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

CURRENT STATUS: POSTED

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

mi zhou
Shenyang Agricultural University

DOI:
10.21203/rs.3.rs-22552/v1

SUBJECT AREAS
Toxicology  Epidemiology

KEYWORDS
bibliometric analysis, research trends, sanitation, WaSH, climate change, sustainability, knowledge mapping
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,
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 facil*”) 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):

$$StScore_{ij} = \frac{x_{ij} - \bar{x}_j}{\frac{1}{m} \sum (x_{ij} - \bar{x}_j)^2} + 1 \quad (1)$$

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

Where $StScore_{ij}$ is the standard score of indicator $j$ in country $i$; $X_{ij}$ is the original score of indicator $j$ in country $i$; $\bar{X}_j$ 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 |
|------------------|-----|-----------|-------------|---------|
| USA              | 3224| 76177     | 23.63       | 104     |
| England          | 1149| 30128     | 26.22       | 68      |
| Brazil           | 614 | 10588     | 17.24       | 43      |
| India            | 570 | 16215     | 28.45       | 45      |
| Switzerland      | 503 | 25146     | 49.99       | 58      |
| South Africa     | 418 | 13346     | 31.93       | 34      |
| Netherlands      | 417 | 13812     | 33.12       | 39      |
| Australia        | 406 | 14982     | 36.90       | 41      |
| Canada           | 388 | 13523     | 34.85       | 36      |
| Germany          | 368 | 14332     | 38.95       | 40      |
| China            | 340 | 12655     | 37.22       | 31      |
| Spain            | 300 | 13856     | 46.19       | 40      |
| France           | 263 | 12611     | 47.95       | 35      |
| Kenya            | 258 | 5593      | 21.68       | 31      |
| 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\textsuperscript{a} | TC/\text{P}\textsuperscript{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\textsuperscript{a}: the total citations for an institution. TC/\text{P}\textsuperscript{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 Studies     | 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.

| 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,
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; Bidkhorti 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.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: Preparation of this manuscript was supported by Grant Nos. 71573179, 71903133 and 71973100 from the National Natural Science Foundation of China.
Authors' contributions

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

Acknowledgements

Not applicable.

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]

References

1. Abdelrahman AA, Eltahir YM. Bacteriological quality of drinking water in Nyala, South Darfur. Sudan Environ Monit Assess. 2011;175(1-4):37-43.
2. Abubakar IR. Access to Sanitation Facilities among Nigerian Households: Determinants and Sustainability Implications. Sustainability. 2017;9(4):547.
3. Abu-Elyazeed R, Wierzba TF, Mourad AS, Peruski LE, Kay BA, Rao M, Churilla AM, Bourgeois AL, Mortagy AK, Kamal SM, Savarino SJ, Campbell JR, Murphy JR, Naficy A, Clemens JD. Epidemiology of enterotoxigenic Escherichia coli diarrhea in a pediatric cohort in a periurban area of lower Egypt. J Infect Dis. 1999;179(2):382-9.
4. Adhikari D, Khatri RB, Paudel YR, Poudyal AK. 2017. Factors Associated with Underweight among Under-Five Children in Eastern Nepal: Community-Based Cross-Sectional Study. Front. Public Health 5, UNSP 350.
5. Agoramooorthy G, Hsu MJ. India needs sanitation policy reform to enhance public health. J Econ Policy Reform. 2009;12(4):333-42.
6. Alderman H, Heady D. The timing of growth faltering has important implications for observational analyses of the underlying determinants of nutrition outcomes. PLOS ONE. 2018;13(4):e0195904.
7. Aleixandre-Benavent R, Aleixandre-Tudó JL, Castelló-Cogollos L, Aleixandre JL. Trends in scientific research on climate change in agriculture and forestry subject areas (2005–2014). J Clean Prod. 2017;147:406-18.

8. Alexander CC, Shrestha S, Toundara MD, Cooper S, Hunt L, Hoj TH, Dearden K, Kezakubi D, Atugonza V, West J, Crookston B, Hall C. 2019. Media Access is Associated with Knowledge of Optimal Water, Sanitation and Hygiene Practices in Tanzania. Int. J. Env. Res. Pub. He. 16(11), 1963.

9. Alhassan S, Hadwen WL. Challenges and Opportunities for Mainstreaming Climate Change Adaptation into WaSH Development Planning in Ghana. Int J Env Res Pub He. 2017;14(7):749.

10. Al-Hmoud RB, Edwards J. Water poverty and private investment in the water and sanitation sector. Water Int. 2005;30(3):350-5.

11. Ali M, Sen Gupta S, Arora N, Khasnobis P, Venkatesh S, Sur D, Nair GB, Sack DA, Ganguly NK. Identification of burden hotspots and risk factors for cholera in India: An observational study. PLOS ONE. 2017;12(8):e0183100.

12. Al-Khatib IA, Abusara LW, Odeh YM, Sbeih SA, Massoud MA. Hand Washing Among Palestinians in the West Bank and Gaza Strip: Attitudes and Practices. J Environ Health. 2015;77(6):50–6.

13. Andrade EL, Bingenheimer JB, Edberg MC, Zoerhoff KL, Putzer EM. Evaluating the effectiveness of a community-based hygiene promotion program in a rural Salvadoran setting. Global Health Promotion. 2019;26(1):69–80.

14. Anwar WA. Environmental health in Egypt. Int J Hyg Envir Heal. 2003;206(4-5):339-50.

15. Appiah-Brempong E, Harris MJ, Newton S, Gulis G. Examining school-based hygiene facilities: a quantitative assessment in a Ghanaian municipality. BMC Public Health.
16. Baig SA, Xu X, Khan R. Microbial water quality risks to public health: potable water assessment for a flood-affected town in northern Pakistan. Rural Remote Health. 2012;12(3):2196.

17. Bartram J, Platt J. How health professionals can leverage health gains from improved water, sanitation and hygiene practices. Perspect Public Heal. 2010;130(5):215–21.

18. Behailu BM, Pietila PE, Katko TS. Indigenous Practices of Water Management for Sustainable Services: Case of Borana and Konso, Ethiopia. SAGE OPEN. 2016;6(4):2158244016682292.

19. Bidkhor M, Yousefi M, Rohani H, Ebrahimi H, Mohammadi AA. The influence of the use of improved sanitation facilities and improved drinking-water sources on the diarrhea-associated deaths in children under 5 years. Hum Ecol Risk Assess. 2019;25(5):1234–41.

20. Biran A, Schmidt WP, Zeleke L, Emukule H, Khay H, Parker J, Peprah D. Hygiene and sanitation practices amongst residents of three long-term refugee camps in Thailand, Ethiopia and Kenya. Trop Med Int Health. 2012;17(9):1133–41.

21. Boukhari S, Djebbar Y, Amarchi H, Sohani A. Application of the analytic hierarchy process to sustainability of water supply and sanitation services: the case of Algeria. Water Sci Tech-W Sup. 2018;18(4):1282–93.

22. Brentlinger PE, Hernandez-Diaz S, McCall M. Childhood malnutrition and postwar reconstruction in rural El Salvador - A community-based survey. Jama-J Am Med Assoc. 1999;281(2):184–90.

23. Brown MG. Investigations of the epidemiology of infections with hepatitis A virus in Jamaica. Ann Trop Med Parasit. 2000;94(5):497–502.

24. Budge S, Hutchings P, Parker A, Tyrrel S, Tulu T, Gizaw M, Garbutt C. Do domestic
animals contribute to bacterial contamination of infant transmission pathways?
Formative evidence from Ethiopia. J Water Health. 2019;17(5):655–69.

25. Cha S, Mankadi PM, Elhag MS, Lee Y, Jin Y. Trends of improved water and sanitation coverage around the globe between 1990 and 2010: inequality among countries and performance of official development assistance. Global Health Action. 2017;10:1327170.

26. Chattopadhyay A, Sethi V, Nagargoje VP, Saraswat A, Surani N, Agarwal N, Bhatia V, Ruikar M, Bhattacharjee S, Parhi RN, Dar S, Daniel A, Sachdev HPS, Singh CM, Gope R, Nath V, Sareen N, De Wagt A, Unisa S. WASH practices and its association with nutritional status of adolescent girls in poverty pockets of eastern India. BMC Womens Health. 2019;19:89.

27. Chen C, Song IY, Yuan X, Zhang J. The thematic and citation landscape of data and knowledge engineering (1985–2007). Data Knowl Eng. 2008;67:234–59.

28. Choi SYP. Mechanisms of racial inequalities in prevalence of diarrhoea in South Africa. J Health Popul Nutr. 2003;21(3):264–72.

29. Cisse G. Food-borne and water-borne diseases under climate change in low- and middle-income countries: Further efforts needed for reducing environmental health exposure risks. ACTA Trop. 2019;194:181–8.

30. Clark R, Gundry SW. The prominence of health in donor policy for water supply and sanitation: a review. J Water Health. 2004;2(3):157–69.

31. Cotton A, Adams J, Shaw D. Improving water supply and sanitation programme effectiveness: lessons from WaterAid's outcome evaluation studies. Water Environ J. 2013;27(1):1–9.

32. Dearden KA, Brennan AT, Behrman JR, Schott W, Crookston BT, Humphries DL, Penny ME, Fernald LCH. Does household access to improved water and sanitation in infancy
and childhood predict better vocabulary test performance in Ethiopian, Indian, Peruvian and Vietnamese cohort studies? BMJ OPEN. 2017;7(3):e013201.

33. Delemarrevandewaal HA. Environmental-Factors Influencing Growth and Pubertal Development. Environ Health Persp. 1993;101:39-44.

34. Dey NC, Parvez M, Islam MR, Mistry SK, Levine DI. Effectiveness of a community-based water, sanitation, and hygiene (WASH) intervention in reduction of diarrhoea among under-five children: Evidence from a repeated cross-sectional study (2007-2015) in rural Bangladesh. Int J Hyg Envir Heal. 2019;222(8):1098-108.

35. Dorice K, Josephine N, Margaret TA, Gaston L, Veronique KKB, Henriette AB, Emmanuel EG. Bacterial contamination of water points of the upper Mfoundi watershed, Yaounde, Cameroon. Afr J Microbiol Res. 2010;4(7):568-74.

36. Ducrot R, Bourblanc M. Promoting equity in water access: the limits of fairness of a rural water programme in semi-arid Mozambique. Nat Resour Forum. 2017;41(3):131-44.

37. Dzwairo B, Hoko Z, Love D, Guzha E. Assessment of the impacts of pit latrines on groundwater quality in rural areas: A case study from Marondera district. Zimbabwe Phys Chem Earth. 2006;31(15-16):779-88.

38. Ekundayo TC, Okoh AI. A global bibliometric analysis of Plesiomonas-related research (1990-2017). PLOS ONE. 2018;13:e0207655.

39. Enwonwu CO, Falkler WA, Idigbe EO, Afolabi BM, Ibrahim M, Onwujekwe D, Savage O, Meeks VI. Pathogenesis of cancrum oris (noma): Confounding interactions of malnutrition with infection. Am J Trop Med Hyg. 1999;60(2):223-32.

40. Ercumen A, Pickering AJ, Kwong LH, Mertens A, Arnold BF, Benjamin-Chung J, Hubbard AE, Alam M, Sen D, Islam S, Rahman MZ, Kullmann C, Chase C, Ahmed R, Parvez SM, Unicomb L, Rahman M, Ram PK, Clasen T, Luby SP, Colford JM. 2018. Do Sanitation
Improvements Reduce Fecal Contamination of Water, Hands, Food, Soil, and Flies? Evidence from a Cluster-Randomized Controlled Trial in Rural Bangladesh. Environ. Sci. Technol. 52(21), 12089–12097.

41. Ezbakhe F, Perez-Foguet A. Multi-Criteria Decision Analysis Under Uncertainty: Two Approaches to Incorporating Data Uncertainty into Water, Sanitation and Hygiene Planning. Water Resour Manag. 2018;32(15):5169–82.

42. Fancony C, Soares A, Lavinha J, Barros H, Brito M. Efficacy of Nutrition and WASH/Malaria Educational Community-Based Interventions in Reducing Anemia in Preschool Children from Bengo, Angola: Study Protocol of a Randomized Controlled Trial. Int J Env Res Pub He. 2019;16(3):466.

43. Forget G, Gagnon P, Sanchez WA, Dutka BJ. Overview of methods and results of the eight country International Development Research Centre (IDRC) WaterTox project. Environ Toxicol. 2000;15(4):264–76.

44. Fry LM, Mihelcic JR, Watkins DW. Water and nonwater-related challenges of achieving global sanitation coverage. Environ Sci Technol. 2008;42(12):4298–304.

45. Galiani S, Gertler P, Schargrodsky E. Water for life: The impact of the privatization of water services on child mortality. J Polit Econ. 2005;113(1):83–120.

46. Garcia PA. Water, society and environment in the history of one Mexican city. Environ Urban. 2006;18(1):129-40.

47. Garn JV, Brumback BA, Drews-Botsch CD, Lash TL, Kramer MR, Freeman MC. Estimating the Effect of School Water, Sanitation, and Hygiene Improvements on Pupil Health Outcomes. EPIDEMIOLOGY. 2016;27(5):752–60.

48. Goh KL, Chan WK, Shiota S, Yamaoka Y. Epidemiology of Helicobacter pylori Infection Public Health Implications Helicobacter. 2011;16:1-9.

49. Guerrini A, Romano G, Ferretti S, Fibbi D, Daddi D. A Performance Measurement Tool
Leading Wastewater Treatment Plants toward Economic Efficiency and Sustainability. Sustainability. 2016;8(12):1250.

50. Hacker ME, Kaminsky JA. Cultural preferences for the methods and motivation of sanitation infrastructure development. J Water Sanit Hyg De. 2017;7(3):407-15.

51. Hall NL. Challenges of WASH in remote Australian Indigenous communities. J Water Sanit Hyg De. 2019;9(3):429-37.

52. Hoque BA, Hallman K, Levy J, Bouis H, Ali N, Khan F, Khanam S, Kabir M, Hossain S, Alam MS. Rural drinking water at supply and household levels: Quality and management. Int J Hyg Envir Heal. 2006;209(5):451-60.

53. Hsan K, Naher S, Griffiths MD, Shamol HH, Rajman MA. Factors associated with the practice of water, sanitation, and hygiene (WASH) among the Rohingya refugees in Bangladesh. J Water Sanit Hyg De. 2019;9(4):794-800.

54. Humphrey JH, Mbuya MNN, Ntozini R, Moulton LH, Stoltzfus RJ, Tavengwa NV, Mutasa K, Majo F, Mutasa B, Mangwadu G, Chasokela CM, Chigumira A, Chasekwa B, Smith LE, Tielsch JM, Jones AD, Manges AR, Maluccio JA, Prendergast AJ. Independent and combined effects of improved water, sanitation, and hygiene, and improved complementary feeding, on child stunting and anaemia in rural Zimbabwe: a cluster-randomised trial. Lancet Glob Health. 2019;7(1):E132-47.

55. Husseini M, Darboe MK, Moore SE, Nabwera HM, Prentice AM. Thresholds of socio-economic and environmental conditions necessary to escape from childhood malnutrition: a natural experiment in rural Gambia. BMC Med. 2018;16:199.

56. Imada KS, de Araujo TS, Muniz PT, de Padua VL. Socioeconomic, hygienic, and sanitation factors in reducing diarrhea in the Amazon. Rev Saude Publ. 2016;55:77.

57. Iribarnegaray MA, Seghezzo L. Governance, Sustainability and Decision Making in Water and Sanitation Management Systems. Sustainability. 2012;4(11):2922-45.
58. Johannessen A, Wamsler C. What does resilience mean for urban water services? Ecol Soc. 2017;22(1):1.

59. Johri M, Sylvestre MP, Kone GK, Chandra D, Subramanian SV. Effects of improved drinking water quality on early childhood growth in rural Uttar Pradesh, India: A propensity-score analysis. PLOS ONE. 2019;14(1):e0209054.

60. Jones SA, Silva C. A practical method to evaluate the sustainability of rural water and sanitation infrastructure systems in developing countries. Desalination. 2009;248(1-3):500–9.

61. Joseph K. Stakeholder participation for sustainable waste management. Habitat Int. 2006;30(4):863–71.

62. Kaminsky JA. Culturally appropriate organization of water and sewerage projects built through public private partnerships. PLOS ONE. 2017;12(12):e0188905.

63. Kim H, Son J, Lee S, Koop S, van Leeuwen K, Choi YJ, Park J. 2018. Assessing Urban Water Management Sustainability of a Megacity: Case Study of Seoul, South Korea. Water 10(6), 682.

64. Kirshen P, Aytur S, Hecht J, Walker A, Burdick D, Jones S, Fennessey N, Bourdeau R, Mather L. Integrated urban water management applied to adaptation to climate change. Urban Climate. 2018;24:247–63.

65. Kwami CS, Godfrey S, Gavilan H, Lakhanpaul M, Parikh P. Water, Sanitation, and Hygiene: Linkages with Stunting in Rural Ethiopia. Int J Env Res Pub He. 2019;16(20):3793.

66. Lauer JM, Duggan CP, Ausman LM, Griffiths JK, Webb P, Bashaasha B, Agaba E, Turyashemererwa FM, Ghosh S. Unsafe Drinking Water Is Associated with Environmental Enteric Dysfunction and Poor Growth Outcomes in Young Children in Rural Southwestern Uganda. AM J TROP MED HYG. 2018;99(6):1606–12.
67. Li J, Chen C. 2017. CiteSpace: Text Mining and Visualization in Scientific Literature (Second Edition); Capital University of Economics and Business Press: Beijing, BJ, China.

68. Liu W, Wang J, Li C, Chen B, Sun Y. Using Bibliometric Analysis to Understand the Recent Progress in Agroecosystem Services Research. Ecol Econ. 2019;156:293–305.

69. Mallow M, Gary L, Jeng T, Bongomin B, Aschkenasy MT, Wallis P, Cranmer HH, Debasu E, Levine AC. WASH activities at two Ebola treatment units in Sierra Leone. PLOS ONE. 2018;13(5):e0198235.

70. Mara D, Drangert JO, Anh NV, Tonderski A, Gulyas H, Tonderski K. Selection of sustainable sanitation arrangements. Water Policy. 2007;9(3):305–18.

71. McKee M, Balabanova D, Akingbade K, Pomerleau J, Stickley A, Rose R, Haerpfer C. Access to water in the countries of the former Soviet Union. Public Health. 2006;120(4):364–72.

72. Mertens TE, Jaffar S, Fernando MA, Cousens SN, Feachem RG. Excreta Disposal Behavior and Latrine Ownership in Relation to The Risk of Childhood Diarrhea in Sri-Lanka. Int J Epidemiol. 1992;21(6):1157–64.

73. MFA UN. 2015. Report on China's Implementation of the Millennium Development Goals (2000–2015), Beijing.

74. Moe CL, Sobsey MD, Samsa GP, Mesolo V. Bacterial Indicators of Risk of Diarrheal Disease from Drinking-Water in The Philippines. B World Health Organ. 1991;69(3):305-17.

75. Naik KS, Stenstrom MK. Evidence of the influence of wastewater treatment on improved public health. Water Sci Technol. 2012;66(3):644–52.

76. Nakagiri A, Niwagaba CB, Nyenge PM, Kulabako RK, Tumuahirwe JB, Kansiime F. Assessing ambient and internal environmental conditions of pit latrines in urban
slums of Kampala, Uganda: effect on performance. J Water Sanit Hyg De. 2017;7(1):92–101.

77. Ngasala TM, Masten SJ, Phanikumar MS. Impact of domestic wells and hydrogeologic setting on water quality in peri-urban Dar es Salaam. Tanzania Sci Total Environ. 2019;686:1238–50.

78. Null C, Stewart CP, Pickering AJ, Dentz HN, Arnold BF, Arnold CD, Benjamin-Chung J, Clasen T, Dewey KG, Fernald LCH, Hubbard AE, Kariger P, Lin A, Luby SP, Mertens A, Njenga SM, Nyambane G, Ram PK, Colford JM. Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: a cluster-randomised controlled trial. Lancet Glob Health. 2018;6(3):E316–29.

79. Nurgalieva ZZ, Malaty HM, Graham DY, Almuchambetova R, Machmudova A, Kapsultanova D, Osato MS, Hollinger FB, Zhangabylov A. Helicobacter pylori infection in Kazakhstan: Effect of water source and household hygiene. Am J Trop Med Hyg. 2002;67(2):201–6.

80. Oderda G. Transmission of Helicobacter pylori infection. Can J Gastroenterol. 1999;13(7):595–7.

81. Oluyege JO, Dada AC, Odeyemi AT. Incidence of multiple antibiotic resistant Gram-negative bacteria isolated from surface and underground water sources in south western region of Nigeria. Water Sci Technol. 2009;59(10):1929–36.

82. Oswald WE, Stewart AEP, KramerTekola MR, Endeshaw T, Zerihun M, Melak B, Sata E, Gessese D, Teferi T, Tadesse Z, Guadie B, King JD, Emerson PM, Callahan EK, Flanders D, Moec CL, Clasen TF. Active trachoma and community use of sanitation. Ethiopia B World Health Organ. 2017;95(4):250–60.

83. Pickering AJ, Null C, Winch P, Mangwadu G, Arnold BF, Prendergast A, Njenga SM, Rahman M, Ntozini R, Benjamin-Chung J, Stewart CP, Huda TMN, Moulton LH, Colford
JM, Luby SP, Humphrey JH. The WASH Benefits and SHINE trials: interpretation of WASH intervention effects on linear growth and diarrhea. Lancet Glob Health. 2019;7(8):E1139-46.

84. Sansom K. Government engagement with non-state providers of water and sanitation services. Public Admin Develop. 2006;26(3):207-17.

85. Sastry N. Community characteristics, individual and household attributes, and child survival in Brazil. Demography. 1996;33(2):211-29.

86. Saxton J, Rath S, Nair N, Gope R, Mahapatra R, Tripathy P, Prost A. Handwashing, sanitation and family planning practices are the strongest underlying determinants of child stunting in rural indigenous communities of Jharkhand and Odisha, Eastern India: a cross-sectional study. Matern Child Nutr. 2016;12(4):869-84.

87. Schmitt F. Sulfate Reduction in Sewer Sediments. Water Sci Technol. 1992;25(8):83-90.

88. Shiffrin RM, Börner K. 2004. Mapping knowledge domains. Proc. Nat. Acad. Sci. U.S.A. 101, 5183-5185.

89. Song J, Zhang H, Dong W. A review of emerging trends in global PPP research: Analysis and visualization. Scientometrics. 2016;107:1111-47.

90. Speer J. The right to infrastructure: a struggle for sanitation in Fresno, California homeless encampments. Urban Geogr. 2016;37(7):1049-69.

91. Stephensen CB. Burden of infection on growth failure. J Nutr. 1999;129(2):534S-538S.

92. Sun Y, Wu S, Gong G. Trends of research on polycyclic aromatic hydrocarbons in food: A 20-year perspective from 1997 to 2017. Trends Food Sci Technol. 2019;83:86-98.

93. Tulloch J, Richards L. Childhood Diarrhea and Acute Respiratory-Infections in
94. Ulukanligil M, Seyrek A. Demographic and parasitic infection status of schoolchildren and sanitary conditions of schools in Sanliurfa, Turkey. BMC Public Health. 2003;3:29.

95. UNICEF, WHO. Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment. New York: UNICEF; 2015.

96. UNICEF/WHO. Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines. Geneva: World Health Organization; 2017.

97. Vasquez WF, Alicea-Planas J. Unbundling household preferences for improved sanitation: A choice experiment from an urban settlement in Nicaragua. J Environ Manage. 2018;218:477-85.

98. Vella V, Tomkins A, Nviku J, Marshall T. Determinants of Nutritional-Status in South-West Uganda. J Trop Pediatrics. 1995;41(2):89-98.

99. Wamuchiru E. Thinking through ALMOLIN: the community bio-centre approach in water and sewerage service provision in Nairobi's informal settlements. J Environ Plann Man. 2018;61(12):2166-85.

100. Wang ZH, Zhao YD, Wang B. A bibliometric analysis of climate change adaptation based on massive research literature data. J Clean Prod. 2018;199:1072-82.

101. Wayland J. Constraints on foreign aid effectiveness in the water, sanitation, and hygiene (WaSH) sector. J Water Sanit Hyg De. 2018;8(1):44-52.

102. Whitley L, Hutchings P, Cooper S, Parker A, Kebede A, Joseph S, Butterworth J, Van Koppen B, Mulejaa A. A framework for targeting water, sanitation and hygiene interventions in pastoralist populations in the Afar region of Ethiopia. Int J Hyg Envir Heal. 2019;222(8):1133-44.

103. WHO. (2019): .

104. WHO/UNICEF. (2019): Joint Monitoring Programme 2019 update report: Progress on
household drinking water, sanitation and hygiene:.

105. Xiao F, Li C, Sun J, Zhang L. Knowledge domain and emerging trends in organic photovoltaic technology: A scientometric review based on CiteSpace analysis. Front Chem. 2017;5:67.

106. Yu D, Xu C. Mapping research on carbon emissions trading: A co-citation analysis. Renew Sustain Energy Rev. 2017;74:1314–22.

107. Yu H, Wei YM, Tang BJ, Mi ZF, Pan SY. Assessment on the research trend of low-carbon energy technology investment: A bibliometric analysis. Appl Energ. 2016;184:960–70.

108. Zhong WJ, Li J, Yang XJ. The Research of Co-word Analysis (3)-The Principle and Characteristics of the Co-Word Cluster Analysis. Journal of Information. 2008;7:118–20. (in Chinese).

109. Zhou W, Kou AQ, Chen J, Ding BQ. A retrospective analysis with bibliometric of energy security in 2000–2017. Energy Rep. 2018;4:724–32.

110. Zhou X, Zhao G. Global Liposome Research in the Period of 1995–2014: A Bibliometric Analysis. New York: Springer; 2015. pp. 231-48.

Figures
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.
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.
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 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.
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 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 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.
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.