articles which are 3391 and 2786, respectively. Nonetheless, China still ranked one of the lowest number citations per article (8.60) as the total citations only 23,968 compared to the USA due to short publication time. One explanation for the low impact factor is that Chinese scientists prefer to publish papers with few references. Another explanation is that, like scientists in other countries, Chinese scientists tend to publish their best work in big or top English-language journals. Austria contributed a high number of citations per article (40.35) and ranked first because of the lower number of publications but high number of citations. Meanwhile, Spain, Germany, Australia, the Netherlands, Canada, Belgium and Brazil where the average of citations per article is above 20 had performed the fundamental roles in soil moisture using remote sensing research study. The USA and China also had contributed significantly in collaborating research with other countries. In addition, the ratio of international collaboration is higher than independent articles for all 20 countries. This indicates that the international cooperation gave the influence of research outputs in the soil moisture using remote sensing. It is remarkable that the publications of the articles were notably correlated with country economy development. All the G7 countries, the USA, France, Italy, Germany, Canada, the UK and Japan, were in the top 20 countries accounting a total of 51.63% articles in the last two decades.

Figure 2 shows the cooperation network of the top 20 productive countries in soil moisture using remote sensing research fields. The bigger node had the most collaborative network with more countries, and the degree of centrality is also an outstanding. The USA is the centre of the global network followed

Table 4 The top 20 productive countries in remote sensing soil moisture research from 2000 to 2020

Country	TA	TC	TC/TA	IA	IC	IC/IA	CA	CC	CC/CA
USA	3391	95,993	28.31	1237	33,552	27.12	2154	62,441	28.99
China	2786	23,968	8.60	1157	6966	6.02	1629	17,002	10.44
France	733	21,744	29.66	178	3927	22.06	555	17,817	32.10
Italy	648	14,169	21.87	196	2357	12.03	452	11,812	26.13
Spain	520	10,122	19.47	148	1650	11.15	372	8472	22.77
India	503	3455	6.87	219	1250	5.71	284	2205	7.76
Germany	486	10,693	22.00	124	1489	12.01	362	9204	25.43
Australia	484	11,733	24.24	120	1510	12.58	364	10,223	28.09
Netherlands	452	15,708	34.75	58	952	16.41	394	14,756	37.45
Canada	395	7825	19.81	131	2190	16.72	264	5635	21.34
UK	320	10,906	34.08	54	878	16.26	266	10,028	37.70
Japan	254	2961	11.66	82	561	6.84	172	2400	13.95
Austria	226	9119	40.35	34	366	10.76	192	8753	45.59
Belgium	188	4170	22.18	40	799	19.98	148	3371	22.78
South Korea	156	2543	16.30	60	858	14.30	96	1685	17.55
Russian Federation	155	1522	9.82	60	166	2.77	95	1356	14.27
Iran	121	561	4.64	44	160	3.64	77	401	5.21
Brazil	99	2343	23.67	29	278	9.59	70	2065	29.50
Taiwan	82	782	9.54	28	106	3.79	54	676	12.52
Israel	62	1144	18.45	22	240	10.91	40	904	22.60

Abbreviations: *TA* total number of articles, *TC* total number of citations, *TC/TA* number of citations per article, *IA* number of independent articles, *IC* number of citations for independent articles, *IC/IA* number of citations per independent articles, *CA* number of internationally collaborative articles, *CC* number of citations for internationally collaborative articles, *CC/CA* number of citations per internationally collaborative articles

by China and France. The USA had associated mostly with China, France, Spain and the Netherlands based on the thickness of the network line of the countries. Thick line network signified the large number of collaborative articles globally. South Korea and the Russian Federation showed thin lines of collaborative network as they published more independent articles that collaborate with other countries. Among the top 20 countries, Israel and Taiwan not have published any internationally cooperation with other top 20 countries. Major countries such as the USA, France and others were also expanded their collaboration network outwards. From the visualisation network and analysis, it can be proved that countries with advanced technology of science manage the direction of soil moisture using remote sensing research fields. In addition, global collaboration also can contribute to advancement of the study.

3.4 Analysis of Keywords

Researchers used lists of keywords to obtain expressive terms of particular genres (Tang et al., 2020). For a specific scientific field study, keyword plays a large role as it can reflect the root contents of articles and compilation of keywords can reveal the pattern and trends of specific academic research (Wang et al., 2012). In the study of soil moisture using remote sensing, noticeably there was a gap of keywords that are missing in the early MODIS launched between the years 2000 and 2005. Keywords that are related to plant growth mechanism such as "evapotranspiration" and agricultural production such as "agriculture" and "drought" as shown in Table 5 are missing in the early stages. After MODIS was launched in December 1999, the frequencies of keywords were the combination of soil moisture and remote sensing research. With the rapid development of remote sensing and computer technology in recent years, the research of soil moisture and other soil properties has become significantly matured and shown noteworthy increase frequency of keywords since 2006.

Alongside the search terms, "climate change" is one of the greatest global concerns that captivated worldwide attention which was ranked 9th in 2011 and recent indicated that soil moisture is a vital role in forecasting climate change. Research had been done and it is proved that soil moisture can be a limiting factor for land carbon uptake where, through the water stress, it could decrease the gross primary

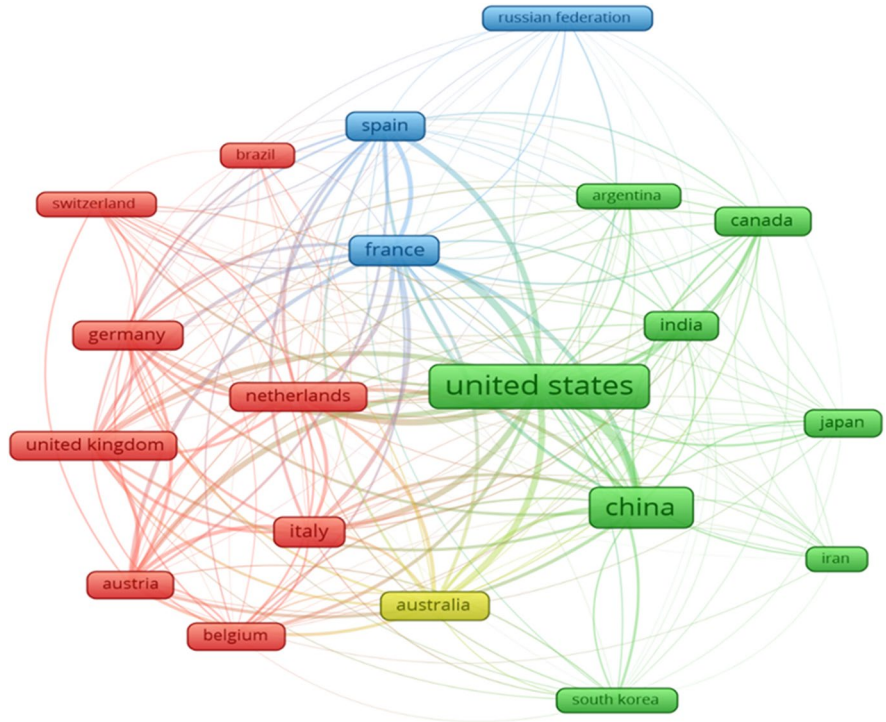

Fig. 2 Core international collaboration network map of the top 20 productive countries

Table 5 The top 20 high-frequency keywords from 2000 to 2020

Publication year	2000–2005		2006–2010		2011–2015		2011–2020	
Keywords	F	R	F	R	F	R	F	R
Soil moisture	494	2	1113	2	1679	1	2052	1
Remote sensing	811	1	1182	1	1629	2	2033	2
Soil surveys	-	-	259	6	400	3	528	3
Soils	471	3	143	12	241	7	383	4
Moisture	465	4	146	11	249	5	366	5
Evapotranspiration	-	-	101	21	202	9	259	6
Satellite data	-	-	87	31	203	8	258	7
Radiometers	161	6	197	8	242	6	257	8
Drought	-	-	114	15	166	14	249	9
Climate change	-	-	-	-	92	54	230	10
Satellites	79	16	96	22	111	37	221	11
The mean square error	-	-	-	-	75	69	218	12
Crops	56	24	84	33	115	32	214	13
Modis	-	-	75	43	161	16	211	14
Agriculture	-	-	67	48	157	17	210	15
Satellite imagery	-	-	108	18	202	10	196	16
Ndvi	-	-	68	46	103	45	191	17
China	-	-	58	59	119	27	178	18
Moisture control	-	-	107	19	86	58	174	19
Rain	-	-	89	28	128	24	166	20

Abbreviations: *F* frequency of keywords, *R* the rank of the keywords

production and worsen climate extremes (Green et al., 2019). Mainly, the study of soil moisture in climate

change topic consists of the effect of climate change on soil moisture and soil moisture erosion (Guo et al., 2019; Haile, Tang, Li, Liu, & Zhang, 2020) applying the soil moisture as one of the essential variables that plays a major role in predicting the climate change models (Berg & Sheffield, 2018).

Figure 3 is a visualised network of keywords that had a frequency more than 50 and more using VOSviewer software from the recent years of 2011 until 2020. The network is divided into four clusters and illustrated by different colours. For the biggest cluster which is displayed in red colour, keywords "water content", "drought", "evapotranspiration" and other keywords that were related to "soil moisture" were included. This searched cluster indicated the relationship between soil moisture and agricultural production and growth mechanisms. It is essential to focus on the soil moisture in monitoring drought predicting, early warning and others as soil moisture drought can give huge influences the irrigation agriculture and long period of draught can be a threat to food security (Haile et al., 2020). In the smallest cluster in yellow colour, keywords related to soil–vegetation–atmosphere system such as "vegetation" and "atmospheric temperature" were included. This cluster is highly related to climate change as there are differences in responses of soil moisture to climate change in various parts worldwide, and the projection of soil moisture remained uncertainties (Berg & Sheffield, 2018). Therefore, further research needs to be done to enhance the prediction and forecast models of climate change and drought by understanding and investigating among the element of soil–vegetation–atmosphere mechanism.

"Satellite data," "radiometer" and "calibration" alongside with other keywords were included in green cluster as it was related to the MODIS remote sensing tools. Almost related to blue cluster, both of these cluster describing the research approach of soil moisture based on remote sensing technology. This method used to improve and upgrade the accuracy of soil moisture measurement and monitoring as remote sensing technology is establishing multi-index or multivariate soil moisture inversion models by using multiple satellite datasets (Zhang et al., 2020). Soil moisture data in deep soil layers can be obtained by developing method by using satellite data thus can be a great approach on drought monitoring in large spatial scale (Haile et al., 2020).

4 Conclusions

In this study, bibliometric review was portrayed to analyse and reveal the trends and patterns in soil moisture using remote sensing research fields. MODIS is one of the remote sensing satellites launched that benefitted soil moisture study. This study collected reliable SCOPUS database from 2000 until 2020 with data interpreted software VOSviewer.

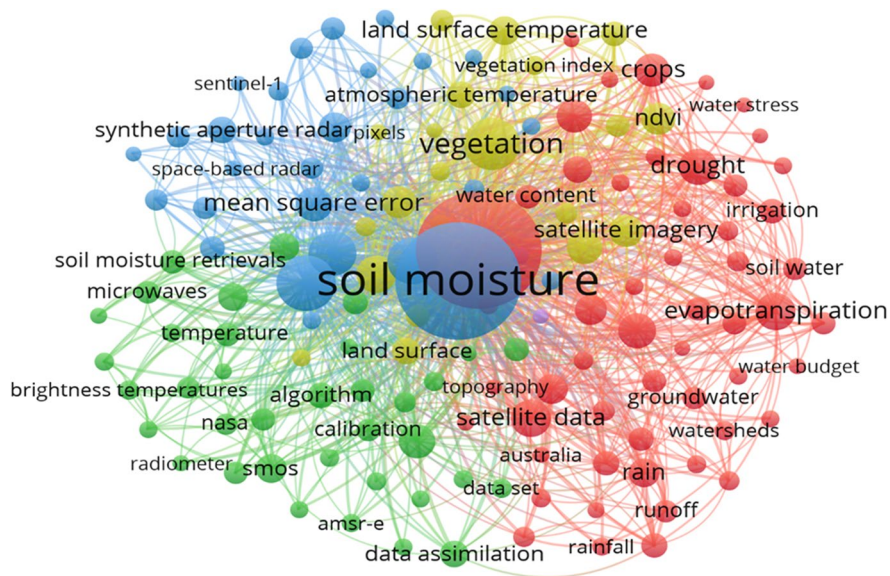

Fig. 3 The co-occurrence network map of keywords from 2011 to 2020

The exported and analysed data shows that annually, the number of articles gradually increases steadily proving that soil moisture using remote sensing had wide study prospects. Global cooperation specifically between developed countries such as the USA, France and other countries is noticeably an essential incentive to the further study in soil moisture using remote sensing. This can be seen from the published articles, and citations per article of international cooperation had higher frequency than independent published articles. As for developing countries, more high impact articles and outputs are needed to be produced in the future. Many developed countries' universities lack the framework of ethical oversight boards. Colleagues from both developing and developed countries could work together on requests for support from agencies. Researchers from developing countries will be able to access the existing ethical review processes at universities in developed countries as a result of this collaboration. In terms of soil moisture, the study is mostly related to agriculture production and life such as environmental, agriculture and ecology. The soil moisture data are also important as it can be applied for drought and climate change prediction models. With the aid of remote sensing technology, the ease of access of internet, advanced satellite data and high-quality references from the previous studies by other researchers, the accuracy of the models can be improved remarkably. Hence, global warming issue that concerned worldwide could be reducing with high precision models.

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Data Availability Not applicable.

Code Availability Not applicable.

Declarations

Conflict of Interest The authors declare no competing interests.

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