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Water Utilities Challenges: A Bibliometric Analysis

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Abstract: The water utilities are under big pressure to guarantee water access to their customers with the right level of service and quality due to challenges such as climate change, aging infrastructure, water scarcity, and growing populations, which put pressure on their operations. The scientific community has worked intensively over the last years to propose solutions and alternatives for the utilities to improve their operation and management in order to overcome these challenges. This paper aims to review scientific contributions to this field. The result shows increasing awareness from the scientific community in this topic which translates into a growing number of publications since the beginning of the current century. This paper analyzes the evolution of the publications, identifies the main countries and institutions working in this field and their scientific relationships over time. It also identifies the main keywords in the literature, which are grouped into three main topics: water quality, water management, and water optimization. The development of smart technologies is accelerating the scientific production towards the topic of water optimization, which is acquiring more importance over the last years. Future trends of research are related to identifying specific challenges per country and the specific solutions proposed by the scientific community to address them and its feasibility to be applied in other places.

Keywords: urban water; water distribution network; water utility challenges; sustainability; bibliometric

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1. Introduction

The United Nations (UN) 2030 Agenda for sustainable development declares equitable access to safe drinking water as one of its goals [1]. Access to drinking water in urban areas is provided by water utilities, responsible for safe and reliable water convenience from the different sources to their customers, the end-users [2]. These kinds of utilities, extended worldwide, have been operating for more than 100 years [3]. The achievement of the UN 2030 goal by the different countries through their water drinking network operators, usually operating in monopoly [4], face some common challenges all over the world. These main challenges identified in the literature are the growing and increasing population to deliver water with the right level of service and quality [5], water scarcity [6], climate change [7,8], and aging infrastructure [9].

Water demand is expected to increase significantly in the coming years as a result of the growth of the world population. This increase will potentially lead to a water scarcity situation [10]. The World population is increasing mainly in places where water is less abundant, such as Sub-Saharan Africa, the Middle East, and Central Asia [11,12]. By 2050 it is expected that more than half of the total world population will habitat in places that will experience water shortage at least once a year [13].

Climatic change is responsible for extreme weather events such as long drought periods [14], flood risks [15], and changes in rainfall patterns [16]. All these events put additional pressure on the operation of the water utilities [17]. In addition to that, the average temperature of the Earth is increasing year after year and could grow up to 2 C by 2021 [18]. Previous studies have already found a relationship between a temperature increase and an increase in water consumption [19,20]. Lastly, seasonal temperature changes between winter and summer periods, which are becoming wider with climate change, have been identified to have a negative impact on the infrastructure and are one of the causes for water mains failure [21,22].

Water distribution networks' (WDN) aging infrastructure is another of the challenges the water operators have to deal with. Aging infrastructure is responsible for service disruption, potential entry doors for pollutants to the network, and revenue loss for the operator. There are many places and cities where water infrastructure was constructed a long time ago and is becoming old, deteriorated, and might not be able to meet future demand conditions. Some of the potable water transmission systems in Europe and the United States are more than 100 years old [23,24]. In North America, it is estimated that 28% of the mains are older than 50 years [25]. Traditionally, the age of pipes has been considered to be one of the major factors leading to a deterioration of WDN [26]. However, recent studies indicate that more parameters related to pipe attributes, location, and rehabilitation should also be considered when evaluating pipe conditions [9]. The last available edition of the American Water Works Association Water Industry report identifies renewal and replacement of aging infrastructure as the most pressing issue challenging American water utilities for the seventh consecutive year [27].

One of the main performance indicators used to evaluate WDN is non-revenue water (NWR), defined as the difference between the total amount of water entered into a system minus the revenue water or water billed to the users. NRW is the indicator recommended by the International Water Association [28] and their different components are widely studied and described in the literature [29]. In 2018, the total cost of NRW all over the world was quantified at USD 39 billion per year [30]. Water operators have traditionally fought against NRW using different techniques [31]. During the last years, smart solution and data analytics tools implemented within the water utilities have emerged as an efficient alternative to address and reduce NRW levels [32,33].

To the best of our knowledge, there are no previous bibliometric works in the literature related to the current challenges water utilities face to deliver potable water with the right level of service and quality, thus prompting the realization of this research. Previous related bibliometric analyses have been focused mainly on water footprint and water productivity [34,35] and work has only been found in relation to water utilities, which concentrates on the benchmarking, regulation, and level of service of the operators [36]. The situation is different for the wastewater industry, where more bibliometric analyses have been found on the Scopus database. These studies have been focused on wastewater management [37], wastewater treatment technologies [38,39], and industrial wastewater [40].

The aim of this document is to provide an overview and a detailed analysis of the evolution of global research and publications since the beginning of the current century over the challenges water utilities have to deal with to deliver potable water to the population they serve, and, at the same time, assuring environmental sustainability and long-term resources availability.

2. Materials and Methods

Bibliometrics is a part of scientometric which is extended to all scientific fields and applies statistical and mathematical methods to analyze scientific publications within specific field research [41].

The search engine used in this investigation was the Scopus database, considered as one of the main sources of peer-reviewed literature for bibliometric analysis [42], including a diversified wide of subjects.

The search was conducted using the fields TITLE, ABSTRACT, KEYWORDS to scientific publications related to the challenges water utilities are facing in their operation. The search was limited to the period from 2000 to 2020. All the output information was downloaded from the Scopus database and analyzed using Excel to determine publication trends, sources of information, institutions, countries, main keywords, and authors in this research field. Moreover, the information was also treated in the Vosviewer software, specially developed for these kinds of analysis [43], to locate clusters of countries, scientific committees, and keywords. Figure 1 shows the work methodology employed in this research. The search string introduced in the Scopus database is the following:

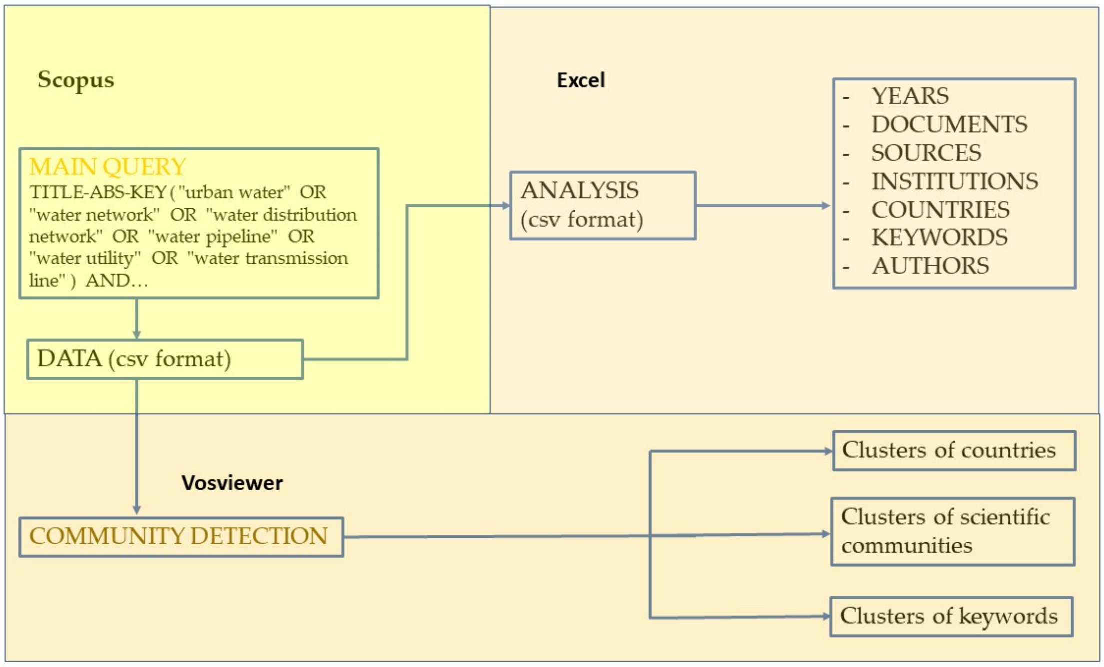

Figure 1. Methodology of work.

TITLE-ABS-KEY ("urban water" OR "water network" OR "water distribution network" OR "water pipeline" OR "water utility" OR "water transmission line") AND (TITLE-ABS-KEY ("non-revenue water" OR "non revenue water" OR "water loss" OR "leakage reduction" OR "leakage detection" OR "NRW" OR "pressure management" OR "water saving" OR "apparent losses" OR "physical losses") OR ("energy recovery" OR "energy consumption" OR "energy efficiency" OR "energy saving") OR ("customer care" OR "customer service") OR ("level of service") OR ("drought" OR "water scarcity") OR ("ageing workforce") OR ("water quality") OR ("ageing infrastructure" OR "asset management") OR ("increasing demand")).

3. Results and Discussion

The review consists of a bibliometric analysis of a sample of 9803 articles obtained from the Scopus database.

3.1. Number of Publications Per Year and Type

Since 2000, the number of papers has increased in an exponential way. The number of publications has grown year after year with some minor exceptions during 2001, 2006, and 2008. It is remarkable that 50% of the total number of publications in the last twenty years have been produced in the period between 2015 and 2020. This is in line with the results showed in the bibliometric analysis for wastewater management [38], where 40.59% of the total production shown by the Scopus database was concentrated in the period between 2012 and 2018.

The number of publications on this field of science per year is described in Figure 2.

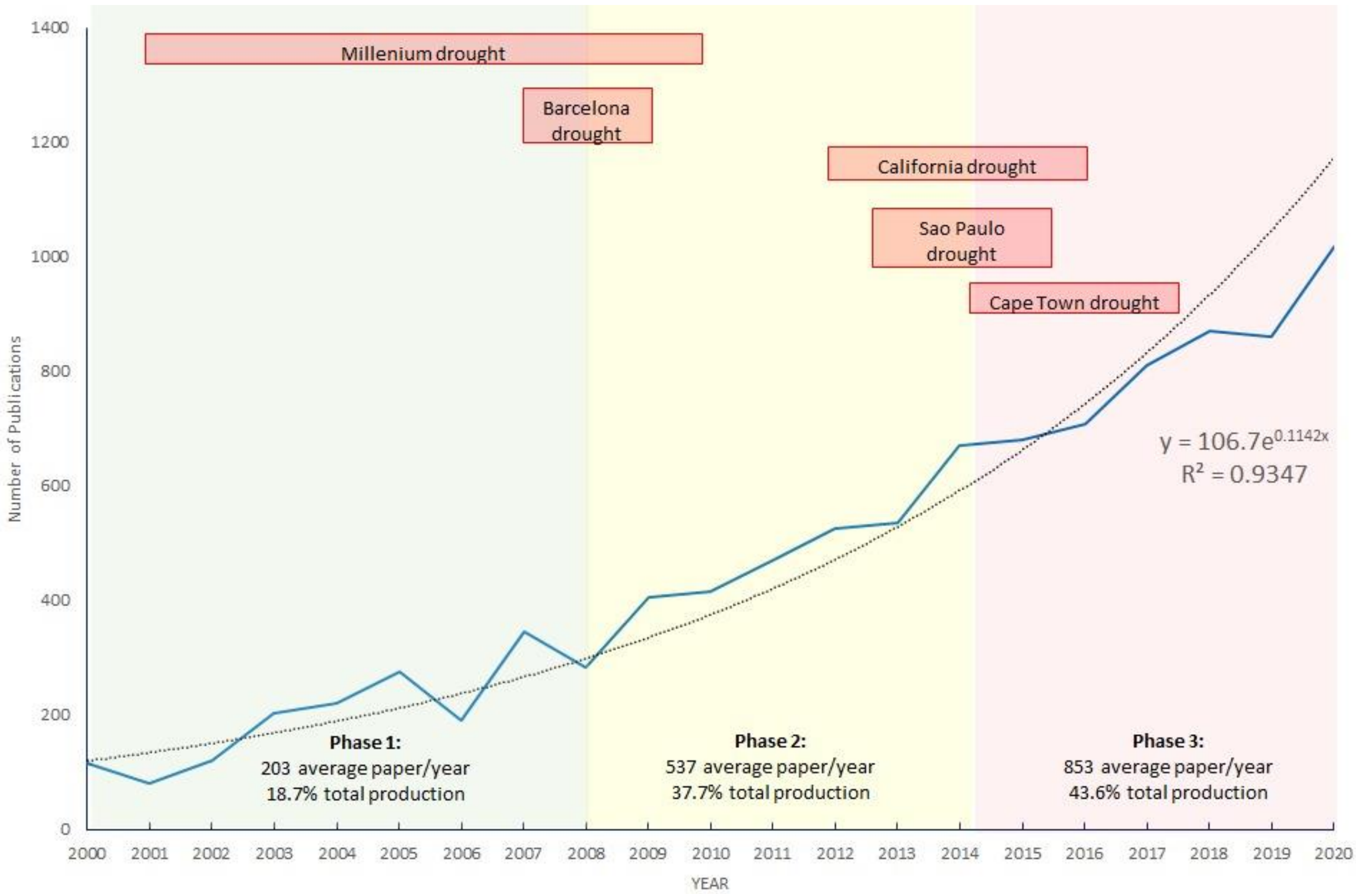

Figure 2. Yearly number of articles on water utilities challenges from 2000 to 2020.

Three different phases are identified in the graph. These phases have been selected according to two criteria: the percentual increment of scientific production compared to the previous year and the occurrence of the major events represented in the graph. During phase 1, from 2000 to 2008, the average production was 203 paper/year representing 18.7% of the total production in the period of study. In phase 2, from 2008 to 2013, the average number of publications per year was 537, contributing 37.7% of the total amount of publications. Eventually, during the last phase, from 2014 to 2020, the average was 853, 43.6%. Clearly shown is a growing tendency in each of the phases. The number of publications in 2021 is also expected to increase again. Despite not being included in this research, as of April 2021, there were already 421 publications on this science field on the Scopus database in 2021. If the same trend for the first four months of 2021 keeps till the end of the year, the total number of publications at the end of 2021 would be higher than the previous year, keeping with the same growing tendency described in the graph. The growing number of publications demonstrates increasing awareness in the scientific community towards the issues and challenges water utilities must deal with to provide potable water, which translates into a growing number of publications and scientific contributions.

One of the factors which could explain this increasing tendency over the last years is the exceptional drought events affecting largely populated areas that have occurred since the beginning of the century. Some of the biggest cities of the world have suffered long unprecedented drought and water shortage periods, which have had a huge impact not only on the water utilities operation and performance, but have also generated economic losses, disruption of social networks, and health damages [44]. In order of occurrence, the major droughts have been: Melbourne underwent a long millennium-heralded drought from 2001 to 2009 [45]; Barcelona suffered water scarcity from 2007 to 2008 when water had to be taken to the city from new distant water sources [46]; the California area experienced water scarcity from 2012 to 2016, being 2014 the most severe in the last 1200 years [47]; the Sao Paulo region had to apply water restrictions to near twenty million people between 2013 and 2015 [48]; Cape Town underwent a major drought from 2015 to 2018 [49] when the population started to talk about "Day Zero", the day when the city would run out of water [50]. These are the largest droughts that occurred since the beginning of the century, but not the only ones. In total, 79 droughts in large cities have been identified in the first twenty years of the current century [51]. Two main conclusions are obtained from this graph; exceptional drought events are happening more frequently in the last years and scientific publications are increasing as these events happen.

The type of publications has also been analyzed. Figure 3 shows the percentage of documents according to the type of publication. Most of the publications are articles in scientific journals (64% of the total) and conference papers (27%). The rest of the types of publications, reviews, book chapters, and conference reviews represent a small percentage of the total. The contribution to the total amount of other types of publications, such as books, editorials, and letters is negligible.

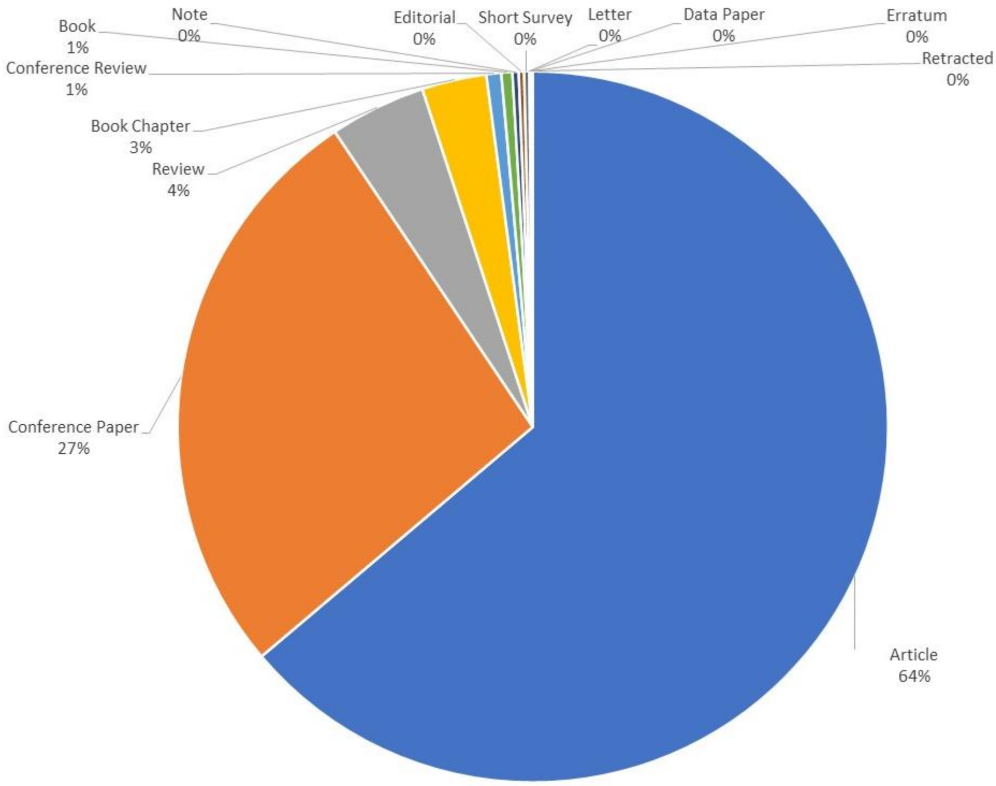

Figure 3. Publications type between 2000 and 2020 for challenges related to potable WDN.

3.2. Global Subject Category

The Scopus database shows a total of 28 subject areas for the publications on challenges associated with WDN. Figure 4 shows the subject category where documents have been published, according to the Scopus database, for the top ten subject areas. The main subjects in order of appearance are Environmental Science, Engineering, Social Sciences, Earth and Planetary Sciences, and Computer Sciences. The contribution for the rest of the subject areas is reduced.

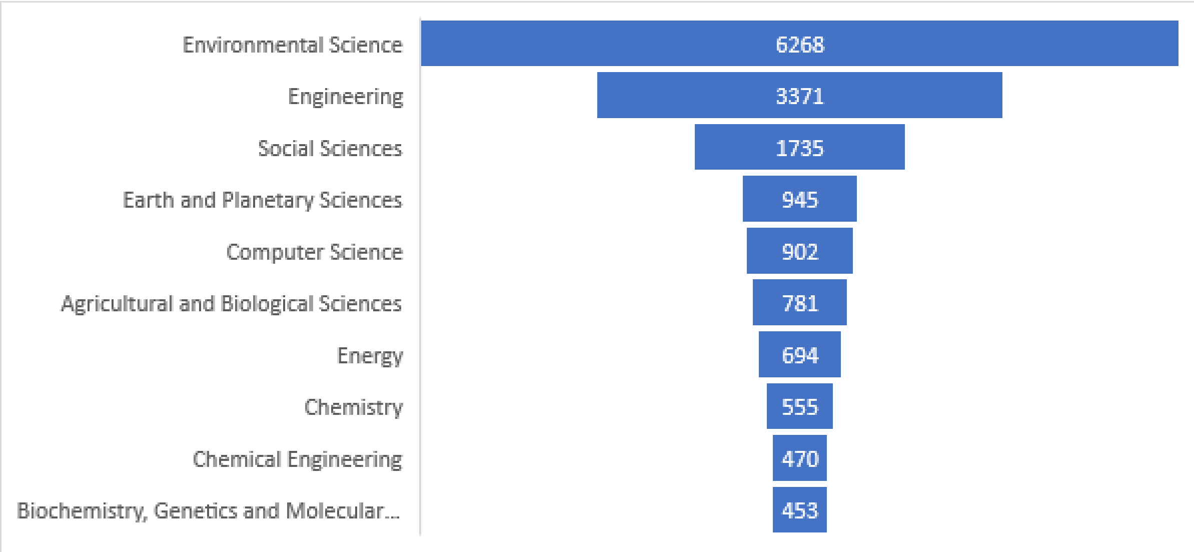

Figure 4. Water utilities challenges publications by scientific categories indexed in Scopus.

If the evolution trend for the top five scientific categories from 2000 to 2020 is analyzed, Figure 5 is obtained. These top five subject categories amount to 81% of the total number of publications. This figure shows that Environmental Sciences and Engineering have always been the two predominant subjects. The other three, Social Sciences, Earth and Planetary Sciences, and Computer Science rank in a similar position till 2015 when Social Sciences has clearly distanced itself from the other two. Since 2015, the Scopus database shows that publications have been more focused on the social component of the water utilities as a basic service provider and the sustainable management of the resource supplied to their customers.

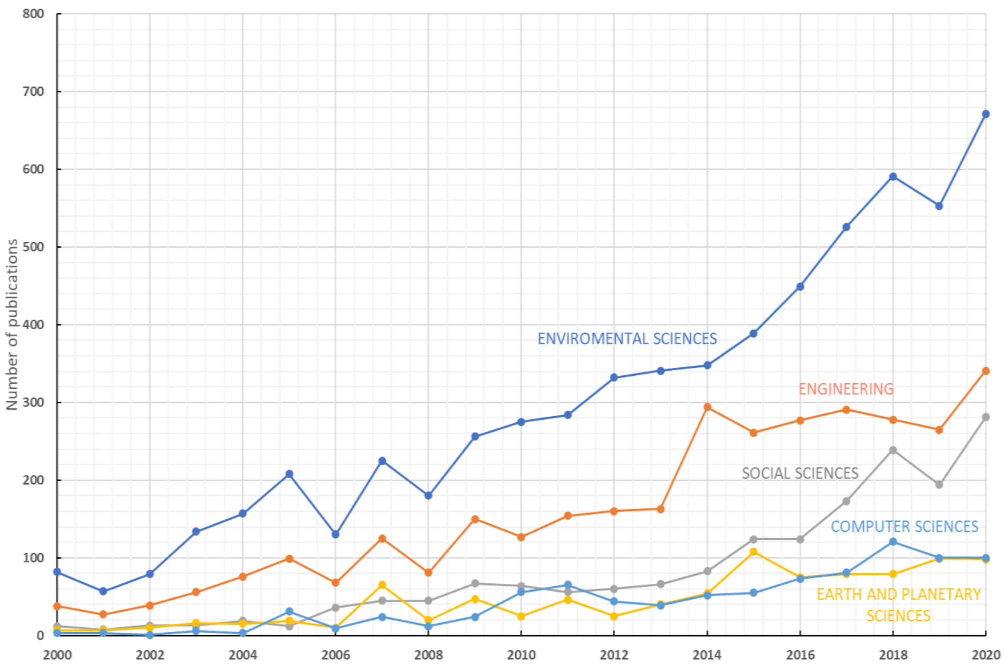

Figure 5. Scientific categories' evolution over time.

Figure 6 shows the five main subject areas the top ten producing countries are working on. The main subject for all countries is Environmental Sciences, which is between 40%

(Italy) to 57% (Germany) of the total publications for all countries. The second subject is usually Engineering, except for Germany, where it is equal to Social Sciences, and the Netherlands, where Social Sciences is slightly ahead. It is remarkable that the subject area Chemistry appears only in the top producer, USA. If the articles published by the USA with the subject area Chemistry are analyzed, 69% of them are in the same publication, Journal of American Water Works Association, the rest being spread among different sources. The subject of Chemical Engineering only appears in France, with 54 publications, 64% of them being published by the Techniques Sciences Methodes journal.

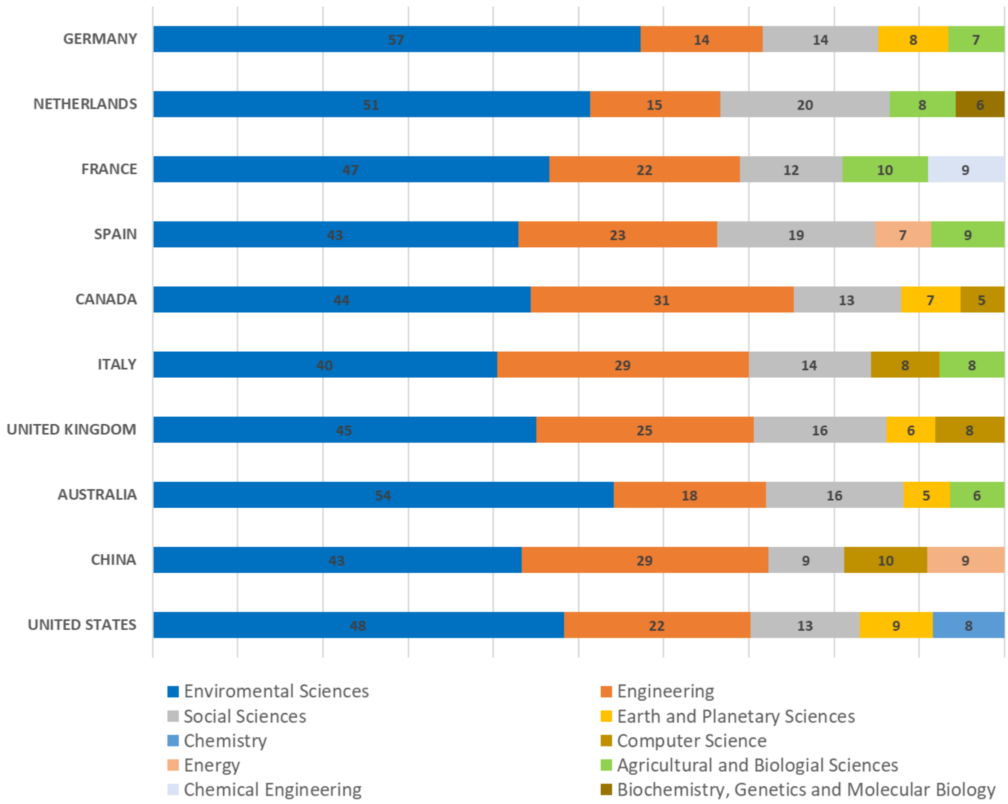

Figure 6. Subject area distribution per country.

3.3. *Relevant Countries in Research in Water Utilities Challenges*

Figure 7 shows the most relevant countries in the research of water utility challenges. The most producing countries are located in North America (Canada, USA), Europe (United Kingdom, Spain Portugal, Germany, France, the Netherlands, Italy), Australia, and Asia (India, China). The evolution of publications for the top ten countries in this field is shown in Figure 8. These top ten countries amount for nearly 80% of the total of publications included in the scope of this research.

The United States has been the top country in the number of publications for the whole period of study. The second country was the United Kingdom until 2008 when it was surpassed by China. Since 2015, there has been a notorious increase in the number of publications from the United States and China, distancing them from the rest of the countries. The graph shows that in 2019 the number of publications decreased for almost all countries, except for the United States and China where the number kept growing.

For analysis purposes, the main active countries in the number of publications have been divided into two different groups: European and non-European countries.

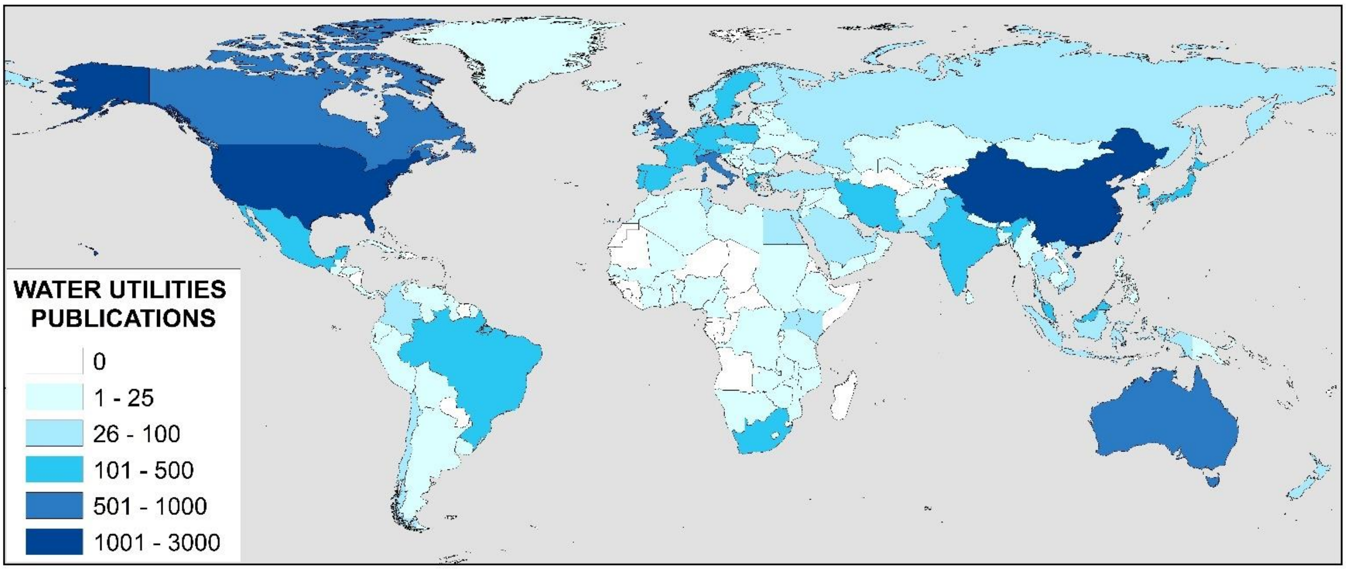

Figure 7. Number of documents by country.

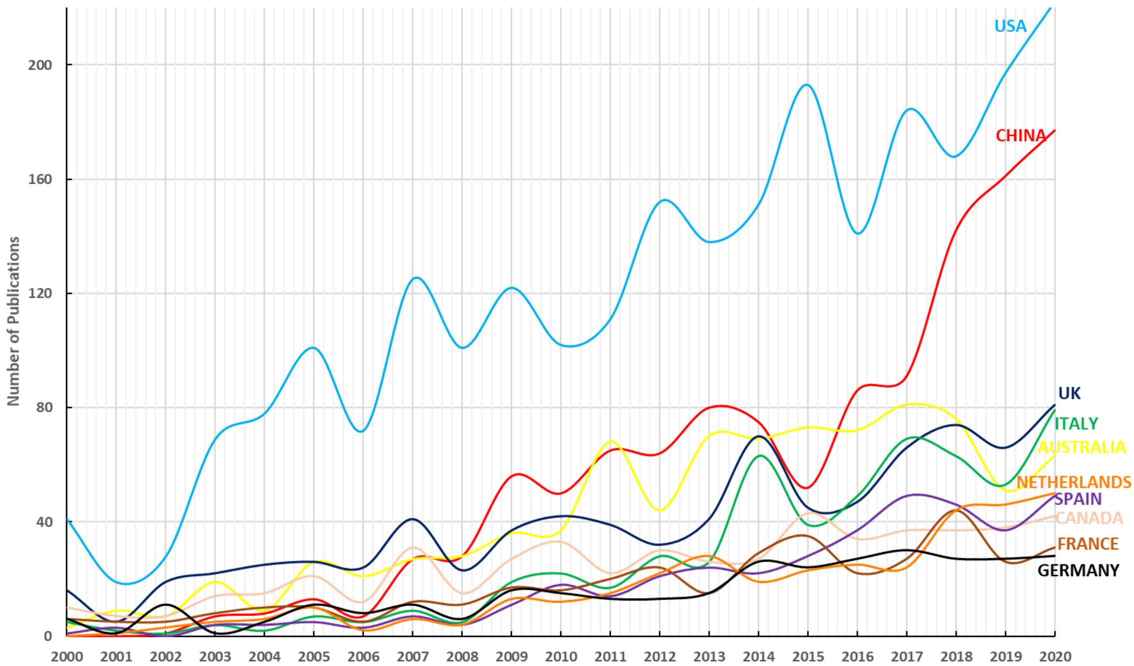

Figure 8. Evolution of publications for the top ten countries in this field.

The non-European countries: United States, China, Canada, and Australia are vast countries included within the six largest land areas in the world. In total, they amount to 34% of the total world surface, being countries with large water infrastructure. China and the United States are the world leaders in scientific production, so it is not surprising to find them in the first two positions for challenges associated with WDN too.

Within Europe the number of publications has been related to two main indicators: the pipe length and the volume of drinking water supplied.

The top six European countries in the number of publications are included within the seven European countries with the largest length of drinking network. Only Poland, which is the fifth country in drink network length, has a limited contribution to this scientific community with regards to the subject of this research.

The volume of drinking water supplied has also been analyzed, evidencing a similar situation: the six European countries with more publications are included within the seven countries which deliver more water to the network. Poland appears again on the list, just before the Netherlands.

Table 1 shows the top ten countries in number of publications, pipe length, and the total amount of drinking water supplied. It clearly shows a connection between pipe length/total amount of water supplied and the number of publications. Pipe length and water supplied data have been collected from Europe's water figure report [52] and the Global Water Market report [53].

Table 1. Relationship between the number of publications per country and pipe length/water supplied.

Country	Population ($\times 10^6$)	Publications	Publications/Million Habitants	Pipe Length ($\times 10^3$ km)	Water Supplied (Million m^3/Year)	Water Supplied (Million m^3/Year/Million Habitants)
USA	328	2515	7.67	1388	490,830	1496.43
China	1398	1190	0.85	1429	609,488	435.97
Australia	25	889	35.56	174	3738	149.52
UK	66	841	12.74	382	5985	90.68
Italy	60	568	9.47	473	8350	139.17
Spain	47	387	8.23	270	4400	93.62
France	67	378	5.64	920	5820	86.87
Netherlands	17	358	21.06	118	1126	66.24
Germany	83	321	3.87	530	5000	60.24
Portugal	10	200	20.00	104	781	78.10

Apart from the two indicators mentioned above, there are some other reasons which could explain why these countries are the top producers:

- Canada: The development of the Canadian Water Sustainability Index in 2016 [54], CWSI, could be the trigger for the increase of publications from this country. The CWSI is used to assess various elements of water well-being in Canadian communities.
- The United Kingdom is the European country with the largest contribution in this field of science. One of the reasons which could explain this is the presence of the regulator, Ofwat. The regulator aims to secure England and Wales privatized water utilities provide a good level of service to their customers and set ambitious targets the utilities must meet in their operation. The Ofwat is looking out continuously for water utility operation [55] and promotes long-term planning and ensures proper water resources management. Due to this, the UK water sector has made huge investments and investigations to optimize the performance and operation of their WDN. This fact is also highlighted by Huat Goh and Fong See in their benchmarking bibliometric analysis for water utilities where the UK resulted as being the most productive country due to the presence of Ofwat [37].
- The contributions from Italy and Spain are ahead of Germany for this specific topic, despite Germany's pipe length being larger. One reason to explain this is that potable water services in Spain and Italy usually operate in more challenging conditions than in Germany:
    - Mediterranean countries suffer more drought periods, and the climatic change is making these events more frequent and longer in duration [56].
    - Germany is performing better than Spain and Italy in terms of NRW: the level of NRW in Germany is around 9% [52], while Italy/Spain stands at 37%/23% [52,57].
    - Water infrastructure in Spain and Italy is much older than in Germany, where huge investments were made after World War II to rehabilitate and renew the infrastructure [58].

The number of publications and the total amount of water supplied has also been related to the population of each country. In this case, we can see how the tendency for the amount of water supplied related to the population of each country is in line with the total amount of publications, with some minor alterations; for example, Italy and Spain are ahead of the UK. However, the situation is completely different if we compare the number of publications related to the population of each country. In this case, less populated countries, Australia, Netherlands, and Portugal are the largest contributors, and China, the most populated, would have the lowest contribution.

Networking investigation collaborations between the different countries are displayed in Figure 9. The number of publications is represented by the circle size and the color represents the cluster built up by countries working in the same group. The three main producers, the United States, China, and Australia are each leading a different cluster. Table 2 identifies the cluster and the main countries part of it.

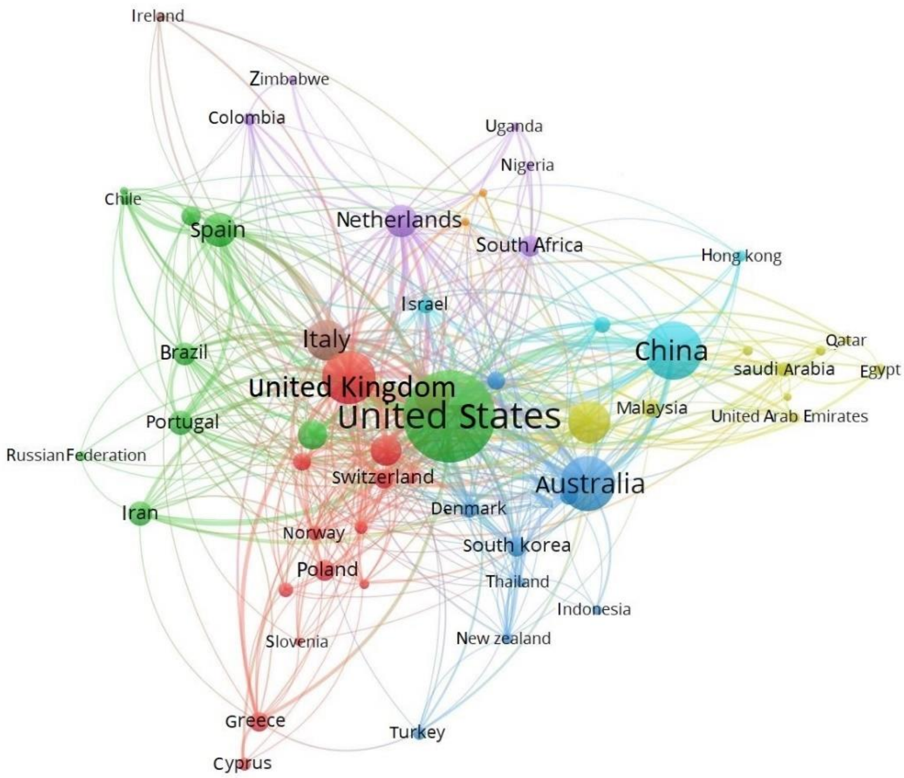

Figure 9. Research relations between countries.

Table 2. Countries collaboration in the period 2000–2020.

Cluster	Color	Main Countries	Number of Countries	Leader
1	Red	United Kingdom, France, Germany, Poland	14	United Kingdom
2	Green	United States, Spain, India, Iran	10	United States
3	Blue	Australia, South Korea, Sweden, Japan	9	Australia
4	Yellow	Canada, Malaysia, Saudi Arabia, Egypt	9	Canada
5	Purple	Netherlands, South Africa, Colombia, Uganda	6	Netherlands
6	Cian	China, Singapore, Israel, Hong Kong	4	China
7	Orange	Kenya, Ghana	5	Kenya
8	Brown	Italy, Ireland	5	Italy

The formation of the clusters seems to be determined by two main factors. The first factor is that nearby countries located in a specific geographical area tend to work together: for example, clusters 1, 3, and 6. These countries usually share some common challenges. The second factor is countries which despite being very far from the other, share some kind of bonds, such as language or culture. An example could be cluster 4, where South

Africa and the Netherlands appear together, or cluster 5 which groups Muslim countries (Malaysia, Egypt, Saudi Arabia) working together with Canada.

The evolution of the countries' publishing clusters appears in Figure 10. The scale of the graph has been selected to show when new countries start to publish in this scientific field and make the graph relevant. Until 2010, the United States and Canada were the main countries that were already working on this subject. From 2011 onwards, the contribution from China, and the Netherlands became greater, followed by Spain and Italy.

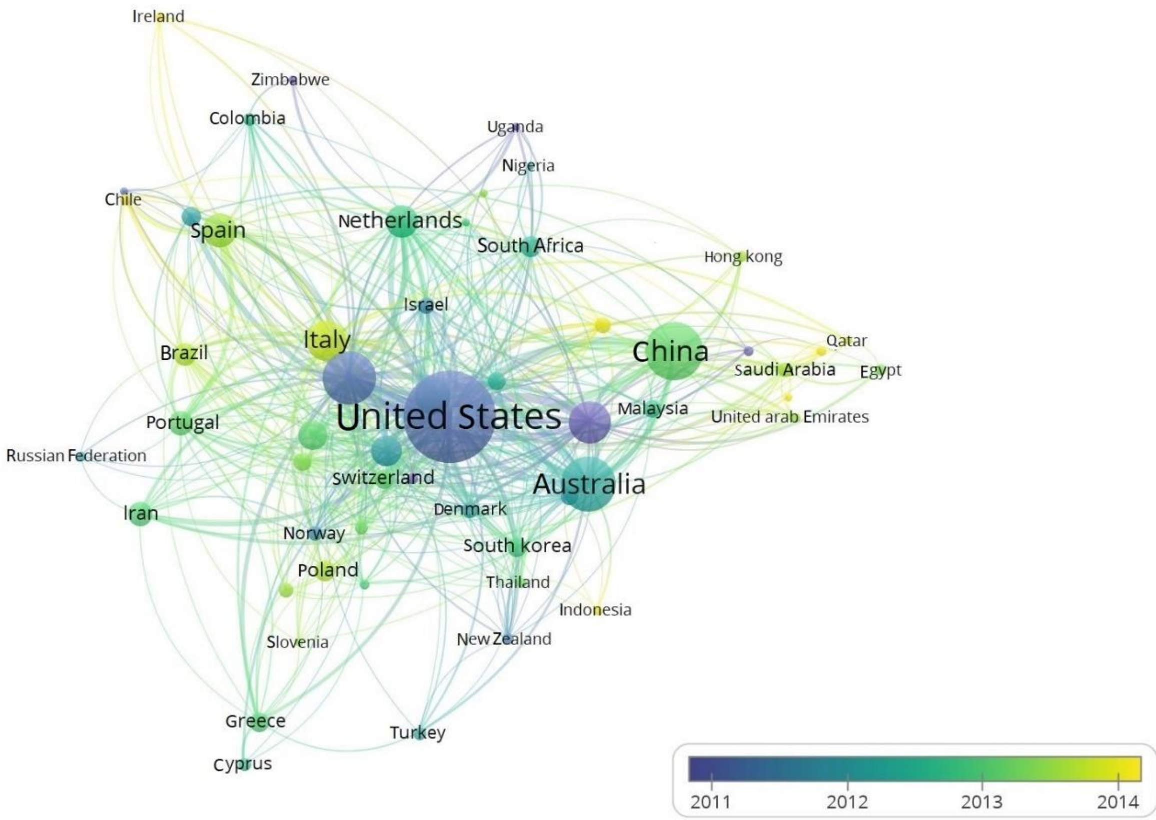

Figure 10. Evolution of countries' network collaboration.

3.4. Relevant Institutions

Apart from identifying the main countries working in this field, it is important to analyze the institutions indexed in Scopus working in this field. Table 3 shows the most relevant institutions in the number of publications from 2000 to 2020. The table also displays the total number of publications and the three main keywords for them. Keywords included in the search string such as "water distribution", "water supply", "water distribution network" were omitted to avoid result distortion.

The main institution is the University of Exeter which contributes 1.36% of the total publications studied. The second institution is the Chinese Academy of Sciences and the third one Delft University of Technology. While the United States is the country with the largest production, the first institution from this country is the Environmental Protection Agency, which ranks in position 5 of the total of publications bodies.

Below, Figure 11 shows the percentage of publications per year from 2000 to 2020 for the top ten institutions publishing in this science field. It is notorious to analyze how in 2020 only two institutions of the top ten had already started to work in this field. Progressively, more institutions have started to contribute with their investigations and for the last ten years, there is a common tendency for the sharing of publications among these top ten institutions.

Table 3. Top 10 affiliations main keywords.

Institution	Country	N	Keyword		
			1	2	3
University of Exeter	United Kingdom	133	Optimization	Water Management	System Analysis
Chinese Academy of Sciences	China	129	Water quality	Water Management	Water Pollution
Delft University of Technology	Netherlands	118	Water Management	Water Treatment	Decision Making
Monash University	Australia	111	Water Management	Urban Area	Water Quality
United States Environmental Protection Agency	United States	110	Water Quality	Contamination	Water Management
Universitat Politècnica de València	Spain	94	Water Management	Water Quality	Optimization
Tsinghua University	China	93	Water Quality	Water Management	Urban Area
CSIRO Land and Water	Australia	92	Water Management	Urban Area	Water Quality
Instituto Superior Técnico	Portugal	89	Water Management	Energy Efficiency	Optimization
IHE Delft Institute for Water Education	Netherlands	85	Water Management	Water Quality	Urban Area

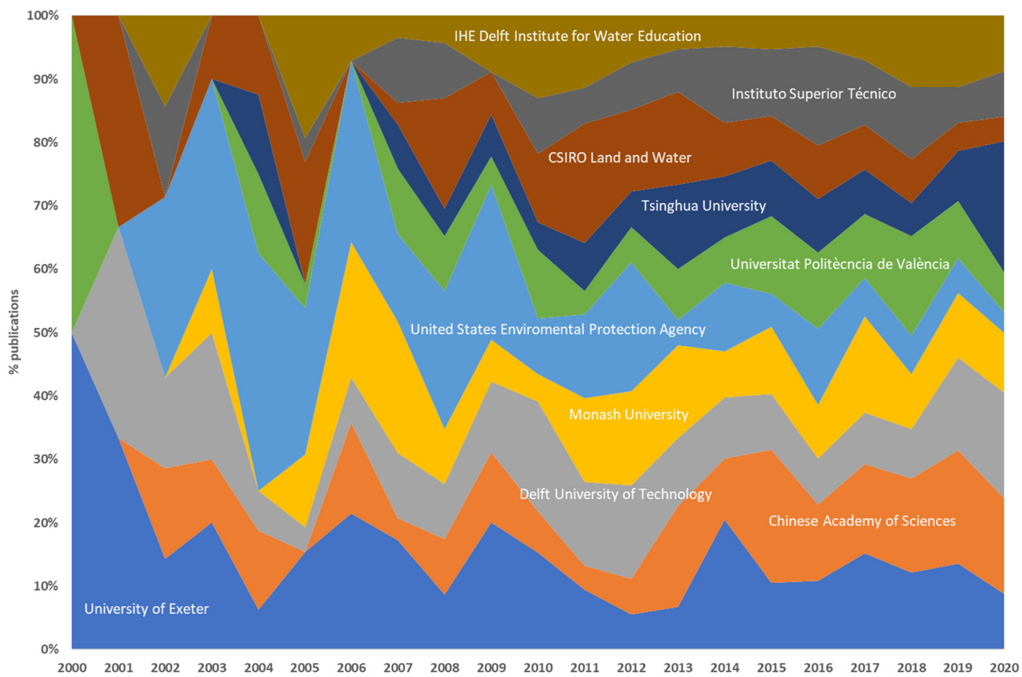

Figure 11. Evolution of the top 10 institutions with more publications.

3.5. Authors Cluster

The author collaboration network with more than 15 documents is shown in Figure 12 and Table 4. There is a total of nine clusters. The most important is the red one which groups a total of 24 authors, mainly from China. The second-largest cluster is the green one with nine authors. For the two main clusters, all the authors have a similar contribution weight.

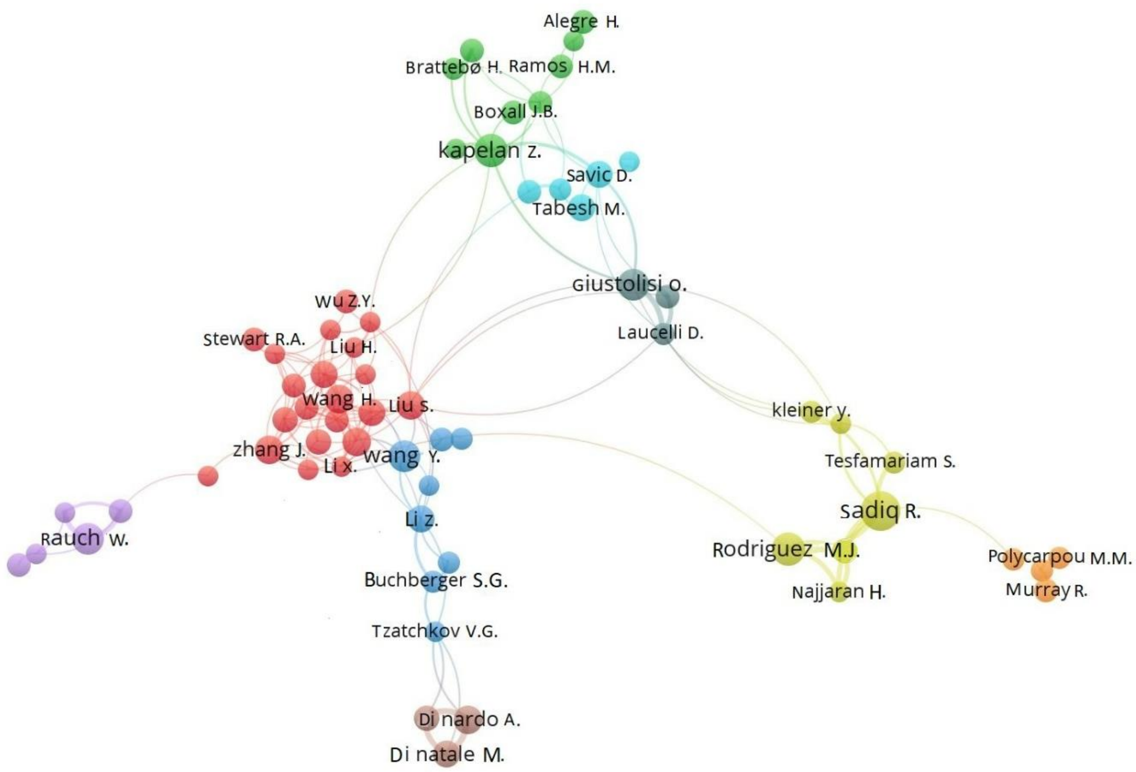

Figure 12. Author collaboration network.

Table 4. Water utility challenges: Research clusters.

Cluster	Color	Authors	Main Topics
1	red	Chen, J.; Kodikara, J.; Li, X.; Li, Y.; Liu, H.; Liu, J.; Liu, S.; Liu, Y.; Stewart, R.A.; Wang, H.; Wang, J.; Wang, S.; Wang, X.; Wu, W.; Wu, Z.Y.; Zhang, H.; Zhang, J.; Zhang, Q.; Zhang, X.; Zhang, Y.; Zhao, M.	Asset Management Water Quality, Demand Management
2	green	Alegre, H.; Boxall, J.B.; Brattebo, H.; Covas, D.; Kapelan, Z.; Makropoulos, C.; Ramos, H.M.; Savic', D.; Venkatesh, G.	Demand Management, Leak Localization, Hydraulic models
3	blue	Buchberger, S.G.; Clark, R.M.; Feng, X.; Foo, D.C.Y.; Li, Z.; Tzatchkov, V.G.; Wang, Y.; Zhao, X.	Demand Management, Water Quality
4	yellow	Hoorfar, M.; Kleiner, Y.; Najjaran, H.; Rajani, B.; Rodriguez, M.J.; Sadiq, R.; Tesfamariam, S.	Leak Localization, Water Quality
5	purple	Brown, R.R.; Deletic, A.; Kleidorfer, M.; Rauch, W.; Sitzenfrei, R.	Urban Water Management
6	cyan	Butler, D.; Giugni, M.; Savic, D. Tabesh, M.	Hydroinformatics
7	orange	Murray, R.; Piller, O.; Polycarpou, M.M., Uber, J.G.	Water Quality
8	brown	Di Nardo, A.; Di Natale, M.; Santonasta	Water Quality
9	grey	Berardi, I.; Giustolisi, O.; Laucelli, D.	Asset Management, Leakage Management

3.6. Keywords

The keywords of a publication allow for identifying the scope of the research. Thus, a basic aspect of bibliometrics is keywords study [59]. In order not to distort the results, keywords included in the search string were not included. Figure 13 provides an overview of the most used keywords, where the size is related to the frequency of occurrence.

Figure 13. Cloudword of keywords in water utility challenges.

The most used keywords are: water supply (4014 times) water management (2236 times), water distribution system (2175 times), potable water (1345 times), and urban area (1161 times).

Finally, keywords cluster analysis permits the classification of the groups where research trends are grouped. Figure 14 shows the three clusters obtained and Table 5 summarizes them with the main keywords for each cluster. The main cluster, represented in red, deals with WDN quality. The second cluster, in green color, is focused on WDN management, and the last one, in blue, is centralized in the optimization of WDN.

The three most cited articles for each of the keyword clusters are displayed in Table 6. There is one publication that is common for all the three clusters, ranking in the third position in WDN quality and in first for WDN management and WDN optimization cluster. This publication discusses the benefits of using low-impact development practices to improve water quality. The other two publications for the WDN quality cluster are focused on the application of disinfection products during the potabilization of water and the formation of haloacetic acids and trihalomethanes under different chlorination conditions. For the WDN management cluster, the second-ranking article dates from 2001 and it is a review of different hydraulic models for the simulation of water quantity and quality of stormwater. The third publication is focused on innovative urban water management strategies to deal with the current challenges water utilities are facing. Finally, the second-ranked article for the WDN optimization cluster describes how an optimized genetic algorithm integrated into EPANET software can be used as an early warning detection system against terrorism hazards. The third publication in this cluster develops a simulation model that relates leakage and demand versus pressure in the water distribution network.

In order to better visualize the keywords for each of the clusters, a detailed figure for each of them is shown below (Figures 15–17).

Lastly, Figure 18 displays the evolution for the keywords from 2011 to 2016. This graph shows that keywords for the WDN optimization cluster started to appear and be more cited as of 2011. Despite, the WDN optimization cluster is the smallest one, the keywords publication evolution reveals that it has won eight in the last years.

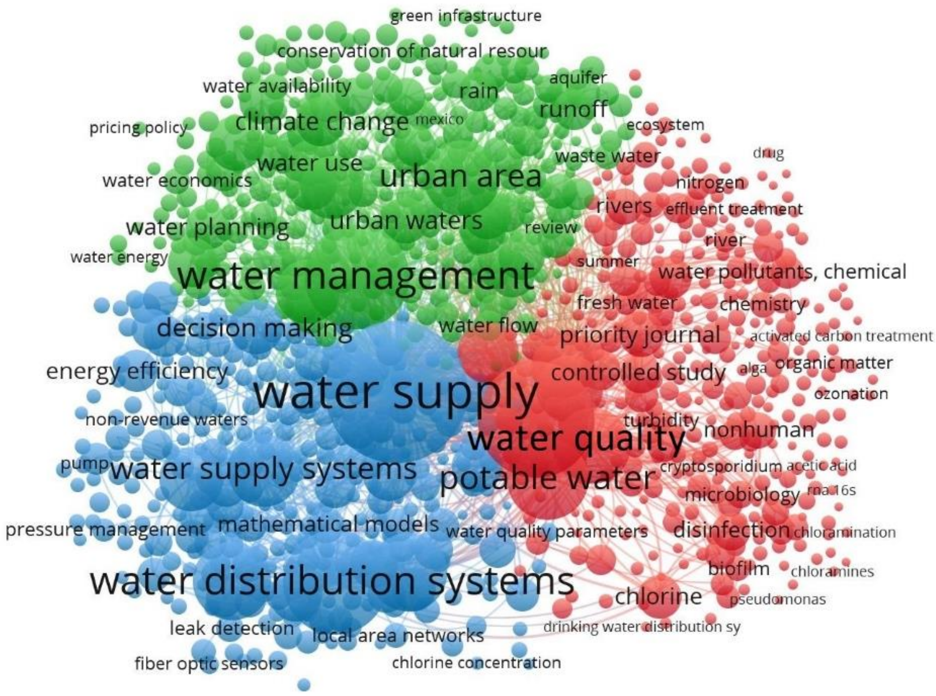

Figure 14. Cloudword of keywords in water utility challenges.

Table 5. Main keywords used by the communities detected in the topic in the period 2000–2020.

Cluster	Weight (%)	Color	Main Keywords
WDN quality	34.9	red	Water quality, potable water, drinking water, water treatment, water pollution, water
WDN management	34.1	green	Water management, urban area, water conservation, water demand, sustainable development, water planning
WDN optimization	31.0	blue	Water supply, water distribution systems, water distribution networks, optimization algorithms, energy efficiency, pipelines

Table 6. Most cited articles per keyword cluster between 2000 and 2020.

Cluster	Title	Authors	Year	Source	Cited by
WDN quality	Disinfection by-products and other emerging contaminants in drinking water	Richardson S.D	2003	Trends in Analytical Chemistry	522
	Factors influencing the formation and relative distribution of haloacetic acids and trihalomethanes in drinking water	Liang, L., Singer, P.C.	2003	Environmental Science and Technology	458
	Effectiveness of low impact development practices: Literature review and suggestions for future research	Ahiablame, L.M., Engel, B.A., Chaubey, I.	2012	Water, Air, and Soil Pollution	402
WDN management	Effectiveness of low impact development practices: Literature review and suggestions for future research	Ahiablame, L.M., Engel, B.A., Chaubey, I.	2012	Water, Air, and Soil Pollution	402
	Review of urban stormwater models	Zoppou, C.	2001	Environmental Modelling and Software	283
	Emerging solutions to the water challenges of an urbanizing world	Larsen, T.A., Hoffmann, S., Lüthi, C., Truffer, B., Maurer, M.	2016	Science	246
WDN optimization	Effectiveness of low impact development practices: Literature review and suggestions for future research	Ahiablame, L.M., Engel, B.A., Chaubey, I.	2012	Water, Air, and Soil Pollution	402
	Optimal layout of early warning detection stations for water distribution systems security	Ostfeld, A., Salomons, E.	2004	Journal of Water Resources Planning and Management	267
	Pressure-driven demand and leakage simulation for water distribution networks	Giustolisi, O., Savic, D., Kapelan, Z.	2008	Journal of Hydraulic Engineering	266

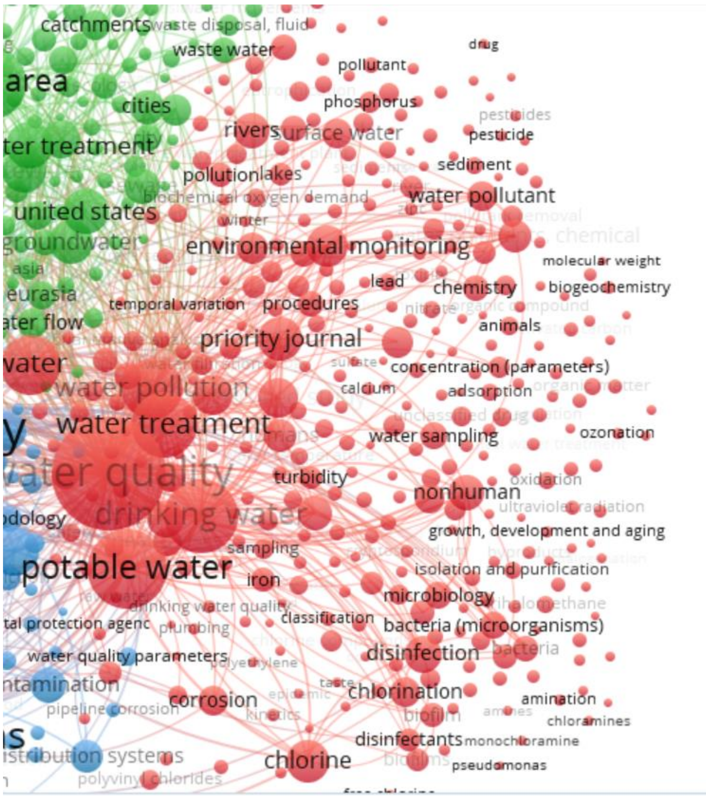

Figure 15. Cluster WDN quality.

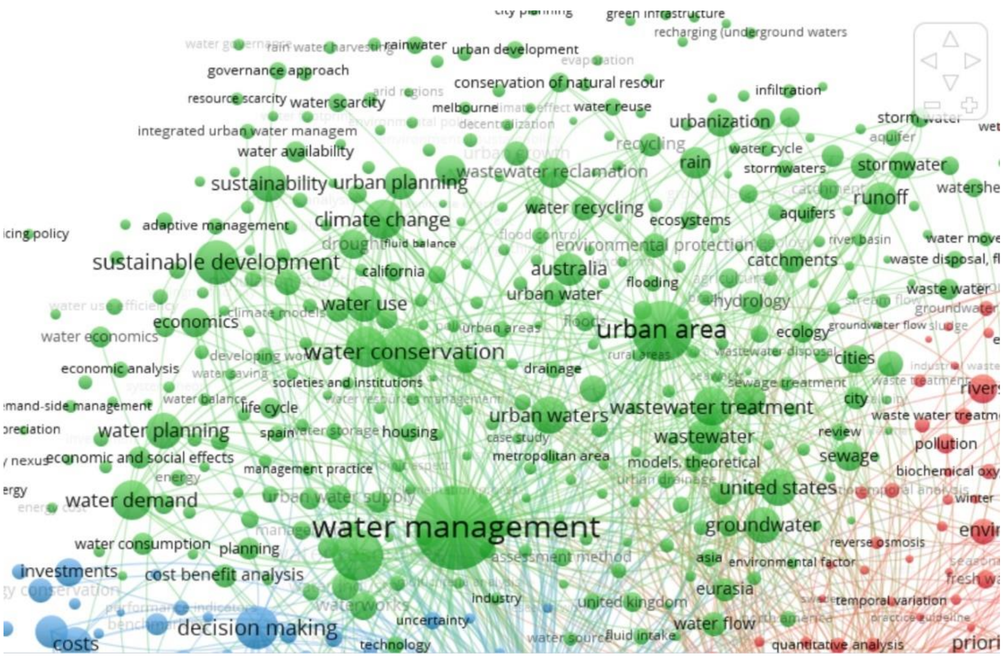

Figure 16. Cluster WDN management.

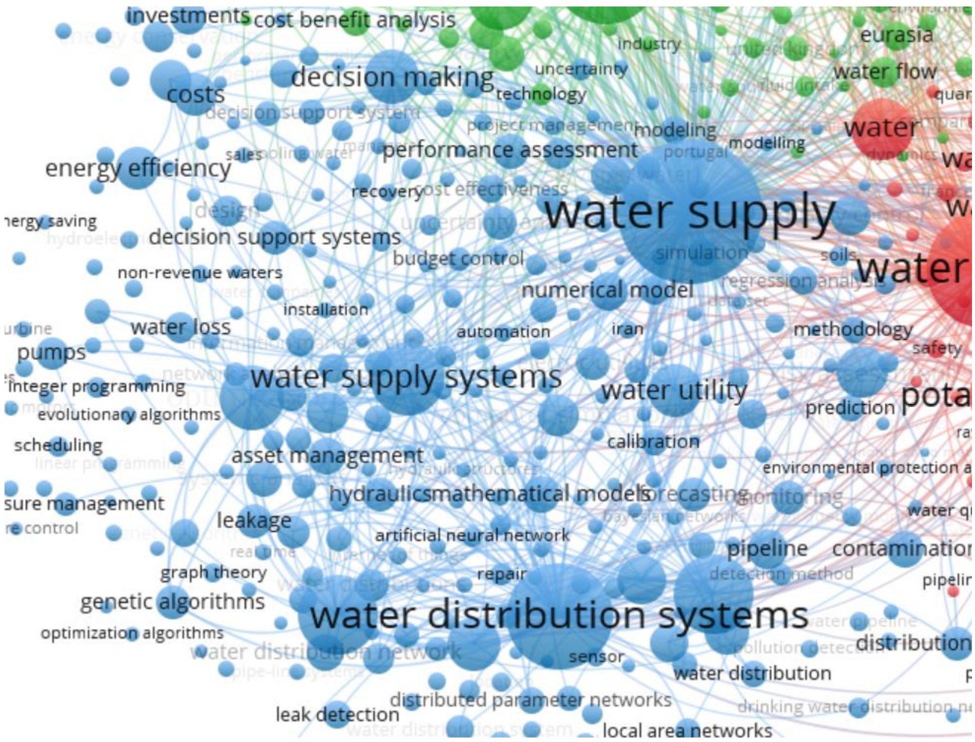

Figure 17. Cluster WDN optimization.

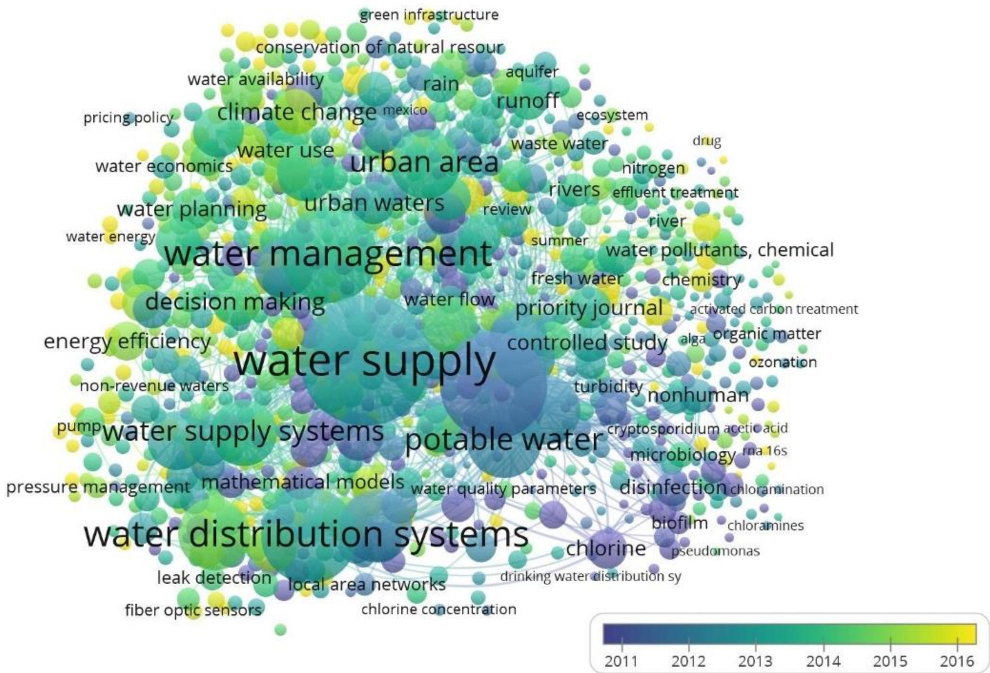

Figure 18. Keywords evolution.

3.7. Future Research

It is suggested to focus future research efforts on identifying the main challenges each country is facing, how they impact the operation of the water utility, the work done by the operators to overcome it, and the results obtained. A benchmark result analysis of the measurements applied by different utilities facing common challenges would be desirable to understand potential benefits in other utilities.

As conditions and challenges are likely to vary even in the same country, it would be preferred to make this analysis per water utility. However, this would require very deep analysis and data and information might not be available for all locations.

A deeper analysis of the WDN optimization cluster would also help to understand why research is moving in that direction and which challenges new proposals and investigations by the scientific community are helping to solve.

4. Conclusions

The aim of this document is to present a review of worldwide research on the challenges water utilities are facing in order to deliver water to their customers in safe and reliable conditions. These challenges are common among utilities and their occurrence has intensified in recent years. A good example is the large drought events that occurred in some megacities. Due to the importance of this matter, the evolution of the number of publications in this scientific field has garnered the attention of the community, growing exponentially from 2000—with only 115 publications in the field—to 2020, where there are now 1018 papers on this topic. This growing production, especially from 2015 as half of the documents have been published since then, justifies the need for this bibliometric research.

The three main report-producing countries are the USA, China, and the UK, leading each of them to an investigation cluster. The three most producing institutions are the University of Exeter, the Chinese Academy of Sciences, and the Delft University of Technology. There is a connection between pipe length per country and the total amount of water supplied with the number of publications, as the countries with the largest pipe network and the highest amount of water delivered the ones with more publications. An exception would be Australia, which is position eight for pipe length and water supplied but in the third position for the number of publications. The long drought events suffered in Australia have boosted scientific production. Other factors, such as external regulators, local climate conditions, and network status also play an important role to define the countries with more contributions.

The research shows great collaboration between different countries identifying eight working clusters composed of two to four countries. New countries and institutions have started to incorporate to the research clusters mainly since 2010, as the subject is acquiring relevance and importance among the scientific community. The main subject categories under which the articles are published are Environmental Sciences, Engineering, and Social Sciences.

The keywords analysis reveals publications around three main topics: WDN quality, WDN management, and WDN optimization. The keywords evolution proves that the topic WDN optimization is acquiring more weight in the last years to the detriment of the other two. This responds to the need of addressing current challenges by using emerging technology to improve WDN performance. Over the last years, automation, data gathering and analysis, and machine learning tools, commonly known as smart water technologies, are widely employed in the industry to improve access and supply of drinking water with the right level of service.

Finally, the bibliometrics results highlight the interest in this subject and can open new doors for future publications in this research field. This research intends to be an introduction to this subject. It is suggested to focus future investigation lines on identifying which are the challenges each of the countries/investigation institutions are working on and the connection among them.

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Abbreviations

The following abbreviations have been used in this document:

UN	United Nations
WDN	Water distribution network
NRW	Non Revenue Water
CWSI	Canadian Water Sustainability Index

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