Chapter 25
Nano-biotechnology for Water Sustainability: Bibliometric Analysis

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Abstract Nano-biotechnology is regarded as having high potential for solving challenges related to water, food and biodiversity. Of particular interest to sustainability is its promising ability to enhance the supply and security of water resources for human use. The chapter applies bibliometric analysis to describe the trends in the development of nano-biotechnology for issues related to water supply, contamination prevention and treatment. A co-occurrence analysis is used to identify the types of technologies emerging in this area, namely related to bioengineering, chemical engineering, microbiology and material sciences. The majority of the new knowledge comes from the USA, but researchers from China, South Korea, the Netherlands, India and Australia are also making their mark.

Keywords Technological innovation · Water supply · Water contamination · Water treatment · Research trends · Nano-biotechnology · Bibliometric

Introduction

Water is vital for life on our planet, but expanding population, industrialisation and industrial agriculture put immense pressure on this important resource. Taken for granted in developed countries, nations in the developing world are still struggling to provide clean and safe water. Security and scarcity are two major challenges. While the problems across the globe may vary, many regions face multiple changes in water supply and water quality that undermine its accessibility and safety, thereby destabilising human well-being.

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Access to clean and safe drinking water and sanitation is a human right and a prerequisite for adequate standards of living (UNESCO 2011). Yet 884 million people have limited drinking water and 2.6 billion people live without proper sanitation (UNESCO 2011). Although the quantity of water on Earth has been stable for millions of years, its quality has deteriorated progressively due to a combination of human demographic and activity factors (PWC 2012). Climate change coupled with degradation of the quality of surface and groundwater reserves exacerbates the already serious global and region-specific issues.

Technological solutions have always been compelling in assisting with water challenges, ranging from construction of dams, piping and drainage to desalination, filtering devices and wastewater treatment. According to PricewaterCooper (PWC 2012), R&D and innovation can generate solutions related to water production, including alternative sources from sea water and marginal quality water, reuse, intelligent consumption and optimised sanitation. In recent years, nano-biotechnology, a technological field combining nanotechnology and biotechnology solutions, is seen as a significant potential to solve water challenges across the globe and enhance the supply of clean water for human use (Diallo and Brinker 2011). Nano-biotechnology is the branch of nanotechnology that deals with biological and biochemical applications and uses (Venkatesh 2009), or in other words, it represents "the use of nano-science for specific biological applications" (Gazit 2007, p. 13). Research in nano-biotechnology (also referred to as nanobiology) developed in embryonic stage in the mid-2000s and is still in its infancy. A search of published papers in Scopus up to year 2013 generates only 9 entries pertaining uniquely to water sustainability and nano-biotechnology. This small number indicates that although nano-biotechnology is promising its overall impact is still negligible. The two areas from which nano-biotechnology emerged, namely nanotechnology and biotechnology, however have been going strongly for decades. Immediate and fast solutions related to water sustainability need to rely on the progress and advancement of knowledge made in these two individual classes of technologies.

How can these new technologies contribute to dealing with water security and scarcity? What is the scientific evidence that they can offer useful and workable solutions? Diallo and Brinker (2011) point out the potential of nanotechnology solutions for safe environment and water resources in efficiently supplying potable water for human use and clean water for agricultural and industrial applications. Similarly, many argue the potential biotechnology holds for biotreatment and bioremediation to control water quality, decontaminate wastewaters, and monitor and prevent pollution (e.g. Zechendorf 1999; Gommen and Verstraete 2002). Both nanotechnology and biotechnology can be used in water treatment, for example nanofiltration membranes for producing potable water from brackish groundwater (Hillie and Hlophe 2007) or biofilm bioreactors for wastewater treatment (Van Loosdrecht and Heijnen 1993).

Using a bibliometric approach, we analyse in this chapter how active the nanotechnology and biotechnology research field is in relation to water. We describe this as nano-biotechnology. While several bibliometric studies have examined nanotechnology and biotechnology through patent or publication activities (Meyer 2001; Marinova and McAleer 2003; Schummer 2004; Leydesdorff and Rafols 2009; Rafols and Meyer 2010; Thursby and Thursby 2011), not much is known about issues related to water sustainability. Despite their promising potential in relation to water, the links between nano- and biotechnology are yet to be firmly established. In order to address water sustainability priorities in the time being, we need to understand the individual trends within the two individual technology groups, and this is where a bibliometric analysis of nano-biotechnology can be very informative. It is also important to see how researchers connect with each other in collaborative efforts to address the water challenges.

Hence, we conduct a study of nano-biotechnology research on water sustainability issues with the aim to present the global trends in the area and give direction for future quantitative studies. We firstly screen publications indexed by the Web of Science (Thompson Reuters ISI) and Scopus to describe the general trends in nano-biotechnology research in the past decades. This allows for the more appropriate database for further analysis to be selected. The methods, data used and scope of the analyses are presented in "Methodology and Data" section. "Results and Discussion" section presents the results from the bibliometric investigation based on co-occurrence analyses. We conclude the study with a discussion and further research directions in "Conclusion" section

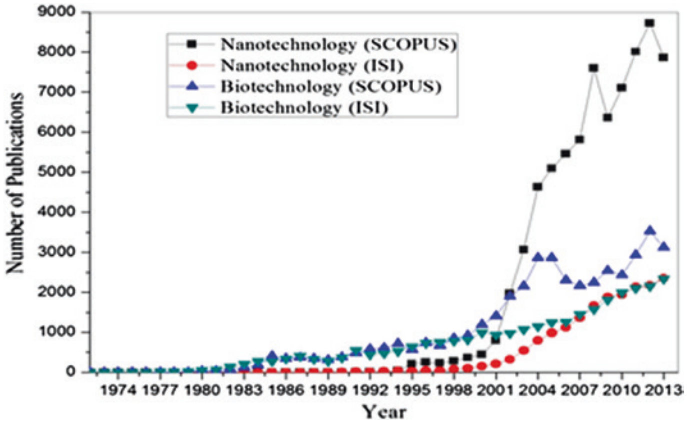
Methodology and Data

Bibliometrics aims to quantitatively analyse the publications covered in scientific sources (De Bellis 2009). Described as the foundation for the science of science (De Solla Price 1963), it applies the methods of science to examine scientific output. The two most commonly used bibliographic databases of academic work are Web of Science established by the Institute for Scientific Information (ISI) and more recently acquired by Thompson Reuters, and Scopus owned and operated by Elsevier.

Data Collection

Choice of Bibliographic Database

In order to determine which of the two databases has a better coverage and is better suited for this study, we firstly conduct queries, using nanotechnology and biotechnology as search words in the total number of publications in Scopus and Web of Science. We search for publications which contain these two words separately in either their titles or lists of keywords. The specific journal databases that we use for the search are Science Citation Index and Social Science Citation Index in Web of Science and Physical Sciences and Social Sciences and Humanities in Scopus (see Fig. 25.1).



(data accessed July 2014)

Fig. 25.1 Number of publications per year with "nanotechnology" and "biotechnology" in the title or keywords

The total numbers of publications in Scopus and Web of Science are 74,361 and 42,375 for nanotechnology and 18,038 and 29,482 for biotechnology. The peak numbers for nanotechnology publications are 8719 for Scopus in 2012 and 2351 for ISI in 2013, while for biotechnology they are 3529 for Scopus in 2012 and 2333 for ISI in 2013. The historical trends in the two databases show that biotechnology research preceded nanotechnology—the first two biotechnology publications appeared in 1972 in Web of Science, while the first nanotechnology publication was registered in 1978 in Scopus. Although there might be earlier publications in both areas in other bibliographic databases, overall research in biotechnology started prior to that in nanotechnology.

Given the broader coverage of publications by Scopus on both technologies, this bibliographic database is chosen for further analysis and we believe it represents well the progress made in the respective fields. We are particularly interested in research and advancement of knowledge through these two types of technologies in relation to water sustainability. This requires narrowing down the publication fields using specific keywords.

Keywords and Dataset

Growing demands for water and increasing agricultural and industrial pollution continuously intensify the stress on surface and groundwater resources and on supply systems. The three main issues related to water sustainability are supply, contamination and treatment (Gray 2010). These are the three retrieval keywords that we used to examine the research progress made in nano-biotechnology in relation to the sustainability of water resources. Hence, the keyword combinations

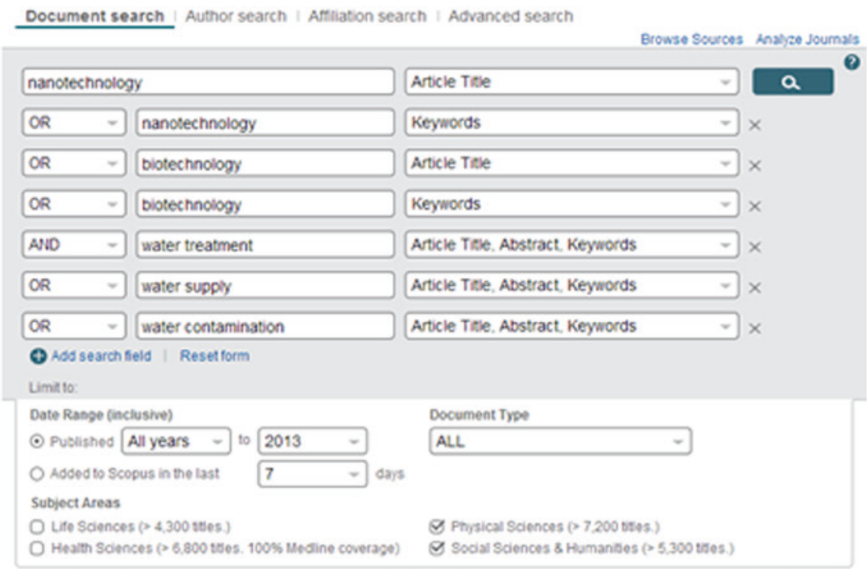


Fig. 25.2 Keywords combinations used in Scopus

are: nanotechnology and water supply, nanotechnology and water contamination, nanotechnology and water treatment, biotechnology and water supply, biotechnology and water contamination and biotechnology and water treatment (see Fig. 25.2). In order to ensure data integrity, we manually cleaned the obtained data set by deleting any repeated publications to avoid double counting and removing all documents for which author(s) names were not available.

Data Analysis

Co-occurrence analysis is applied to identify research hot points and connections in the field of nano-biotechnology for water sustainability. The linguistic term "co-occurrence" refers to analysis of related words (Kroeger 2005), and in this case, the mutual occurrence of two units in the same metadata field, e.g. "climate change" or "Newman and Kenworthy". This type of bibliometric analysis has been previously used to describe research development, including to explore concept networks and reveal research themes (Courtial 1994; Ding et al. 2001; Ronda-Pupo and Guerras-Martin 2010; Hu et al. 2013). One of the first studies applying a co-word analysis was conducted by Rip and Courtial (1984) who mapped developments in biotechnology.

This study is the first to specifically examine water-related issues. The co-occurrence method here comprises two sections, namely co-word and co-authorship analyses, and is employed to reveal on which topics nano-biotechnology researchers focussed their studies on water sustainability and how well they connected with one another. Bibexcel is used for the bibliometric analysis, and Pajek (a software for large networks representation) combined with ArcMap is applied to visualise the networks of dominant topics and co-authorship.[1]

Co-word Analysis

The co-word analysis reveals the research hot points. It is based on the keywords appearing in the lists provided by the authors assuming that they were properly scrutinised and describe the content well. Extended keywords provided by indexers are excluded as they do not always indicate exactly what the authors have done and may lead to double counts. The higher the co-occurrence frequency of two words, the closer relationship they have.

The co-word data set is built by cleaning meaningless publications according to two criteria: (1) when the extracted keywords from the list overlap with the ones used as searching criteria to identify the publication (see Fig. 25.2); and (2) when the keywords from the list are not representatives of a well-defined topic (e.g. being too general, such as "water" or "modelling"). For example, the frequency distribution extracted 114 "nanotechnology" and 16 "modelling" from the keywords lists of all publications. These publications are excluded from the sub-data set because "nanotechnology" is a keyword we used in searching for publications and "modelling" does not reveal any specific subject domain. We use words which appear more than ten times in the co-occurrence matrix and co-words which appeared more than five times in the matrix to build the descriptive networks. This avoids having too many vectors and arcs in the graphic representation which might make the visualisation unclear.

Co-authorship Analysis

The co-authorship analytical method is a good way to discover social networks, scholarly collaborations, scientific evolutions and the research performance of various fields (Barabasi et al. 2002; Liu et al. 2005; Abbasi et al. 2011). We constructed global co-authorship networks for nano-biotechnology research in water sustainability to reveal the scholarly connections among leading authors around the world. To visually present the global connections through the authors' networks, they are graphed onto a world map according to the places with which the researchers affiliate.

[1]Original data and routine files are available from the authors.

Similar rules as for the co-word analysis are applied for the data cleaning in this part. That is, all authors are firstly counted up from the data set of the names appearing in the publications. Then, we conduct frequency distribution analyses in the order of the list. We use five as the minimum number of times an author's name has to appear in the documents to establish a co-occurrence matrix. However, all co-authors are included in the co-occurrence matrix because of the higher complexity in authorships than in keyword use. According to the rules we adopted, the matrix of co-authors is smaller than that of co-words, which is easier and clearer to visualise in the networks. The nodes in the networks represent authors, and the line between two nodes (authors) denotes that they co-authored a publication. The more lines a node has, the more collaborations that author has with others.

Although this way presents well the most productive authors and collaborations between researchers, some links may be missing because of the emphasis on larger number of publications. For example, some authors may have strong relationships with others who are not included in the networks because of their publications' number not matching the rules, e.g. author A and author B are both in the networks and they have two collaborations; author A, however, has four collaborations with author C who is not in the networks because of having only four documents in the defined contexts. This limitation similarly occurs in the co-word networks; however, it does not create significant effects on revealing the relationships between leading scientists as all authors in the networks have more than 5 publications.

Results and Discussion

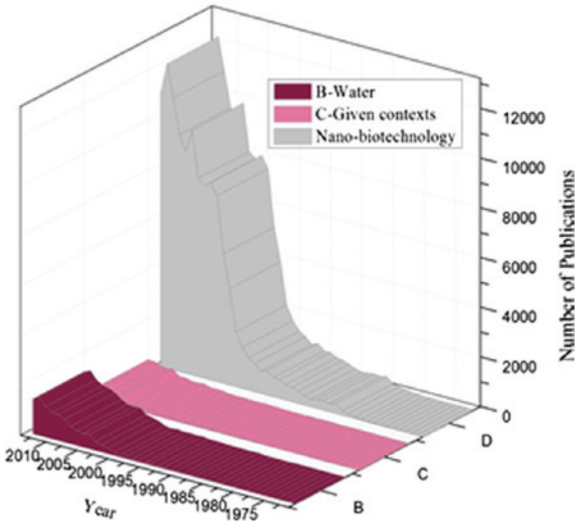
A general description of the trends is first provided. Following this, we present the results from the two co-occurrence analyses.

Research Trends in Nano-biotechnology for Water Sustainability

A total of 4126 publications in nano-biotechnology research were found in Scopus in the contexts of water supply, contamination and treatment, which account for 36 % of all nano-biotechnology research on broader water issues (11,469) and 3.5 % of all nano-biotechnological studies (Fig. 25.3).

The earliest study on nano-biotechnology addressing water issues was published in 1971. Since then, the publication rate grew steadily until the first rise in 1985, following which it continued to increase gradually and later on witnessed a dramatic jump in 2000. A similar trend happened in research on water

Fig. 25.3 Comparison between "nano-biotechnology" in total water research and within sustainability context



sustainability problems (namely supply, treatment and contamination). After the first study on water sustainability problems in 1981, there was a steady growth reaching a peak of 548 in 2013. The number of publications which apply nano-biotechnology to water supply, contamination and treatment rose dramatically after 2001. Afterwards, it experienced a period of seven years (2002–2008) of relatively stable development prior to the next soar between 2009 and 2013.

Co-occurrence Analysis

After 43 documents were removed from the data set during data clearing, the final number of publications for the co-occurrence analysis is 4083. The results from the two co-occurrence analyses based on these publications are presented below.

Co-word Analysis

Overall, 131 key vertices and 1186 lines constitute the network of co-words for all publications. Lines with a value of less than two were removed from the data set to make the visualisation of the networks clearer. Using a manual semantic analysis, the keywords were firstly classified into three groups, namely water treatment—yellow nodes, water supply—red nodes, and water contamination—green nodes (see Fig. 25.4). This is in line with the keywords used originally to identify the publications combined with the keywords in the titles and abstracts of the articles in which they appeared.

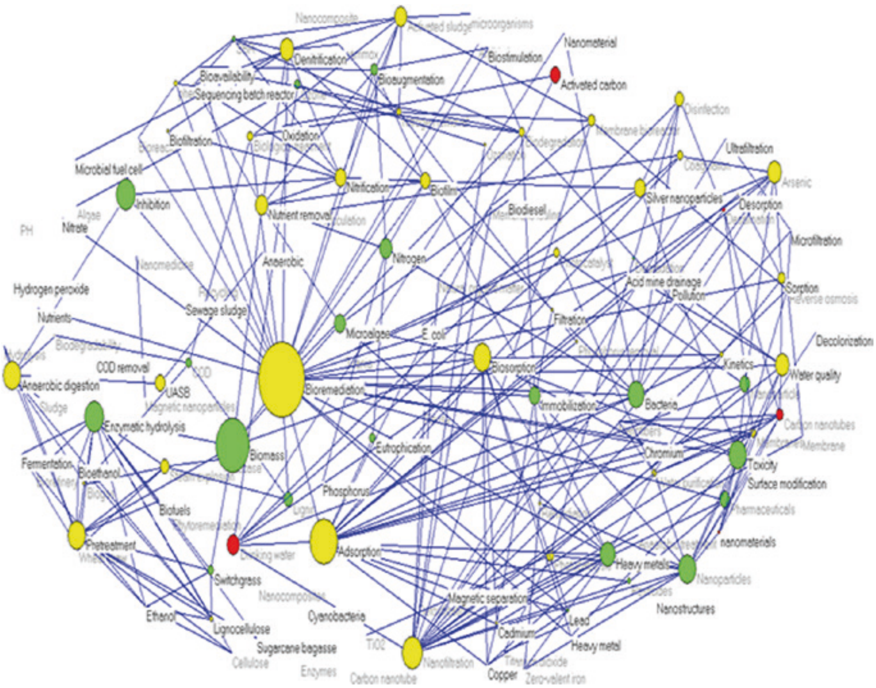


Fig. 25.4 Co-word networks by topics relevant to water sustainability research

Figure 25.4 shows that bioremediation, biomass and drinking water are the three main topics attracting research attention in water treatment, water contamination and water supply, respectively. Water treatment studies dominate the domain of nano-biotechnology research on water sustainability. This indicates that bioremediation is the main way researchers approach the treatment of wastewater. Biomass is the most popular keyword in water contamination studies. This is easy to understand as water treatments are mainly directed towards controlling and dealing with water contaminations, while research on pollution is geared towards managing biomass and other pollutants such as heavy metals, enzymatic hydrolysis, bacteria and toxicity surface modification. Research in nano-biotechnology for water supply, however, is less focused than the other two areas as far as the domain defined by the keywords of this study is concerned. The central topics of water supply are on drinking water and activated carbon related to material sciences.

In order to compare the topics and observe research distribution by main subjects, we use the following classification of the publications' keywords (see Fig. 25.5): biophysics—blue nodes, bioengineering—orange nodes, biomedicine—white nodes, biochemistry—pink nodes, microbiology—red nodes, material sciences—green nodes, and chemical engineering—yellow nodes. This is also diagrammed in the pie chart on Fig. 25.6.

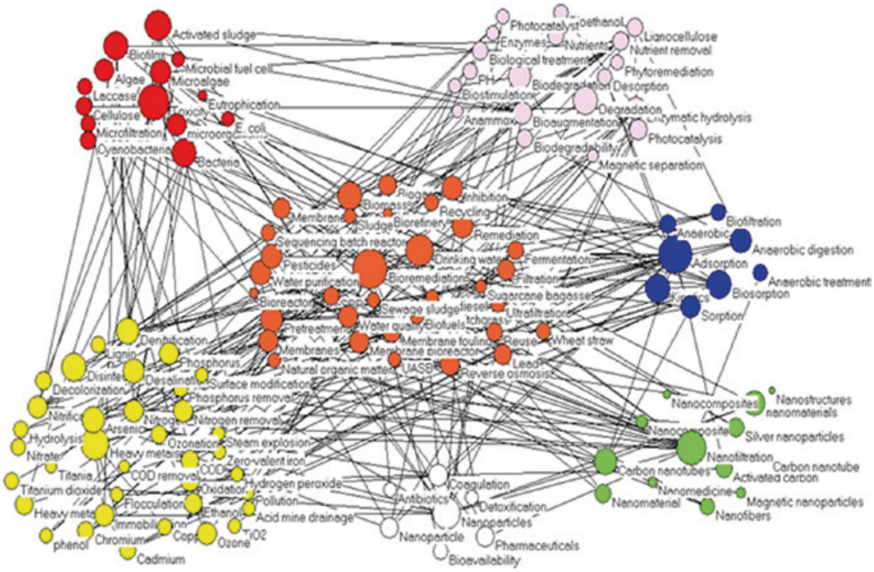
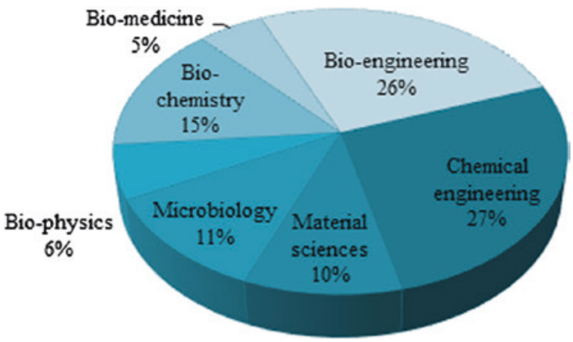


Fig. 25.5 Co-word networks by keyword subjects in water sustainability research

Fig. 25.6 Composition of studies of nano-biotechnology on water sustainability by subject



Similar numbers of studies have been published in bioengineering and chemical engineering in the field of nano-biotechnology for water treatment, supply and contamination. They also have strong connections with the other topics. Microbiology and material sciences have again similar but smaller contributions, while limited research has been conducted in biomedicine and biophysics. On the other hand, biophysics and biomedicine have weak connections in the whole network.

Co-authorship Analysis

Based on the 4083 articles, 16,496 authors in total conducted research on either nanotechnology or biotechnology related to water-specific issues. After data cleaning for publications without stated authors and elimination of authors whose names appear less than five times in the documents, the 97 most productive authors were identified for inclusion in the co-authorship analysis. The networks are shown in Fig. 25.7 and are classified in 16 groups according to the degree of the connections between the authors. They are further organised into two classes (see Fig. 25.7): high collaborations (Class One) and low collaborations (Class Two).

The collaborations in Class One are more than those in Class Two meaning that the relationships between authors are closer in Class One. There is a gap between the two classes. Choi, H. is the only author from Class Two linked to Class One by publications (collaboration between Choi, H. and Kim, Y.). In Class One, the connections between authors are closer than those in Class Two. To further assess the relationships between the most active authors, we removed those whose names occurred together with others in the documents less than 6 times and generated new networks (see Fig. 25.8).

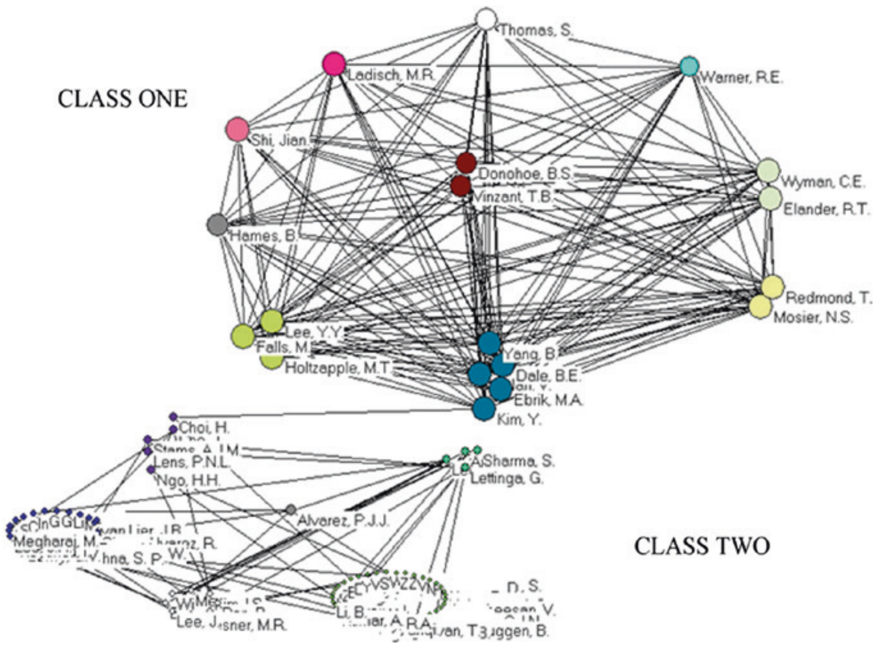


Fig. 25.7 Co-authorships grouped by degrees of connections

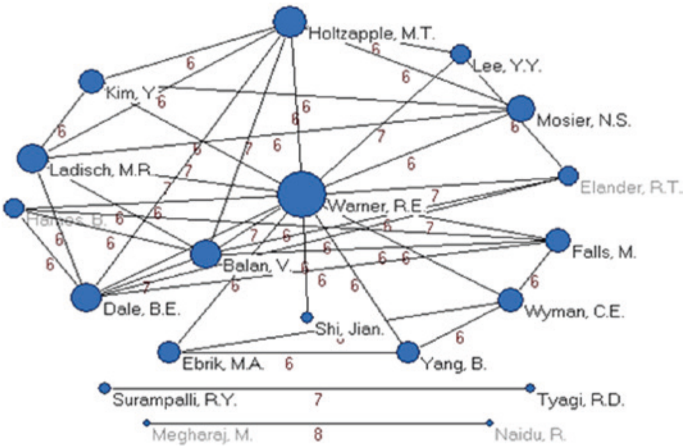


Fig. 25.8 Closely connected authors' networks

Figure 25.8 shows the close relationships between the active authors with nodes representing authors and a line between two nodes meaning that the respective two authors have joint publications. The values on the lines denote the number of publications the authors have co-authored. Warner, R.E. has the most relations with others than any other active author in the networks. Although Megharaj, M. and Naidu, R. have co-authored the most, neither of them has collaborations with other researchers. Similarly, Surampalli, R.Y. and Tyagi, R.D have high numbers of publications (11 and 10, respectively) and are, respectively, the second and the third most productive authors in the data set; however, they have less collaborations with others.

Within the co-authorship networks, it is also interesting how authors are linked to each other among the various countries as this reveals the global collaboration picture in nano-biotechnology. The locations of the 97 authors were determined from the affiliations listed in their publications. For authors with multiple affiliations, the telephone number and mailing address (if applicable) were used to determine the country in which they are based or, if these do not provide a clearly indication, we used the first affiliation as the location base. The spatial distribution of the linked authors is presented in Fig. 25.9. It shows the various productive authors and their closer relations with others who have a similar status in terms of publication numbers and with whom they have collaborated.

At a regional scale, the USA is the leading country in nano-biotechnology studies on water sustainability. The US authors have the majority of collaborations in this field, followed by China, South Korea, the Netherlands, India and Australia. Notwithstanding this, the collaborations conducted by the US researchers were mostly within their own country (see Fig. 25.10).

The main collaborating organisations are Michigan State University, National Renewable Energy Laboratory, University of California (Riverside), Texas A&M University, Auburn University, Ceres Inc. in Thousand Oaks and Purdue

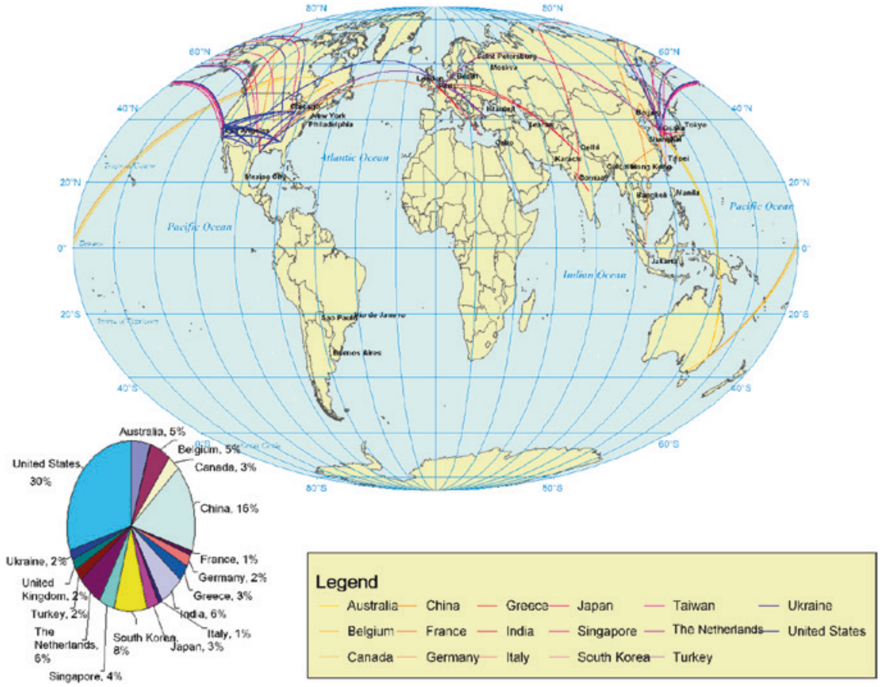


Fig. 25.9 The global spatial networks of linked authors

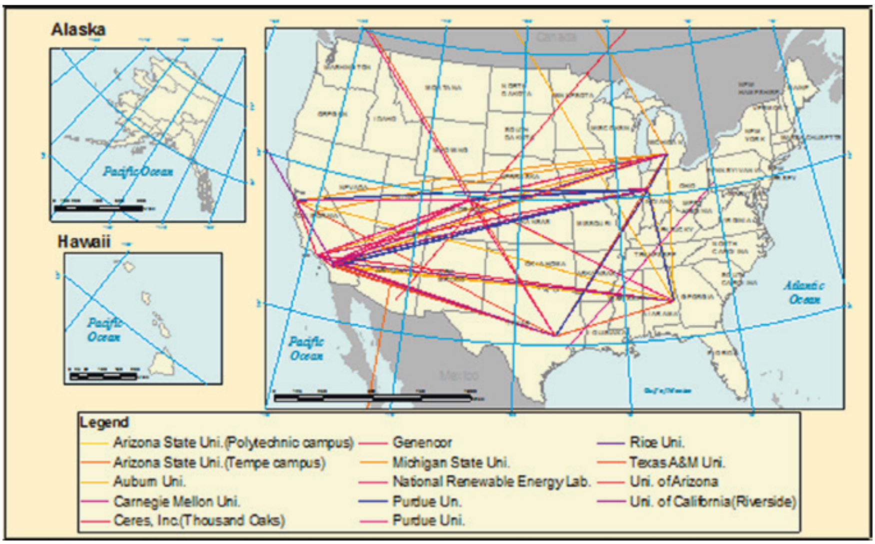


Fig. 25.10 Co-authorship network distributions in the USA

University in the USA, with the University of California (Riverside) being the most involved organisation (accounting for 18 % of the total US authors in the data set). On an individual level, Warner, R.E. from Genencor participated in the largest number of collaborations. External connections were built by the University of California (Riverside), Texas A&M University, Auburn University and Michigan State University (the stretching left purple lines, middle red lines and right light yellow lines in Fig. 25.10).

Conclusion

In the last three decades, the world community recognised water as a global issue which needs to be approached on a planetary scale and that negligence and ignorance could lead to problems threatening human survival (PWC 2012). Progress made in research related to nano-biotechnology represents humanity's ability to respond to these global challenges.

The bibliometric analysis conducted in this study shows that the specialised nano-biotechnology field is yet too small to make a meaningful contribution towards addressing water challenges. More promising technological solutions are emerging from the broader combined nano-biotechnology field whose publication output is consistently growing. The most active publication areas relate to bioengineering, chemical engineering, microbiology and material sciences confirming that water sustainability is a truly interdisciplinary and transdisciplinary research field. Despite the relatively large number of very active researchers, the bulk of the new knowledge is generated within the USA. The contributions by researchers from China, South Korea, the Netherlands, India and Australia are also making their mark.

With continuing population growth and expansion in human activities, water supply, contamination and treatment are likely to remain highly active areas of technological endeavour. Research in nano-biotechnology will also remain important, but further internationalisation and concerted effort are required for society to be able to address the global water challenges and priorities.

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