Trends in global research on Sanitation: A 30-year perspective from 1990 to 2019

li huang (lilyhuang1983013@163.com)
Shenyang Agricultural University https://orcid.org/0000-0001-6048-7277
mi zhou
Shenyang Agricultural University

Research

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Abstract

Background

Sanitation issues have aroused widespread concern around the world, and scholars began research in this area as early as the 1920s. After decades of development, there is a great amount of research on this topic, and the body of research continues to grow rapidly.

Methods

Based on the Web of Science Core Collection databases from 1990–2019, this paper applies the bibliometric method to analyze the research characteristics and developments of scientific publications about sanitation. Visualized knowledge mapping is employed to investigate development status, scientific collaboration, involved disciplines, research hotspots and emerging trends of this field.

Results

The breadth and depth of sanitation studies has improved significantly as the number of related publications increases rapidly in the 21st century. The strength of developed countries is greater than that of developing countries; the comprehensive strength of the United States ranks first in the field, followed by England and Switzerland. This field is a highly interdisciplinary field that covers a wide range of interests, and institutional collaboration is increasing in this field. Keyword clustering analysis shows that the main research topics in the domain of sanitation could be summarized as: (a) drinking water; (b) sustainability; (c) biofilm; (d) epidemiology; and (e) WaSH. Meanwhile, keyword bursts analysis showed that the new research hotspots and research frontiers mainly concentrated on: (a) Sustainable development of sanitation services adapting to climate change; (b) Main determinants affecting child malnutrition; (c) Multinational research and model innovation; and (d) Evaluations on various aspects of performance.

Conclusions

Through in-depth analysis of sanitation research, this paper provides a better understanding of trends that have emerged over the past 30 years, and can serve as a reference for future research.

1. Introduction

Today, 4.2 billion people live without safely managed sanitation, 673 million still practice open defecation and 3 billion lack basic handwashing facilities (WHO and UNICEF, 2019). Poor sanitation around the world results in prevalence of diseases and pollution of the environment (MFA and UN, 2015; UNICEF and WHO, 2015). Inadequate sanitation is estimated to cause 432,000 diarrheal deaths every year (WHO,

2019). Sanitation issues have aroused widespread concern around the world, and scholars began research in this area as early as the 1920s. After decades of development, there is a great amount of research on this topic, and the body of research continues to grow rapidly.

Although the study of sanitation is receiving greater attention, there are very few studies that have tried to answer the following questions: (1) What is an overview of the previous studies on sanitation since 1990? (2) Which subject is most popular in the field of sanitation and how are health-related disciplines linked? (3) Which country or institution is the most active contributor to sanitation research? How has the cooperation between research institutions changed over time? What is the difference in comprehensive research strength between countries? (4) What are the hotspots commonly researched in this field and how have they developed? Answers to these questions are important in order to provide insight into the sanitation research domain. However, it is very difficult to effectively organize, summarize, and quantitatively analyze the development of a specific field across many studies on a large time scale in traditional review articles. Sanitation is an interdisciplinary research field that covers disciplines including environmental science, public health, water resources, medicine and disease, engineering environmental, food science, and microbiology. Bibliometric analysis is needed to create a comprehensive overview of the study of sanitation.

Bibliometric analysis can effectively describe the features and trends in a certain discipline. Bibliometric analysis includes qualitative and quantitative analysis of publications indexed by databases based on statistics and computing technology (Aleixandre et al., 2017; Liu et al., 2019). This technique has been widely used to measure the performance of various disciplines (Wang et al, 2018; Ekundayo and Okoh, 2018). Furthermore, knowledge graphs combine information visualization technology with traditional scientometrics citation analysis to visually display the information contained in a subject or field through data mining, information processing, scientific measurement and graphic drawing. Therefore, using knowledge graphs, one can explore the development of and relationships between different pieces of scientific knowledge (Shiffrin and Börner, 2004; Chen et al, 2008).

The purpose of this study is to comprehensively and systematically provide a bibliometric analysis of research on sanitation. More specifically, CiteSpace was used to conduct a detailed analysis and offer an in-depth and structured review of global expansibility. The data was evaluated for the period of 1990–2019. The overall research status and trends were investigated in addition to scientific collaboration and the involved disciplines. Then, the hotspots and evolution of this field were explored across three periods. The analyses of hotspots and emerging trends in this paper are not limited to results retrieved from CiteSpace; instead, we apply an expansive review that included additional valuable literature on the basis of the database, aiming to provide a comprehensive analysis. Our findings could assist researchers around the world to better understand the current state and latest research in this field and may serve as a potential guide for future study.

2. Materials And Methodology

2.1. Data collection

The Web of Science Core Collection from Thomson Reuters contains more than 12,000 influential academic journals that have been widely recognized by the international academic community. This paper takes the Science Citation Index Expanded (SCI-E) and Social Science Citation Index (SSCI) databases of the “Web of Science core collection” as the object database and sets TS= (sanitation or “sanitary equipment*” or “sanitary facilit*”) as the retrieval condition, with a time span of 1990–2019, to search for related results. The search scope was “topic”, including title, abstract and keywords. The 9,559 retrieved records were downloaded and saved as a plain text file in the format of “Full Record and Cited References”, which was used as the sample in the paper.

2.2. Methodology

2.2.1. CiteSpace Software Parameters Setting

The tool used in this study, CiteSpace, is one of the most influential pieces of software in literature information analysis. The 5.5.R2 version of CiteSpace for 32-bit Windows with Java 8 was used. During execution, the parameters (e.g., time slice, node type, and pruning) in CiteSpace should be properly selected in accordance with the research objectives (Song et al. 2016). The parameters in CiteSpace were set as: (1) Time slicing from 1990 to 2019, years per slice = 1. (2) Node type = institution, category, keyword; (3) In the collaboration network and co-occurring network analysis, we selected the top 50 most-cited or most frequently occurring items from each slice for institutions, categories and keywords.

2.2.2. Comprehensive strength

The academic ability of one country is reflected in academic scale, influence and competence. Just as in other bibliometric studies (Yu et al., 2016), we selected eight indicators to evaluate the national comprehensive research strength of a single country: total number of articles, total number of citations, number of hot articles, number of hot articles citations, number of highly-cited articles (TOP100), number of highly-cited articles citations (TOP100), number of productive authors, and number of productive institutions. Standard scores are calculated using a standard method as shown in Formula (1), and the total score for each country was obtained through summing the eight standard scores as seen in Formula (2):

$$StScore_{ij} = \frac{X_{ij} - \overline{X_j}}{\sqrt{\frac{\sum_i \left(X_{ij} - \overline{X_j}\right)^2}{M}}} + 1 \qquad (1)$$

$$TSS_i = \sum_j StScore_{ij} \qquad (2)$$

Where $StScore_{ij}$ is the standard score of indicator j in country i; X_{ij} is the original score of indicator j in country i; $\overline{X_j}$ is the average score of indicator j; TSS_i is the sum of standard scores in country i; M is the number of countries.

3. Results And Discussion

3.1. Temporal development and global geographic distribution analysis

3.1.1. Quantity of articles and citations

In total, 9,559 valid records were obtained in the field of sanitation between 1990 to 2019. The trends in the quantity of articles over the last 30 years are shown in Fig. 1. From the perspective of quantity, in the first decade (1990–1999), the average annual output was 89 articles, accounting for 9% of the total, while in the last decade (2010–2019), the average annual output was 666 articles, accounting for 70% of the total. In 2013, the United Nations designated November 19 as "World Toilet Day" to promote safe drinking water and basic sanitation facilities and a clean, comfortable and hygienic environment for all. As shown in Fig. 1, the number of publications in this field has risen sharply since 2013, with 1,078 in 2019. The increasing quantity of research indicates that the research on sanitation is in its "growth stage" and has great potential for development.

The total number of citations was 158,563 (1990–2019) and the average number of citations per publication was 16.6. The trends in quantity of citations in the last 30 years are shown in Fig. 1. The citation volume of articles on sanitation research before the 21st century grew slowly, with an average annual total citation volume of only 276.5. After 2000, the total citation volume increased steadily, and increased rapidly after 2010, with an average annual total citation volume of 2269.3 (2000–2009) and 13310.5 (2010–2019) respectively. This trend also reflects the increasing attention devoted to this area during the past decade.

3.1.2. Global geographic distribution

In the past 30 years (1990–2019), 179 countries/regions have contributed to investigating sanitation, which means 91 percent of countries have scholars publishing in this field. Figure 1 shows the geographical distribution of published articles in this field. Different colors represent different numbers of documents in different geographic regions. Among the countries with more than 100 publications are three North American countries, ten European countries, seven Asian nations, seven African nations, plus Brazil in South America and Australia in Oceania. As shown in the diagram, articles about sanitation are mainly concentrated in the USA, England, Brazil, India, and Switzerland. Table 1 lists the top 15 most productive countries. Developed countries accounted for two-thirds of the total, while developing countries accounted for one-third. The USA had the most publications (3,224 articles) and total citations (76,177 citations). England had the second highest number of publications (1,149 articles). In addition, the USA holds the highest H-index of 104, a value far greater than that of any other country. Considering the TC/P value, European countries such as Switzerland (49.99), France (47.95) and Spain (46.19) play leading roles in the overall body of work. The highest TC/P value are in Switzerland, as the result of multiple high-quality articles.

Table 1
Most productive countries in terms of relevant articles.

	Country	Ps	TC[a]	TC/P[b]	h-index
1	USA	3224	76177	23.63	104
2	England	1149	30128	26.22	68
3	Brazil	614	10588	17.24	43
4	India	570	16215	28.45	45
5	Switzerland	503	25146	49.99	58
6	South Africa	418	13346	31.93	34
7	Netherlands	417	13812	33.12	39
8	Australia	406	14982	36.90	41
9	Canada	388	13523	34.85	36
10	Germany	368	14332	38.95	40
11	China	340	12655	37.22	31
12	Spain	300	13856	46.19	40
13	France	263	12611	47.95	35
14	Kenya	258	5593	21.68	31
15	Italy	256	6539	25.54	34

Note: *TC*[a]: the total citations for a country. *TC/ P*[b]: average number of citations per paper for a country.

3.2. Scientific collaboration analysis

Approximately 8,065 institutions have contributed to related research. The top 15 most active institutions are highlighted (Table 2). University of London (especially the London School of Hygiene and Tropical Medicine) led the institutional activity, producing 463 total articles, with a total of 17,075 citations. Other institutions with more than 200 articles were University of California System (353) and the World Health Organization (206). Although the total number of publications from the World Health Organization is less than that of University of London, the total number of citations (19,243) of its papers is higher than that of University of London, which indicates a greater academic influence in this field. Meanwhile, among the top 15 research institutions, Harvard University has the highest average citation volume, reaching 104.01. In terms of impact level, the University of London and the University of California System are the research institutions with the highest h-index (45), followed by the World Health Organization (44) and the Centers for Disease Control Prevention USA (43).

Table 2
Top 15 most productive institutions in terms of relevant articles.

Institution	Country	Publications	TC[a]	TC/P[b]	h-index
University of London	England	463	17075	36.88	45
University of California System	USA	353	15611	44.22	45
World Health Organization	Switzerland	206	19243	93.41	44
Emory University	USA	199	12109	60.85	30
Johns Hopkins University	USA	194	11987	61.79	34
University of North Carolina	USA	179	4068	22.73	33
Centers for Disease Control Prevention USA	USA	171	13502	78.96	43
United States Department of Agriculture USDA	USA	169	3149	18.63	26
Johns Hopkins Bloomberg School of Public Health	USA	156	11051	70.84	29
Rollins School Public Health	USA	149	5129	34.42	25
Harvard University	USA	140	14561	104.01	33
Swiss Federal Institute of Aquatic Science Technology EAWAG	Switzerland	140	2549	18.21	25
State University System of Florida	USA	132	2561	19.40	26
University of North Carolina Chapel Hill	USA	126	3467	27.52	29
University of Basel	Switzerland	122	5964	48.89	35

Note: *TC*[a]: the total citations for an institution. *TC/P*[b]: average number of citations per paper for an institution.

This section further analyzed the longitudinal change of the institutional collaboration networks from 1990 to 2019 (Fig. 2). Over time, the lines between institutions become denser, which indicates that cooperation between research institutions is getting closer and closer and the related sanitation is still one of the most important problems worldwide and will remain as a challenge in the near future. For the influence of institutions, this can also be extracted by the betweenness centrality of the institutions from the collaboration networks. From 1990–1999, the University of London had the largest number of papers, followed by the World Health Organization. However, no definitive leader emerged in this period. From 2000–2009, institutions with a large number of publications included the World Health Organization, United States Department of Agriculture USDA and Centers for Disease Control Prevention USA. The

Swiss Tropical Public Health Institute (betweenness centrality, 0.14) and Harvard University (0.12) were relatively more influential than other institutions during this period. From 2010 and 2019, the number of articles published increased rapidly. The most productive institutions during this period include University of London, Emory University and Stanford University. From the perspective of influence on network, the London School of Hygiene and Tropical Medicine (betweenness centrality, 0.14) and Harvard University (0.10) were more influential than other institutions during this period. Overall, cooperation between research institutions increased during this period (See Fig. 2(c)).

3.3. Involved disciplines analysis

All the articles covered one of 219 ISI (Identified Subject Categories) in the WoS. The top 15 subject categories are shown in Table 3. Sanitation research is a multidisciplinary and interdisciplinary field that involves various subjects, such as environmental science, public health, water resources, medicine and disease, engineering environmental, food science, microbiology and other multidisciplinary sciences. The number of publications in each category reflects sanitation research trends. Environmental sciences, public environmental occupational health and water resources are the top three subjects. The number of publications in these categories significantly increased between 1990 and 2019. The number of publications in every category increased steadily from the first time period to the second time period and most categories grew significantly from the second period to the third period.

Table 3
The article output of the top 15 subject categories of sanitation research.

Subject category	1990–2019	subgroups in different periods		
		1990–1999	2000–2009	2010–2019
Environmental Sciences	1897	125	427	1345
Public Environmental Occupational Health	1879	177	355	1347
Water Resources	1443	103	368	972
Tropical Medicine	728	81	111	536
Engineering Environmental	723	71	208	444
Food Science Technology	716	67	175	474
Infectious Diseases	582	23	89	470
Microbiology	443	17	110	316
Environmental Studies	441	41	77	323
Parasitology	415	26	60	329
Biotechnology Applied Microbiology	370	40	127	203
Multidisciplinary Sciences	300	5	20	275
Medicine General Internal	272	56	70	146
Veterinary Sciences	243	56	75	112
Development Studies	230	14	28	188

Co-occurring categories analysis is used to study interdisciplinary links and can reveal the intrinsic connections between various subject categories by constructing a subject-related network. Figure 3a shows that during the first period (1990–1999), the top three categories in sanitation research were public environmental occupational health, environmental sciences and water resources. Public environmental occupational health (betweenness centrality, 0.37) in this period emerged as an intermediary that connected many different subject categories. In the second and third periods, in addition to public environmental occupational health, the betweenness centrality of environmental sciences is also greater than 0.1, which indicates that both are more important than other categories. Moreover, as time goes by, the links between various subject categories become closer (See Fig. 3). This result reflects the profound effects of sanitation because it shows that joint efforts are required to carry out global research.

3.4 Research topic analysis

3.4.1. Phase evolution analysis of research topics

1990 to 2019 was divided into three periods, and the top 50 keywords in each year were selected for analysis. Each node in Fig. 4 represents a keyword; larger nodes represent higher frequency of keyword occurrence. The links between nodes indicate that two relevant keywords appeared together in an article; a thicker link represents more frequent occurrences between the two keywords. As shown in Fig. 4 (a, b, c), the research nodes increased gradually across the three periods, and the cross fusion of each cluster was significantly enhanced. These results demonstrate that this field was constantly expanding and developing.

During the period of 2000–2009, research on sanitation and children's health in developing countries remained important. Meanwhile, as shown in Fig. 4 (b), “water” became the most-studied subject and “health” was also important. In September 2000, global heads of state voted to pass the United Nations Millennium Declaration and set a series of goals to be met by 2015, known as the "Millennium Development Goals" (MDG). The United Nations Millennium Development Goals have called issues of water and sanitation to the forefront of international development efforts. Safe drinking water is essential for human health and sustainable development and managing water is an essential component of the UN's MDG. While most countries are committed to increasing access to safe water, there is little consensus on how to actually improve water services (Galiani et al., 2005). During this period, researchers discussed ways to increase accessibility and use of water and sanitation, as well as the roles of private providers and civil society institutions in providing water and sanitation services (Al-Hmoud and Edwards, 2005; Sansom, 2006). In addition, they focused on the effects of sanitation reforms and policies on a variety of health outcomes, including public health, environmental health, rural health, health of schoolchildren, and health for poor people (Agoramoorthy and Hsu, 2009; Fry et al., 2008; McKee et al., 2006; Ulukanligil and Seyrek, 2003; Clark and Gundry, 2004; Anwar, 2003).

The breadth and depth of research on sanitation increased significantly during the period of 2010–2019. As shown in Fig. 4 (c), “sanitation”, “water” and “health” remain the most popular subjects, and “hygiene” as well as “impact” became more prominent. The United Nations 2030 Agenda for Sustainable Development proposes 17 sustainable development goals, of which Sustainable Development Goal (SDG) 6 aims to ensure availability and sustainable management of sanitation and water for all people, in all settings. In particular, SDG 6.2 is to achieve access to adequate and equitable sanitation and hygiene for all by 2030 (UNICEF/WHO, 2017). The work in hygiene is aimed at nurturing good hygiene practices and there is growing recognition that comprehensive hygiene behavior improvements should be integral to prevention efforts (Alexander et al., 2019; Bartram and Platt, 2010; Andrade et al., 2019). During this period, a growing number of researchers conducted surveys and assessments of different hygiene conditions, including community-based or school-based hygiene facilities, water container hygiene, personal hygiene (residents, children, parents, etc.) and food hygiene (Andrade et al., 2019; Appiah-Brempong et al., 2018; Al-Khatib et al., 2015; Biran et al., 2012;). Some researchers estimated the impact of drinking water, sanitation, and hygiene improvements on children’ growth and development (Pickering et al., 2019; Johri et al., 2019; Ercumen et al., 2018; Dearden et al., 2017; Garn et al., 2016).

3.4.2. Keyword clustering analysis

We also conducted further keyword clustering analysis using CiteSpace. On the basis of keyword co-occurrence analysis, keyword clustering analysis takes the frequency of co-occurrence as the object of analysis and uses the clustering statistical method to simplify the complex co-occurrence network relationship into the relationship between a relatively small number of groups (Zhong et al., 2008). Table 4 listed the top five clusters based on their sizes. However, since it is difficult to find specific information in the keywords from the cluster name alone, it is necessary to combine the main keywords in the cluster to analyze the specific research content contained in each cluster in a deeper way.

Table 4
The clusters and main keywords within the clusters

No.	Size	Silhouette value	Cluster name	Main keywords
1	72	0.777	drinking water	sanitation; health; diarrhea; hygiene; disease; developing country; children
2	67	0.731	sustainability	water; management; system; waste water
3	65	0.795	biofilm	contamination; escherichia coli; public health; bacteria
4	63	0.755	epidemiology	prevalence; transmission; outbreak; Africa
5	48	0.829	WaSH	infection; growth; mortality; malnutrition

The first cluster is related to drinking water. The main keywords contained in this largest cluster are the current top ten sanitation research keywords, including sanitation, health, diarrhea, hygiene, disease, developing country, and children. In this cluster, the researchers focus on the relationship between sanitation conditions and children's health and risk of disease (especially diarrhea) in developing countries. Safe drinking water is essential for human health and sustainable development (Forget et al., 2000). Therefore, this cluster also focuses on the studies of quality and management of drinking water at the supply and household levels (Dzwairo et al., 2006; Cotton et al., 2013; Hoque et al., 2006).

The second cluster is about sustainability, including water, management, system, and wastewater. Access to improved sanitation facilities is key to the socioeconomic wellbeing and sustainable development of any society (Abubakar, 2017). In this area, researchers explored (1) sustainability and decision making in water and sanitation management systems (Iribarnegaray and Seghezzo, 2012), (2) sustainable services in water supply and sanitation (Behailu et al., 2016) as well as (3) the selection of sustainable sanitation arrangements (Mara et al., 2007). They also explored the connections between governance and sustainability and discussed their possible roles in water and sanitation management systems (WSMS) (Iribarnegaray and Seghezzo, 2012). The researchers are committed to developing and evaluating the application of several methodological tools to sustainability of water supply and sanitation services (such as analytic hierarchy process, Sustainable Water Governance Index (SWGI), Life-Cycle Analysis),

focusing on relevance, effectiveness and sustainability (Boukhari et al., 2018; Iribarnegaray and Seghezzo, 2012; Jones and Silva, 2009; Cotton et al., 2013). In addition, upgrading the coverage of wastewater management and services and increasing their efficiency is necessary to improve the environmental in cities (Joseph, 2006). Many researchers in this cluster have also studied the problems of providing and financing provision for wastewater management as well as the influence of wastewater treatment on improved public health (Garcia, 2006; Naik and Stenstrom, 2012). Their findings indicate that wastewater management problems must be addressed not by the State directly but through a greater degree of participation and involvement by society (Garcia, 2006). They also concluded that an increase in wastewater treatment availability reduces mortality caused by disease (Naik and Stenstrom, 2012).

The third cluster investigates biofilm, with keywords including contamination, escherichia coli, public health, and bacteria. There are still many populations worldwide that do not have access to safe drinking water (Whitley et al., 2019;). The bacteriological quality of some water sources is in doubt because of their proximity to both point and diffuse sources of pollution and can thus present public health risks (Dorice et al., 2010). Therefore, many researchers in this cluster investigated bacterial contamination, bacterial quality, bacterial morbidity, and sources of contamination of various water sources (such as domestic Wells, springs, rivers, surface and groundwater in rural settlements, and community drinking water), as well as sediments in sanitary sewers (Ngasala et al., 2019; Dorice et al., 2010; Oluyege et al., 2009; Baig et al., 2012; Schmitt, 1992). Their studies have shown (1) the importance of greater attention to household contamination, environmental sanitation control and water contamination (Abdelrahman and Eltahir, 2011); (2) the need to develop appropriate sanitation strategies (Dorice et al., 2010); (3) the need for new regulatory mandates for the distance of domestic wells from sanitation systems to protect human health (Ngasala et al., 2019); (4) the importance of water quality monitoring and healthy domestic hygiene practices (Baig et al., 2012).

The next cluster focuses on epidemiology and includes prevalence, transmission, outbreak, Africa and other keywords. In this cluster, researchers analyzed the prevalence of various epidemic diseases (such as diarrhea, hepatitis A, trachoma, Helicobacter pylori, Ebola and cholera) and the potential risk factors (Brown, 2000; Oswald et al., 2017; Nurgalieva et al., 2002; Mallow et al., 2018; Ali et al., 2017). Many scholars focused on the role of hygienic and sanitation improvements in reducing the prevalence of epidemic diseases (Imada et al., 2016; Nurgalieva et al., 2002). In addition, some scholars have explored the differences in epidemic prevalence across different geographical regions and ethnic groups (Goh et al., 2011; Choi, 2003).

Cluster 5 focuses on Water, Sanitation and Hygiene (WaSH), and includes keywords such as infection, growth, mortality and malnutrition. Stunted growth among children is associated with poor WaSH, due to the effect of infection on intestinal nutrient absorption (Budge et al., 2019). Researchers in this cluster focused on assessing WaSH practices and their association with adolescent nutrition and exploring the linkages between stunted growth and WaSH (Chattopadhyay et al., 2019; Kwami et al., 2019). They also investigated the effectiveness of WaSH intervention in reducing the prevalence of childhood diseases like diarrhea and anemia. Most of these studies use the Randomized Controlled Trial method (Dey et al., 2019;

Fancony et al., 2019). In addition, some researchers examine WaSH practices and associated risk factors among different groups (Hall, 2019; Hsan et al., 2019; Whitley et al., 2019). Researchers have found that efforts to improve nutrition and WaSH behaviors are most effective in promoting long-term health outcomes for children when implemented early on (Kwami et al., 2019). The implementation of an effective WaSH awareness program is useful along with improved water supply and sanitation to improve WaSH practices (Hsan et al., 2019).

3.4.3. Keywords in different countries

According to Fig. 1, sanitation has been studied extensively on a global scale. Due to differences in geographical features, history and economy, the subjects studied vary between regions. Figure 5 provides the 5 most frequently used keywords in the 15 most influential countries. We found that, "sanitation" and "water" appear in the top 5 keywords for each country. However, there are differences among other keywords in different countries. For example, from 1990 to 2019, the most frequently used keywords in the USA were “sanitation” (849 times), “water” (361 times), “health” (357 times) “diarrhea” (282 times), and “hygiene” (236 times), while in Brazil, the most frequently used keywords were “Brazil” (87 times), “sanitation” (86 times), “water” (53 times), “children” (48 times), and “prevalence” (38 times). In addition, most countries (11/15) include "health" in high-frequency keywords and one third of countries pay more attention to research on “diarrhea” and sanitation-related “impact.”

3.5. Research frontier analysis

Keywords with bursts refer to those keywords which increase sharply in frequency. Burst detection is a useful analytic method to find the keywords that receive particular attention from the scientific community during a certain period of time (Zhou et al., 2018). Therefore, bursting keywords can be used as indicators to predict research trends (Li and Chen, 2017). Table 5 presents keywords with bursts in the last four years (2016–2019) through CiteSpace, along with their strength and occurrence timespan. The time interval is plotted on the blue line and the period of a burst keyword is plotted on the red line, which indicates the beginning and end of the time interval of each burst (Zhou and Zhao, 2015). As shown in Table 5, we found that “infrastructure”, “country”, “undernutrition”, “performance”, “climate change”, “determinant”, “model” and “sustainability” were the emerging active topics in recent years. Combined with a keyword clustering analysis, the emerging sanitation research frontiers are described as follows:

(1) *Sanitation services adapting to climate change*. Climate change threatens WaSH facilities and services (Alhassan and Hadwen, 2017). The effect of water on infectious disease deserves attention, particularly in low- and middle-income countries. Climate change effects will exacerbate water-borne disease challenges for the public health sector (Cisse, 2019). Therefore, research on the threats to current sanitation services from extreme weather events and the capacity of sanitation services to respond to climate change has increased rapidly in recent years. Some scholars have pointed out that climate change impacts, as well as increased water demand, pose serious risks to the provision of sustainable urban water services, e.g., drinking water, sanitation, and safe drainage (Johannessen and Wamsler, 2017). Moreover, a megacity may pose a greater risk due to its scale and complexity (Kim et al., 2018).

Therefore, some studies have discussed Integrated Urban Water Management, which is the holistic management of urban water, sanitation, stormwater, and wastewater in order to achieve sustainable objectives of sanitation services (Kirshen et al., 2018). Meanwhile, because WaSH facilities tend to be unique in their vulnerability, they need region-based data to reveal local vulnerabilities that can inform strategic national or global planning. This requires more effort from researchers in different fields. In addition, rural fresh water and sanitation is a vulnerable sector in the context of climate change, so more research in this area is required.

(2) *Main determinants affecting child malnutrition*. The World Health Organization has called for global action to reduce stunted growth among children by 40% by 2025. Childhood malnutrition remains highly prevalent in low-income countries (Husseini et al., 2018). Therefore, in recent years, scholars have continued to research the strongest determinants of stunted growth among children and highlight key areas for intervention (Saxton et al., 2016). While the link between nutrition and stunted growth is well-recognized, some scholars believe that environmental factors such as water and sanitation may influence feeding practices and result in potential infection pathways. Some studies have found that interventions focusing on water and sanitation practices may reduce the prevalence of underweight children (Kwami et al., 2019; Adhikari et al., 2017; Null et al., 2018;). There are also studies investigating the relationship between WaSH practices and child nutrition. These studies suggest a need to address poor WaSH conditions, particularly household drinking water quality (Lauer et al., 2018). On the other hand, some studies found that water quality improvements are unlikely to impact stunted growth among children and large trials of improved WaSH conditions reported no benefits to child growth (Johri et al., 2019; Humphrey et al., 2019). For now, further research into the major determinants of child malnutrition is necessary.

(3) *More focus on multinational research and model innovation*. In the era of Sustainable Development Goals, universal access to safe water and WaSH services is a goal for countries around the world (Ezbakhe and Perez-Foguet, 2018). There has been a recent increase in research about sanitation, both nationally and internationally (Alderman and Headey, 2018; Bidkhori et al., 2019). At the same time, in terms of research methods, scholars have also increased discussion about the application of different models (such as the Multi-criteria decision analysis (MCDA), Generalized multinomial logit, and instrumental variable regression models) (Ezbakhe and Perez-Foguet, 2018; Vasquez and Alicea-Planas, 2018; Wayland, 2018). However, the application of big data in research about this field can be improved. Future studies could focus on applying big data to sanitation research. For example, machine learning can be used to predict the effect of different climates on current sanitation services.

(4) *More evaluations focusing on performance*. Due to the increasing attention paid to sanitation issues globally, many related projects have emerged in countries around the world. At the same time, research is being done to evaluate these projects (Cha et al., 2017; Nakagiri et al., 2017; Guerrini et al., 2016). In addition, bridging the water infrastructure gap has become a major policy concern (Ducrot and Bourblanc, 2017). Therefore, there has also been an increase in sustainable water and sanitation infrastructure

research (Kaminsky, 2017; Wamuchiru, 2018; Speer, 2016; Hacker and Kaminsky, 2017). However, further research in these areas is necessary.

Table 5
Keywords with bursts in the last four years.

Keywords	Strength	Begin	End	1990–2019
infrastructure	15.8208	2016	2019	
country	8.5416	2016	2019	
undernutrition	22.9043	2016	2019	
performance	14.7411	2016	2019	
climate change	19.415	2016	2019	
determinant	18.336	2017	2019	
model	7.7918	2017	2019	
sustainability	3.498	2017	2019	

3.6. National comprehensive strength

In this section, we rank the research strength of selected countries in the field of sanitation according to formulae (1) and (2) (Fig. 6). The indicators and the total standard score (TSS) of the USA are much higher than those of other countries, with a total standard score of 33.65. For England, the scores of the three indices TH, PA and THC are relatively high, and the total standard score is 16.36, putting it in second place. Although Switzerland has not published many particles, it has many citations and prolific authors, placing it in third. In terms of total publications, Brazil and India are the top two developing countries. As shown in Fig. 6, India's TSS scores are higher than Brazil's, which is mainly due to Brazil's low TMCC value.

4. Conclusions

This paper, using bibliometric analysis, provides a unique snapshot of sanitation research over the past 30 years. Publication data indicates increases in researcher output, especially after 2013. Scholars from 91% of the countries in the world publish in this field. These publications are mainly concentrated in the USA, England, Brazil, India, and Switzerland. The USA ranks first in this field, followed by England and Switzerland, as reflected in its total number of articles, productive institutions and highly-cited papers. This domain is a highly interdisciplinary field that covers a wide range of interests, including environmental science public health, water resources, medicine, engineering, food science and microbiology.

Based on keyword clustering analysis, the main research topics in the field of sanitation can be summarized as: (a) drinking water; (b) sustainability; (c) biofilm; (d) epidemiology; (e) WaSH. Keyword burst analysis showed that new research mainly concentrated on (a) Sanitation services adapting to climate change; (b) child malnutrition; (c) Multinational research and model innovation; (d) Evaluations of performance. Sanitation research has not changed much over the past 30 years. However, more scholars are beginning to do work about “hygiene” and sanitation-related “impact.”

However, there are some limitations to this study: (1) the complexity of analyzing authors from different countries, regions and organizations poses a significant difficulty in any statistical analysis; the statistics about the number of published papers may not be entirely accurate. (2) Due to the continuous renewal of papers in the database, the results of this study, such as citation rates, will change over time, and as such can never represent the latest results. However, the findings of this paper are based on objective data, and are stable, reliable and, on the whole, not influenced by empiricism.

Declarations

Ethical Approval and Consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and material

All the data used in this paper are publicly available.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Li Huang: Data curation, Software, Writing-Original draft; Mi Zhou: Methodology, Writing-Reviewing and Editing.

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Authors' information

Corresponding author: Mi Zhou [Department: College of economics and management of Shenyang Agricultural University] [Address: Dongling Road 120, Shenyang, Liaoning province, China] [TEL:86-13609830205] [Email:zhoumi2011@syau.edu.cn]

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Figures

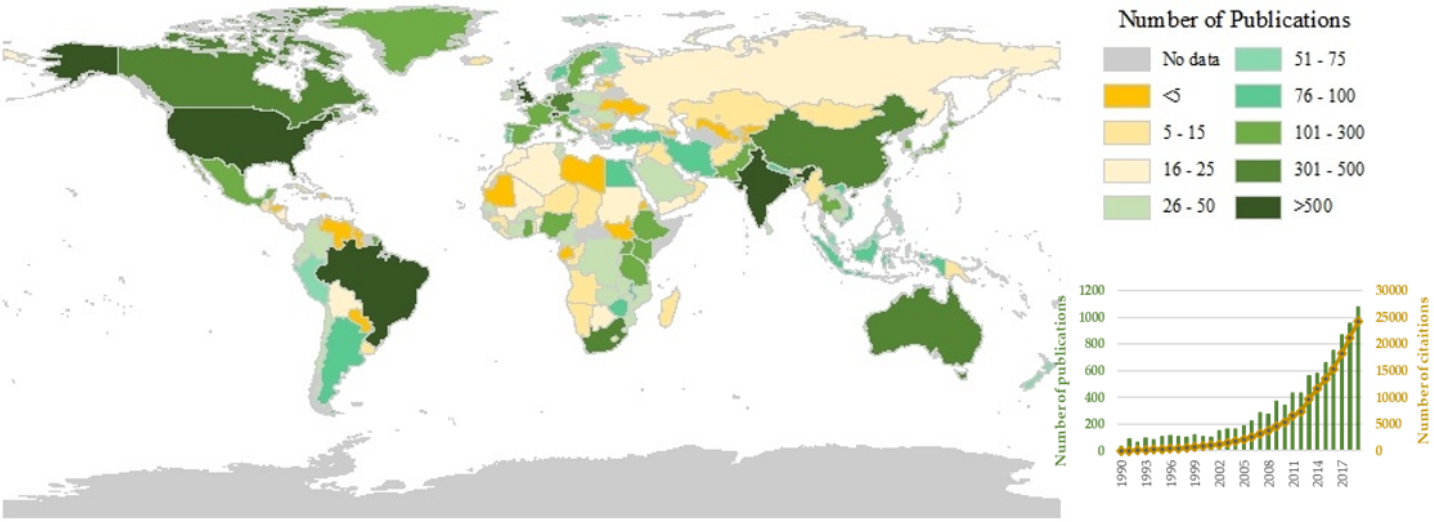

Figure 1

Characteristics of annual publications and the global geographic distribution of publications. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country,

territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

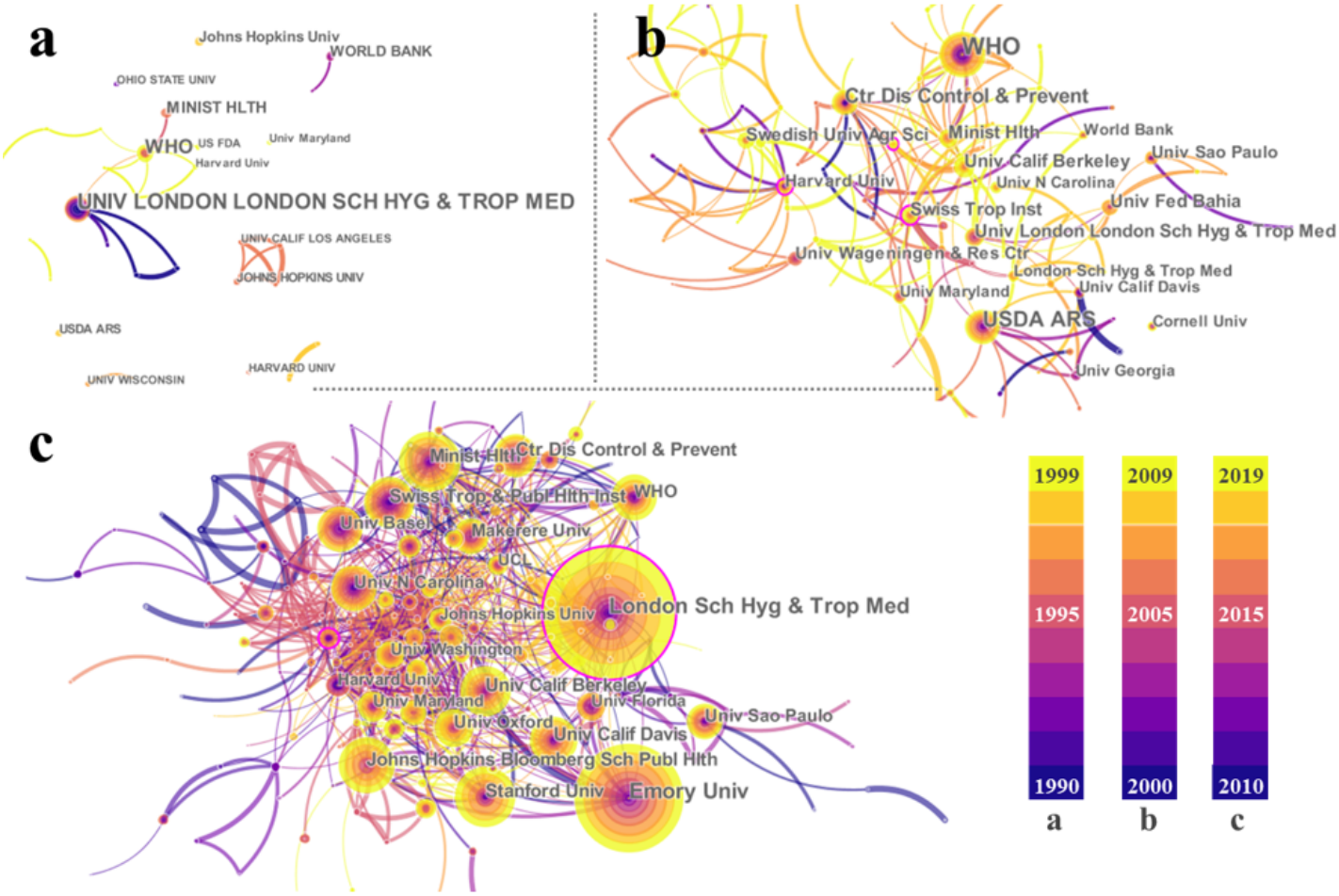

Figure 2

Scientific collaboration networks during (a) 1990–1999, (b) 2000–2009, and (c) 2010–2019. Nodes represent institutions. The size of a node is proportional to the amount of literature produced by the institution. The links represent collaborative relationships between different institutions. The colors of the rings and links correspond to the year. Purple rings indicate high centrality.

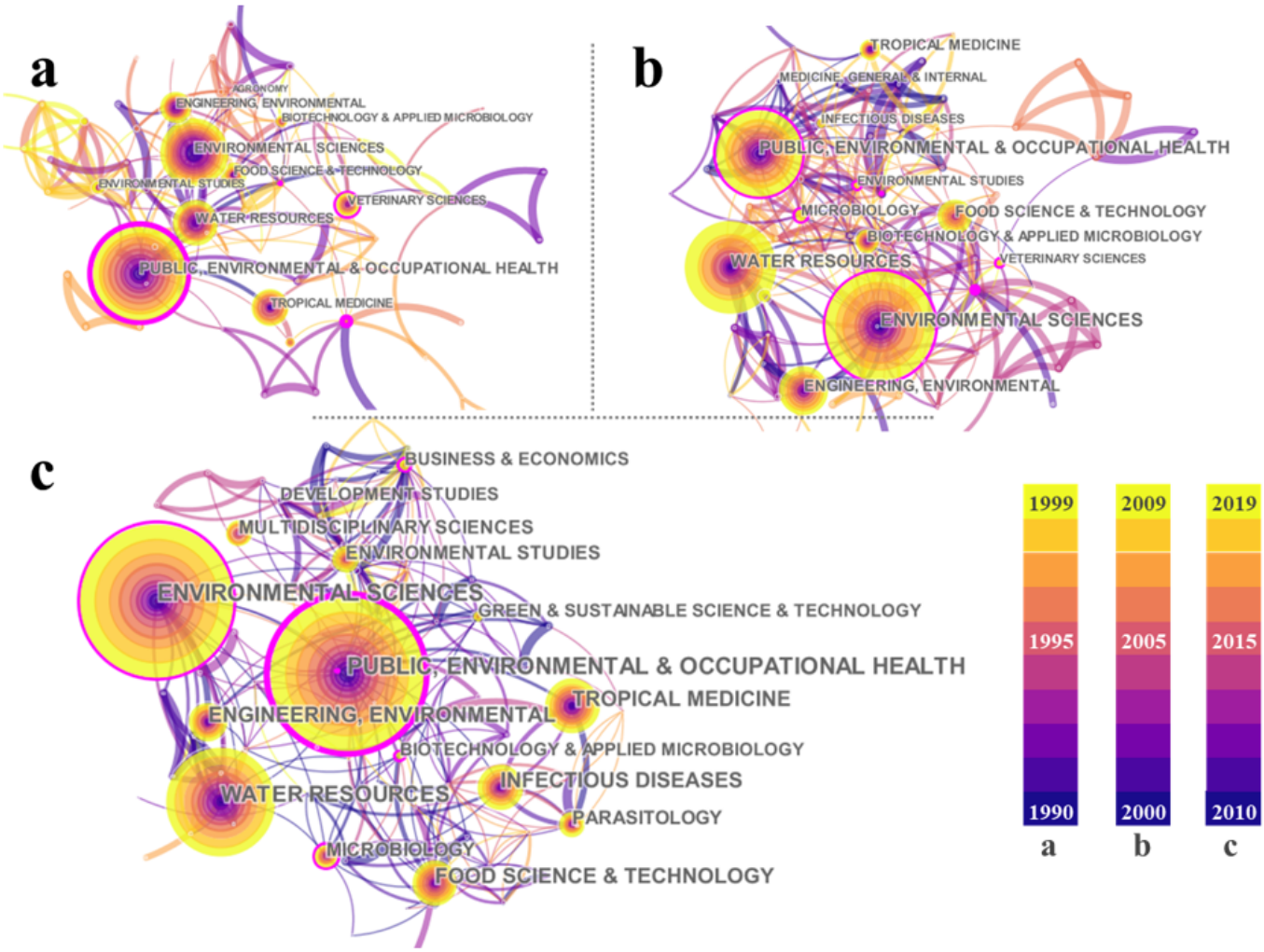

Figure 3

Co-occurring subject categories networks during (a) 1990–1999, (b) 2000–2009, and (c) 2010–2019. Nodes represent subject categories. The size of a node is proportional to amount of literature in the subject category. The links represent the co-occurring relationship between different subject categories. The colors of the rings and links correspond to the year. Purple rings indicate high centrality.

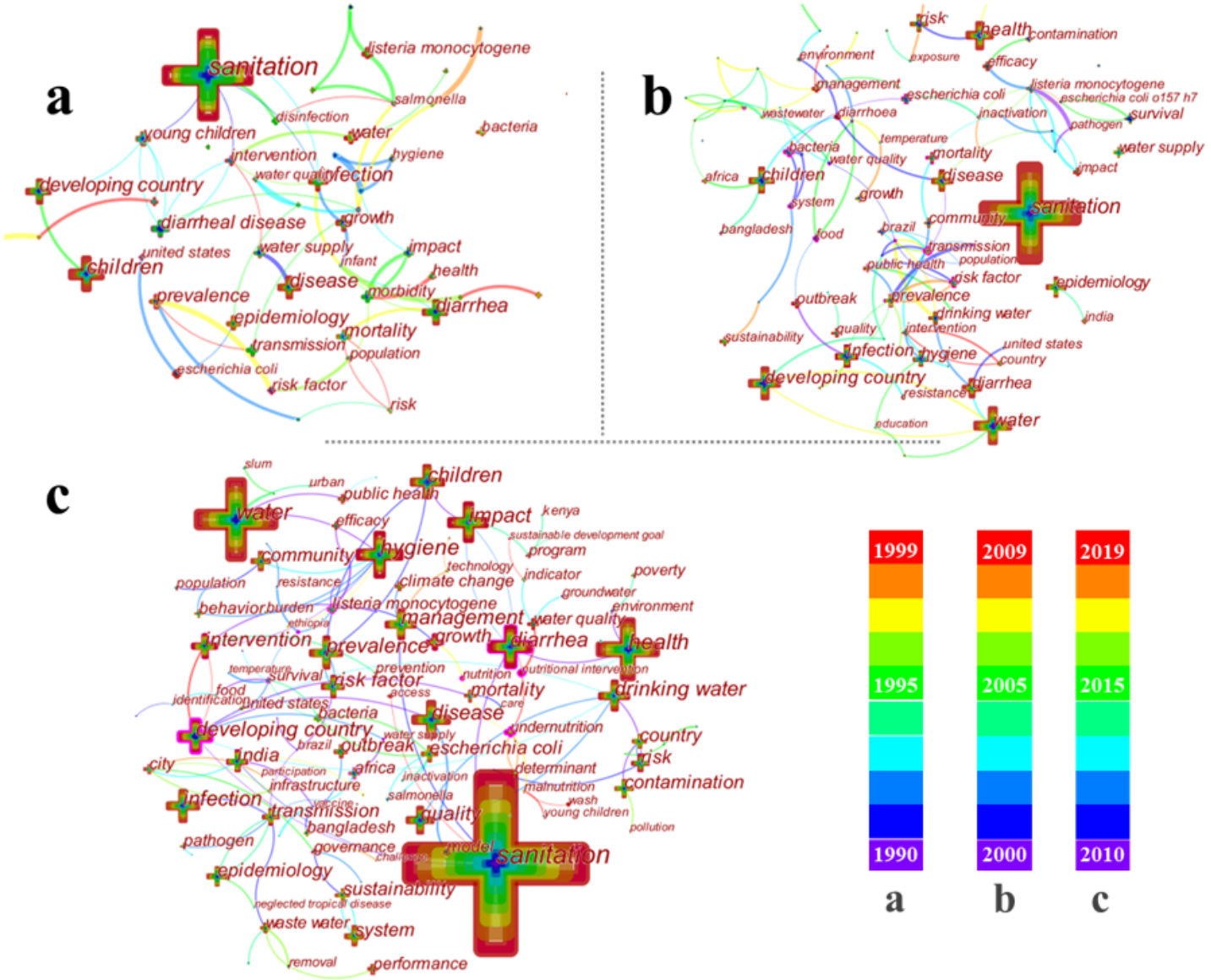

Figure 4

Co-occurring keywords networks during (a) 1990–1999, (b) 2000–2009, and (c) 2010–2019. Nodes represent keywords. The size of a node is proportional to the amount of literature related to the keyword. The links represent the co-occurring relationship between different keywords. The colors of the rings and links correspond to the year. Purple rings indicate high centrality.

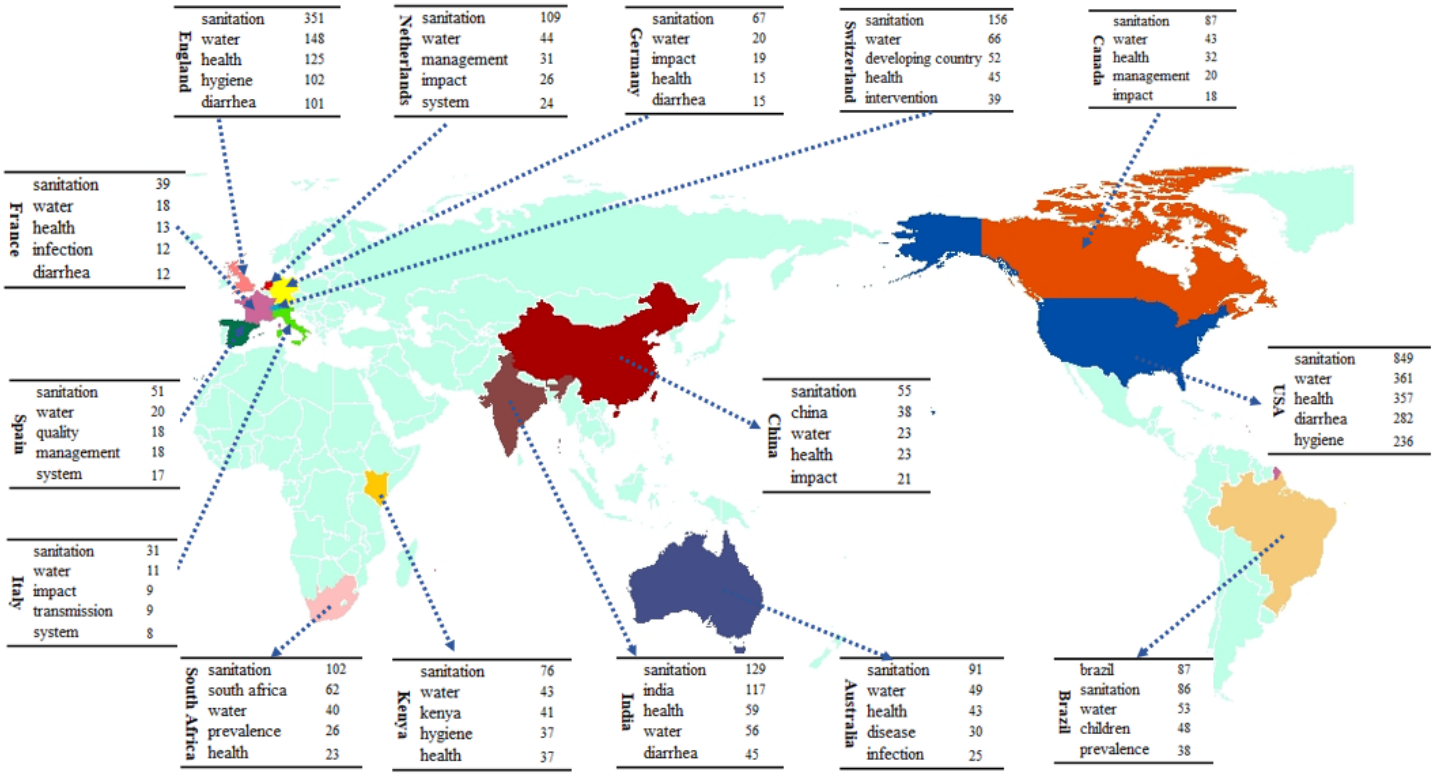

Figure 5

The 5 most frequently used keywords in the 15 most influential countries. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

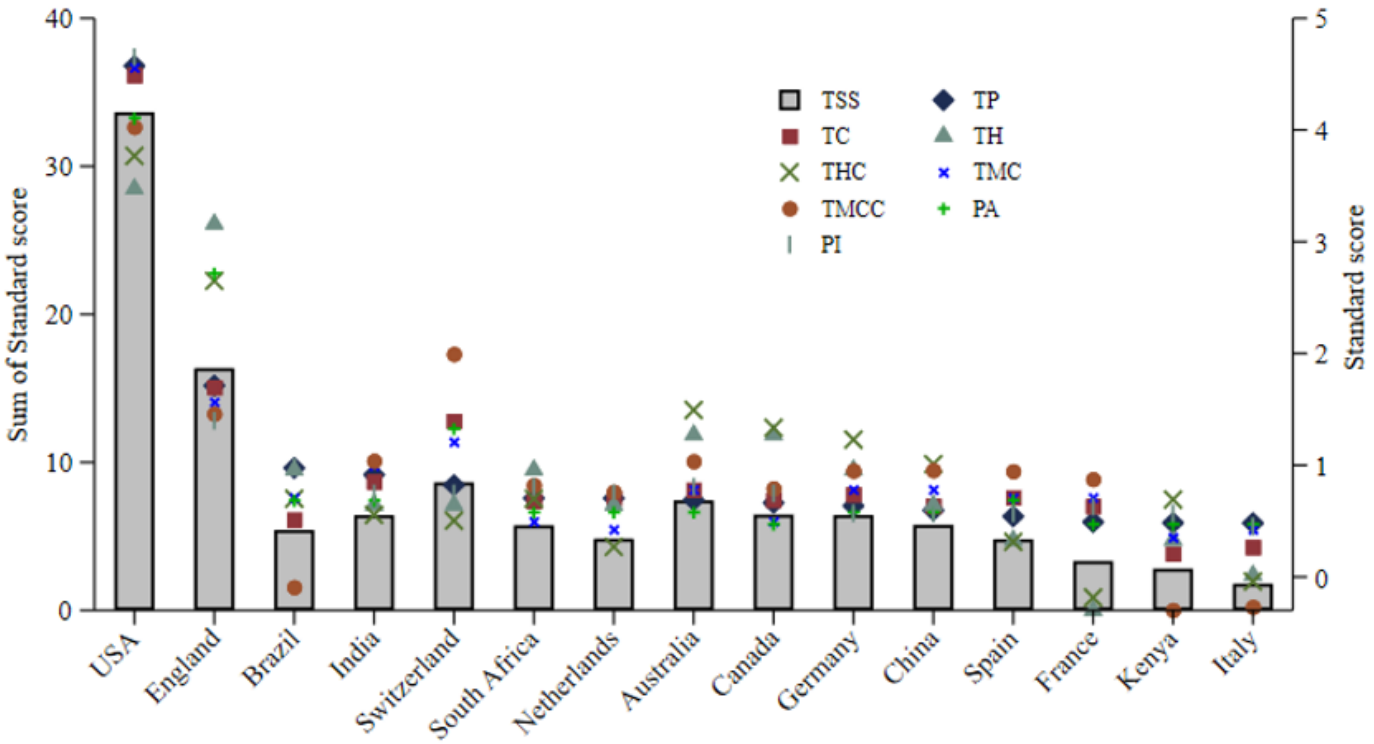

Figure 6

National comprehensive strength, 1990–2019. Note: TP: total publications; TC: total citations; TH: total hot articles; THC: citations of hot articles; TMC: total most cited articles; TMCC: total most cited articles' citations; PA: productive authors; PI: productive institutions; TSS: total standard score.