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Articles

Virtual water and water footprint: Bibliometric valuation of its scientific analysis

Agua virtual y huella hídrica: valoración bibliométrica de su análisis científico

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Abstract

The concepts of virtual water and water footprint are complementary tools for understanding the direct and indirect use of water in anthropogenic processes. While the former refers to the amount of water required to produce a product (along with the direct impacts this generates on other users, in different regions, or on water quality), the latter addresses the indirect use of this resource in detail. In this context, the present study conducts a comprehensive bibliometric analysis of scientific publications on these concepts between 2001 and 2023, using information available in the Scopus database, supported by VOSviewer for mapping and STATA for generating graphs. The results highlight the prevalence of transdisciplinary approaches led by contributions from the People's Republic of China, the United States, England, the Netherlands, Italy, Germany, and Canada. Grounded in environmental, biological, and socioeconomic sciences, these approaches have provided precise insights into the diverse direct and indirect anthropogenic uses of water resources. In particular, China stands out as a leader in knowledge generation and in providing institutional support for research on virtual water and Water Footprint. Beyond these results, it is concerning that research activity on these topics is primarily conducted by developed countries, while the contribution from developing countries continues to lag behind. This underscores the importance of promoting equitable participation in research to address global water challenges.

Keywords: water consumption, water resources management, bibliology, scientific publications, developed countries, developing countries.

Resumen

Los conceptos de agua virtual y huella hídrica son herramientas complementarias para comprender el uso directo e indirecto del agua en los procesos antropópicos. Mientras que el primero se refiere a la cantidad de agua necesaria para producir un producto (junto con los impactos directos que esto genera en otros usuarios en distintas regiones o en la calidad del agua), el segundo aborda en detalle el uso indirecto de este recurso. Ante esto, el presente estudio realiza un análisis bibliométrico integral de las publicaciones científicas sobre tales conceptos entre 2001 y 2023, utilizando información disponible en la base de datos Scopus, apoyado por el *software* VOSviewer para la elaboración de mapas y el *software* estadístico STATA para la generación de gráficos. Los resultados destacan la prevalencia de enfoques transdisciplinarios liderados por contribuciones de la República Popular China, EUA, Inglaterra, Países Bajos, Italia, Alemania y Canadá con base en las ciencias ambientales, biológicas y socioeconómicas. En particular, China se destaca como líder en la generación de conocimiento y en el apoyo institucional a la investigación sobre agua virtual y huella hídrica. Más allá de estos resultados, es muy preocupante que la actividad de investigación sobre estos temas sea llevada a cabo principalmente por países del primer mundo, mientras que la contribución de los países en desarrollo muestra un creciente rezago respecto a los primeros lugares; esto enfatiza la importancia de promover una participación equitativa en la investigación para abordar los desafíos globales del agua.

Palabras clave: consumo de agua, gestión de los recursos hídricos, bibliometría, publicación científica, país desarrollado, país en desarrollo.

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Introduction

Water, a fundamental element for life in its various manifestations, not only serves as an ecosystem for oceanic species but also organizes the terrestrial biome by playing a crucial role in regulating climate, precipitation patterns, temperature, and atmospheric circulation. Culturally, both ancient and contemporary societies have attributed symbolic traits to it in rituals of purification, renewal, and life. Its essential utilization transcends the geographical, cultural, and economic boundaries of the planet. However, although the Earth's surface is composed of water, 98 % of it is saline, while only the remaining 2 % is potentially potable. Of this fraction, 68.9 % is frozen in polar glaciers, 30.8 % is concentrated in underground reserves, and only 0.3 % is available on the surface (USGS, 2019).

In addition to this relative scarcity, water availability faces significant threats linked to excessive anthropogenic pressure on nature's goods and services including rapid population growth, urbanization, pollution, the dynamics of a consumerist society, and an insatiable industrial sector, among others. For example, the agricultural sector accounts for 72 % of global freshwater withdrawals (FAO, 2023). And 20 % is attributed to industry (FAO, 2009). In response to these phenomena, human initiatives continuously emerge and evolve to analyze,

disseminate, raise awareness, and counteract the outcomes of this paradigmatic challenge. To this end, concepts such as virtual water and water footprint have been developed, whose academic discussion has intensified, positioning them as indicators of anthropogenic impact on the environment—essential for designing strategies that ensure water sustainability.

However, in non-specialized institutional spheres, there remains a tendency to confuse the conceptual content of these terms or to overlook their distinctions, often limiting the scope of public and private actions aimed at addressing, preventing, and/or remedying water-related issues. In light of this situation, this analysis seeks to clarify the evolution and interconnections of these concepts by identifying research patterns, areas of concentration, and knowledge gaps.

Fundamentally, it aims to understand how these environmental indicators have been developed and applied in scientific literature, as well as their specific complementarities in identifying water consumption patterns, assessing the sustainability of supply chains, and managing sustainable water use practices.

The joint analysis of the concepts of virtual water and water footprint responds to their close theoretical and methodological interrelationship, as well as their positioning within the global debate on sustainable water management. Understanding the specific factors that have driven scientific interest reveals not only thematic specialization patterns by country but also the regional strategic interests linked to the institutional and academic appropriation of these analytical frameworks.

Accordingly, to fulfill this objective, the present document is organized into six sections, and is structured into six sections, including

this introductory note. The second section presents the background and conceptual boundaries of the analysis. The third describes the research sequence and the analytical tools used to mine information from Elsevier Scopus databases. The fourth section presents the results of the comparative analysis of variables such as authors, citations, funding, fields of knowledge, contributing countries, publication types, and institutional affiliations, among others. The fifth section discusses the findings of the analysis. Finally, the main conclusions of the article are presented, highlighting the existence of methodologies for studying water use, ranging from a strictly volumetric approach to a more complex perspective that considers indirect consumption.

Background

Water is referred to as the universal solvent due to its unique molecular composition; its electric charges allow it to bond with multiple compounds and react with acidic oxides, basic oxides, metals, and nonmetals. It enables the survival of societies, species, and organisms inhabiting the Earth. Beyond the biological needs it fulfills, water is an essential support for activities that sustain human well-being and progress, including primary food production (fishing, agriculture, livestock farming, etc.), energy production, and industrial processes (Larramendi *et al.*, 2021).

Among the vast array of biological species on the planet, only humans alter hydrological cycles to meet their needs, often disregarding the damage caused to a resource that, despite its abundance, remains scarce in the face of growing anthropogenic demand (López *et al.*, 2017). Since the late 20th century, academic literature has confirmed that the natural availability of water is approaching a critical threshold. Only 0.3

% of the Earth's water is directly accessible for human consumption without requiring treatment for potability (Lanz, 1995; Murillo *et al.*, 2022; Ulloa-Gutiérrez, 2023).

The factors responsible for water pollution stem from human activities, including waste from industrial processes, malfunctioning wastewater treatment plants, leaks from oil pipelines or petroleum derivatives, the disposal or discharge of solid waste, and the release of toxic gases such as carbon monoxide, sulfur dioxide, and nitrogen oxides (Ramos-Mancheno, 2024). The scientific community has developed criteria and procedures to document evidence of these impacts on ecosystems. This is illustrated by the concepts of *virtual water* and *water footprint*. The latter, proposed by Hoekstra (2003), initially faced criticism regarding its relevance for analyzing indirect water use. Critics argued that water resource management should be limited to allocating water to actual users and should not consider the final consumers of goods; they claimed it was inappropriate to hold consumers responsible for the negative impacts of producing external goods or services. However, the academic community adopted the concept as it recognized its complementary value with respect to the term *virtual water*, proposed by Allan (2001) to quantify water inputs in the production of goods and services, particularly in relation to real exports and imports between countries. The *water footprint* concept expanded this by incorporating the assessment of both direct and indirect water consumption throughout the entire production chain (Herrero, 2020). Thus, while the term *virtual water* focused on analyzing the volume of water used —without specifying its characteristics— the concept of *water footprint* enabled a more detailed analysis by including water typologies, proportions, and sources.

In short, the virtual water refers to the total amount of water needed throughout the production of a good —covering cultivation, growth, processing, manufacturing, transport, and sale— even though this water is not contained in the final product; while the water footprint, on the other hand, measures all the water we use in daily life, including that consumed in food production, industrial activities, energy generation, and the water that is polluted or lost during these processes (Conagua, 2007).

Methodology

The database used to support this analysis is Elsevier Scopus, which holds the most relevant record of literature due to its quality standards and ease of virtual access (Salazar-Velázquez & Mejía-Trejo, 2021; Cañedo *et al.*, 2010). The second analytical tool is VOSviewer, a preferred software for creating maps from databases, simplifying the graphical representation of co-authorship links, co-occurrence, citations, and bibliographic coupling, which are essential for achieving the outlined objectives (Van Eck & Waltman, 2022). Additionally, the statistical software STATA was chosen for data analysis due to its versatility and advanced imaging capabilities.

The procedure for assessing global scientific production on virtual water and water footprint was based on bibliometric analysis. This technique enables the evaluation of scientific progress across various fields and helps identify knowledge gaps through a systematic review of the existing literature (Palermo & Salazar, 2023).

Based on the selected information filters, the following elements were examined without imposing limitations or exclusions:

- Authors
- Countries
- Document types
- Institutional affiliations
- Journals
- Keywords within the documents
- Languages
- Sponsors
- Thematic areas

Specific concept exploration

This research accessed the electronic records of the Elsevier Scopus platform, extracted on April 9, 2024, to construct databases related to the conceptual variables specified for the study. The queries were conducted using the terms virtual water and water footprint, following the platform's specifications, which are designed for the English language.

The search process was facilitated by Boolean operators, using "AND" to instruct the search engine to select only publications explicitly related to the predefined concepts. The search commands were structured as follows for each case:

"VIRTUAL" AND "WATER"

"FOOTPRINT" AND "WATER"

As a result of the survey of publications related to specific concepts, the following records were identified from 2001 to the cutoff in 2023:

- 829 documents related to the concept of *virtual water*.
- 2 738 publications related to the concept of *water footprint*.

The datasets were downloaded in CSV format without excluding any information fields, encompassing the following collections:

Citation data

Includes author(s), document title, year, EID (Editor Identifier), source title, volume, issue, pages, citation count, source and document type, publication cover, DOI (Digital Object Identifier), and open-access status.

Bibliographic information

Covers affiliations, serial identifiers (e.g., ISSN), PubMed ID, publisher, editor(s), original document language, correspondence address, and abbreviated source title.

Abstracts and keywords

Includes abstracts, author keywords, and indexed keywords.

Co-occurrence and authorship

Finally, co-occurrence and authorship mapping were conducted, disaggregated by country, using VOSviewer. This analysis aimed to assess the cohesion and interaction among the variables of interest. It enabled the identification of clusters and provided a visual representation of the

correlation between the keywords identified through the Scopus search using Boolean operators.

Results

Publications per year

The analysis revealed the annual trend of publications related to the concepts of virtual water and water footprint. The first documents were identified in 2001, with their issuance increasing steadily until 2010. From 2011 onward, literature on the water footprint concept prevailed, growing from one or two annual publications to an exponential increase, reaching 368 publications in 2023. In contrast, studies on virtual water recorded only 59 published documents (Figure 1).

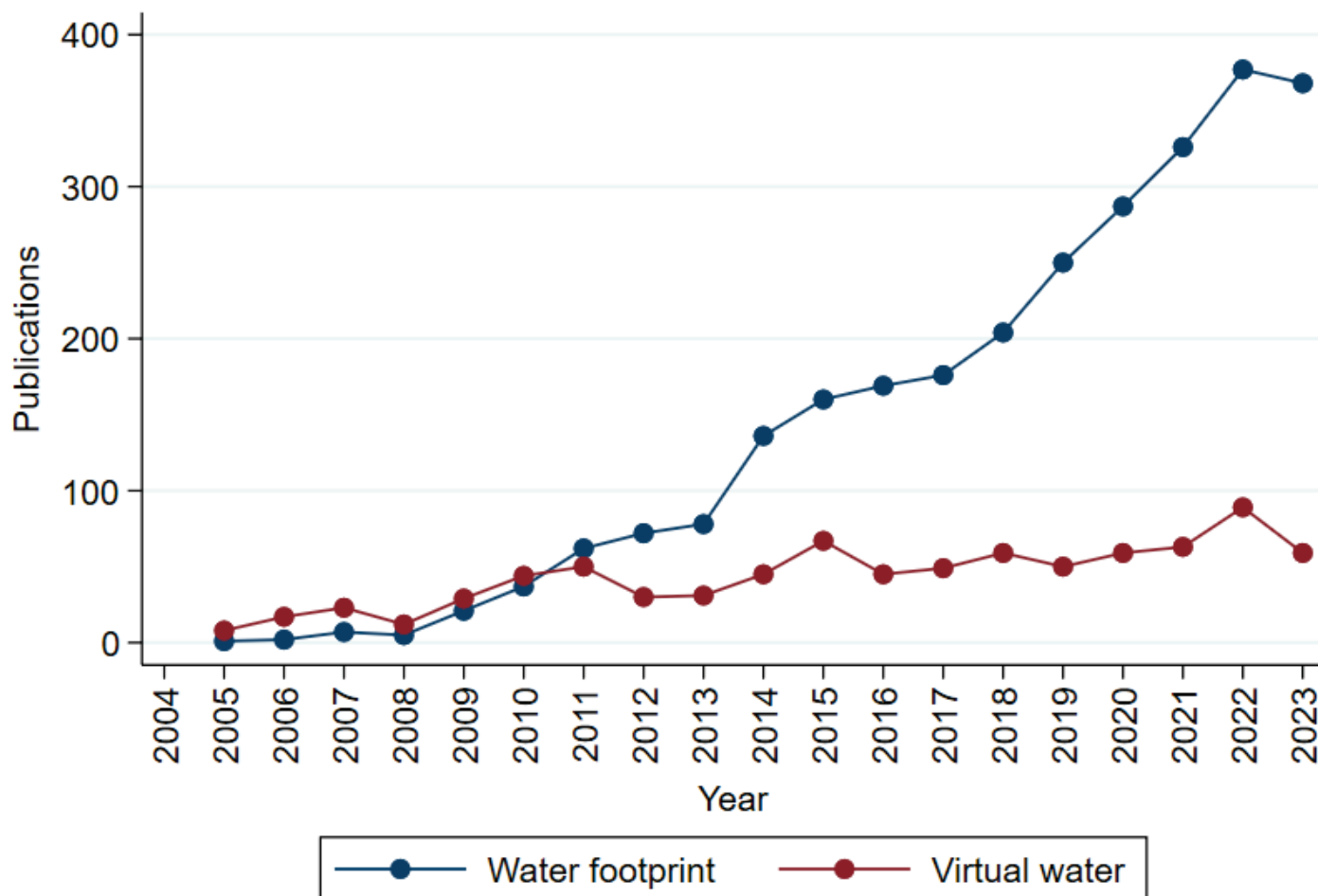


Figure 1. Publications on virtual water and water footprint 2004-2023. Source: Own elaboration with Scopus data 2024.

Publications and quotes by author

The analysis highlights author contributions when they exceed 1 % of the stock identified in the Scopus database. A total of 16 authors specializing in virtual water and 18 focused on the water footprint were identified (Table 1).

Table 1. Notable authorships on virtual water and water footprint Topics. Source: Own elaboration with Scopus data 2024.

Virtual water		Water footprint	
Author	% of publications	Author	% of publications
Hoekstra, A.Y.	2.85	Hoekstra, A.Y.	5.99
Konar, M.	2.36	Wu, P.	3.02
Wu, P.	2.23	Zhuo, L.	2.52
Yang, H.	1.86	Mekonnen, M.M.	2.46
Chen, B.	1.74	Pfister, S.	1.68
Liu, J.	1.61	Wang, Y.	1.62
Wang, Y.	1.61	Cao, X.	1.57
Gao, X.	1.49	Berger, M.	1.46
D´Odorico, P.	1.36	Vanham, D.	1.46
Zhuo, L.	1.24	Sun, S.	1.34
Hanasaki, N.	1.12	Finkbeiner, M.	1.29
Ruddell, B. L.	1.12	Huang, K.	1.23
Sun, S.	1.12	Hong, J.	1.12
Wang, S.	1.12	Gerbens-Leenes, P. W.	1.06
Xu, M.	1.12	Ridoutt, B. G.	1.06
		Wu, M.	1.06
Zhao, X.	1.12	Yu, Y.	1.01
		Wang, L.	1.01

The record of the most cited authors does not correspond to those with the highest number of publications. For example, the volume of literature on virtual water is led by Arjen Y. Hoekstra, with 4 692 documents. However, the leadership in citations belongs to Chapagain, A. K., who has 2 646 publications. The second position is held by Pfister,

Stephan, with 1 498 (Table 2). These authors report an average of 441 and 250 citations, respectively, while Hoekstra averages 204 citations.

Table 2. Author's on the topic of virtual water: Citations and average per publication. Source: Own elaboration with Scopus data 2024.

	Author	Publication	Citations	Average
1	Chapagain, A.K.	6	2 646	441
2	Pfister, S.	6	1 498	250
3	Hoekstra, A.Y.	23	4 692	204
4	Hanasaki, N.	5	1 001	200
5	Hubaceck, K.	8	1 216	152
6	Liu, J.	12	1 702	142
7	Yang, H.	12	1 600	133
8	Feng, K.	8	808	101
9	Zhao, X.	9	840	93
10	Chen, G. Q.	6	525	88
11	Dódrico, P.	9	781	87
12	Konar, M.	15	833	56
13	Vanham, D.	7	392	56
14	Liang, Sai	7	387	55
15	Chini, C. M.	5	242	48
16	Stillwell, A. S.	5	236	47
17	Zhang, Y.	5	213	43
18	Xu, M.	9	367	41
19	Qu, S.	5	202	40
20	Yang, Z.	7	267	38

Note: Only authors with a minimum contribution of 1 % of the production found in the SCOPUS databases are included.

In the specialized literature on water footprint, there is also no direct correspondence between the most-cited authors and those with the highest number of publications. Mekonnen, M.M. leads the list, averaging 182 citations per publication, surpassing Arjen Y. Hoekstra, who leads in total publications with 151 citations per published work. Pfister, Stephan follows in importance, with an average of 116 citations per publication.

The volume of citations per work received by these three researchers sets them apart significantly from the rest of the academics, whose citation count reaches at most half of the leaders in the list (Table 3).

Table 3. Authors on the topic of water footprint: Average citations per publication. Source: Own elaboration with Scopus data 2024.

	Author	Publications	Number of citations	mean
1	Mekonnen, M.M.	42	7 630	182
2	Hoekstra, A. Y.	103	15 512	151
3	Pfister, Stephan	27	3 119	116
4	Gerbens-Leenes, P.W.	26	1 776	68
5	Vanham, D.	25	1 388	56
6	Berger, M.	26	1 378	53
7	Yu, Y.	18	762	42
8	Finkbeiner, M.	23	839	36
9	Huang, K.	22	774	35
10	Zhao, X.	16	547	34
11	Zhuo, L.	44	1 124	26
12	Sun, S.	24	631	26
13	Shen, X.	17	435	26
14	Wang, Y.	29	693	24
15	Hong, J.	20	467	23
16	Wu, P.	54	1 130	21
17	Cao, X.n	28	551	20
18	Zhai, Y.	17	340	20
19	Wu, M.	19	333	18
20	Wang, L.	18	159	9

Publication by disciplinary approach

The trends in scientific analyses of water-related topics (Figure 2) reveal similar patterns across all disciplines. The most prominent areas are environmental and earth sciences, which account for 38.29 % of research on water footprint and 42.47 % on virtual water. These are followed by biological sciences, with 14.08 % and 12.39 %, respectively.

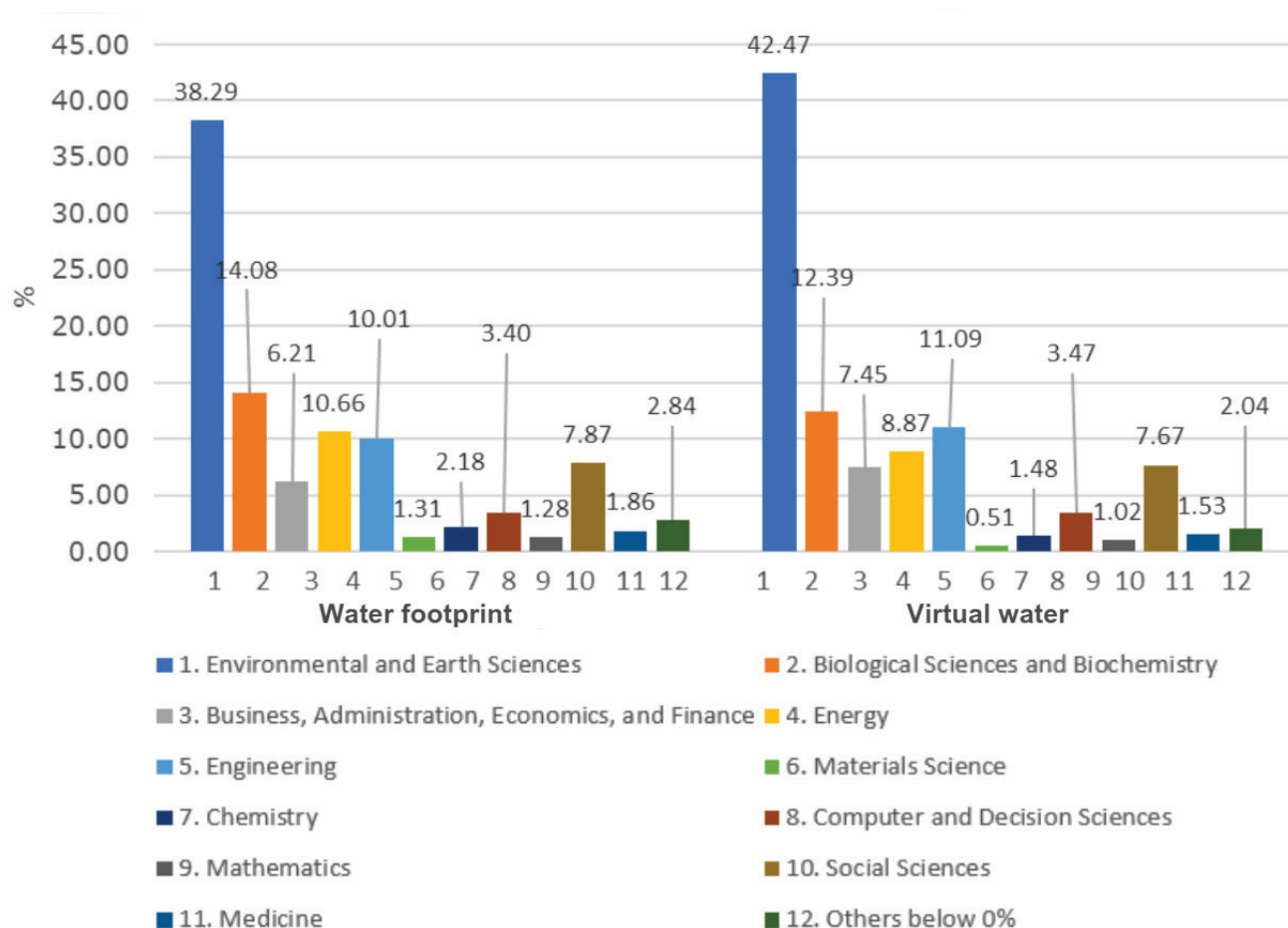


Figure 2. Scientific approaches to the analysis of virtual water and water footprint 2000-2023. Source: Own elaboration with Scopus data, 2024.

However, other disciplines also play a critical role. Research from sociology, anthropology, and psychology contributes to understanding the social and behavioral dimensions of water consumption. Economic sciences analyze the impact of water use on production systems, markets, finance, and employment.

Additionally, emerging themes arise in fields such as physics (energy), biochemistry (molecular energy), and Earth sciences (geology, oceanography, and astronomy).

The dominance of environmental and biological sciences in studying virtual water and water footprint is due to their intrinsic connection with natural and ecological processes. In contrast, mathematics and social sciences have a smaller but significant impact. Their role in water management research is crucial, as they provide tools and strategies to optimize water usage and understand human consumption behaviors.

Publications by type

The analysis of the databases on academic products confirms the predominance of scientific articles. The proportions correspond to 80 % for products on the topic of water footprint and 78 % for virtual water. The rest of works articulate a similar participation with the exception of book chapter, which favors virtual water (Figure 3).

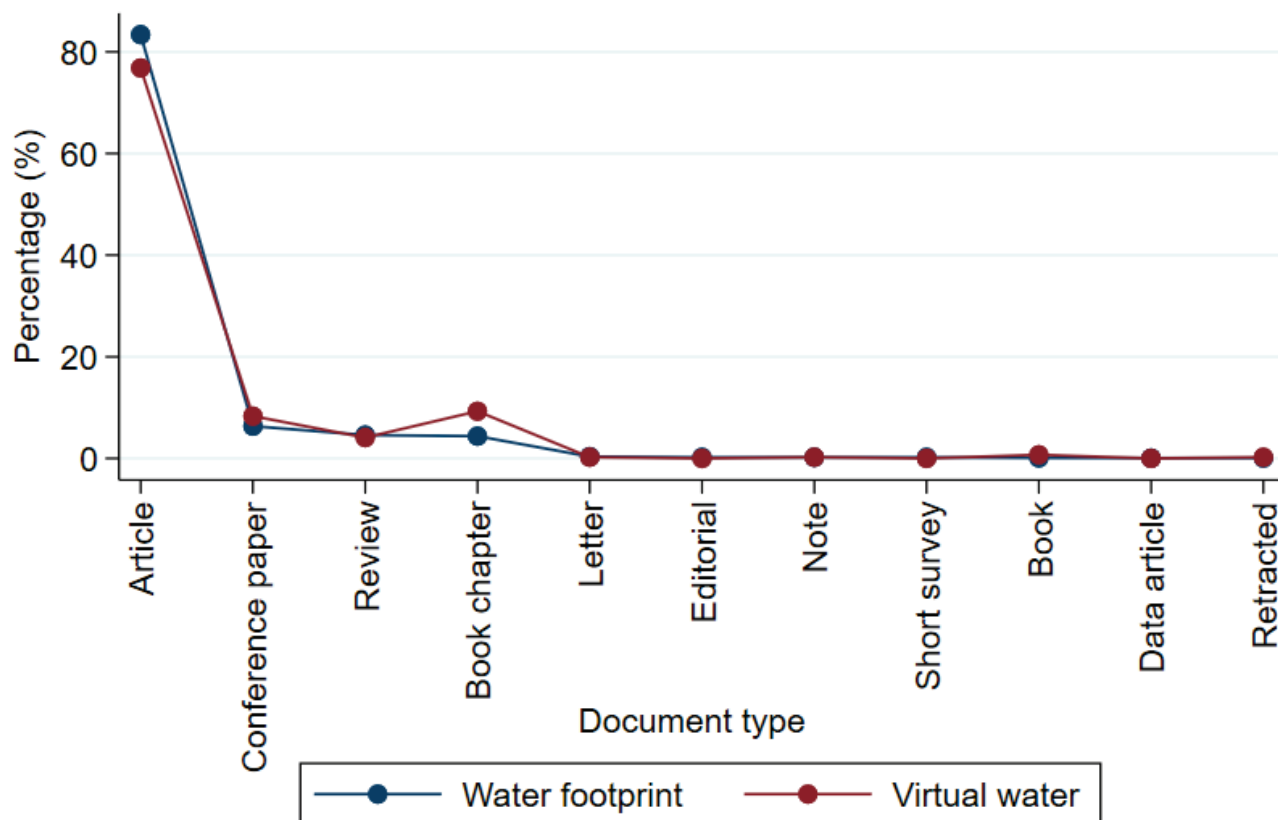


Figure 3. Typology of academic products on virtual water and water footprint, 2005-2023. Source: Own elaboration with Scopus data, 2024.

Publications by country

In the approach to virtual water issues, publications from 16 countries were detected, led by China (27.8 %), the United States (12.3 %), England (6.1 %), The Netherlands (4.3 %), Italy (4.1 %), Germany (3.4 %) and Canada (3.1 %). In addition to this group, there are nine countries with shares of more than 1 % but less than 3 % of publications (Figure 4).

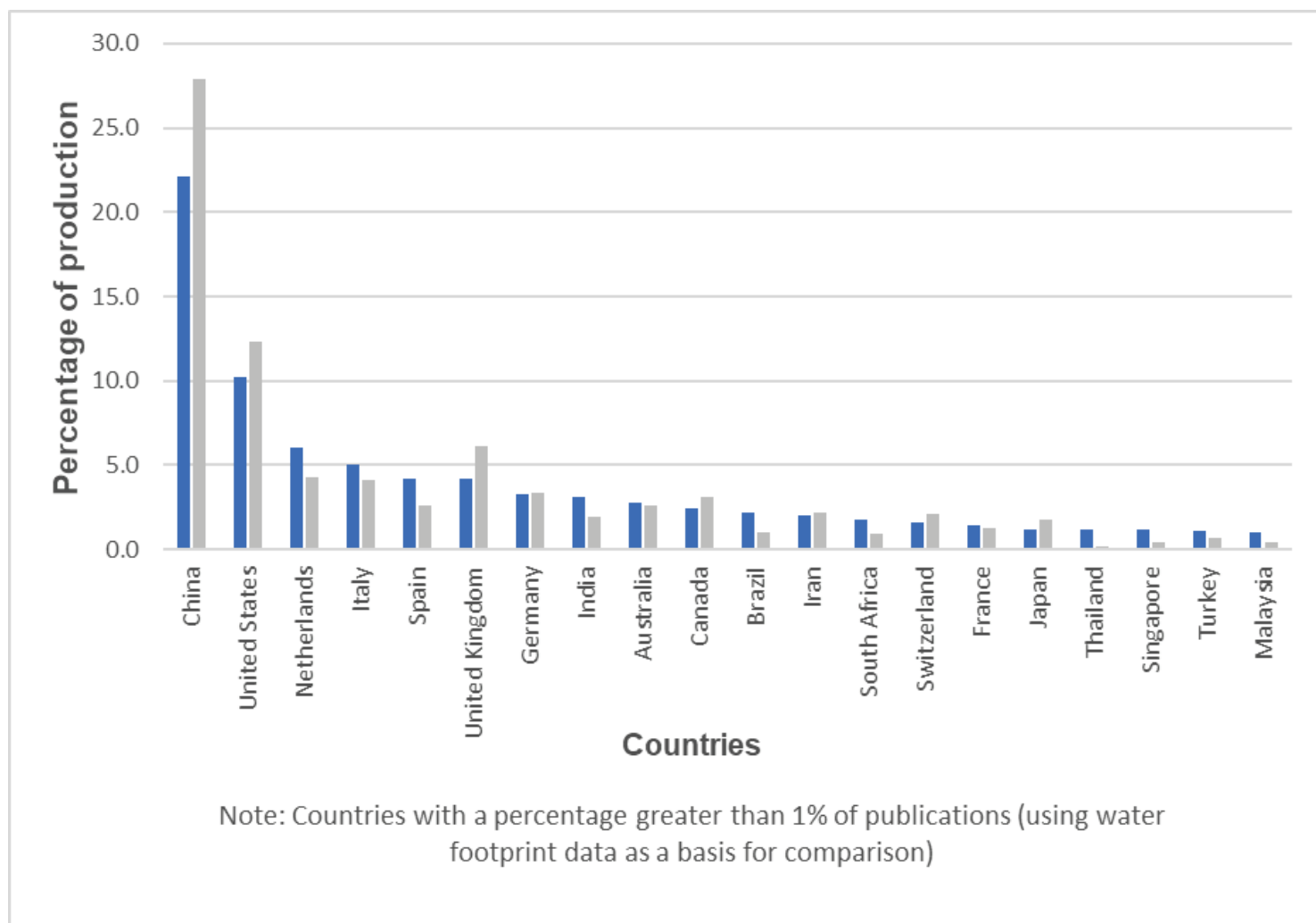


Figure 4. Leading countries in the publication of research on virtual water and water footprint. Source: Own elaboration with Scopus data, 2024.

The leadership of the People's Republic of China has been built with the support of its complex network of links, with the countries with the most publications on the subject (Figure 5): United States, Germany, United Kingdom, Japan and the Netherlands. This group of nations have

increased their productivity as of 2015 supported precisely by these connections.

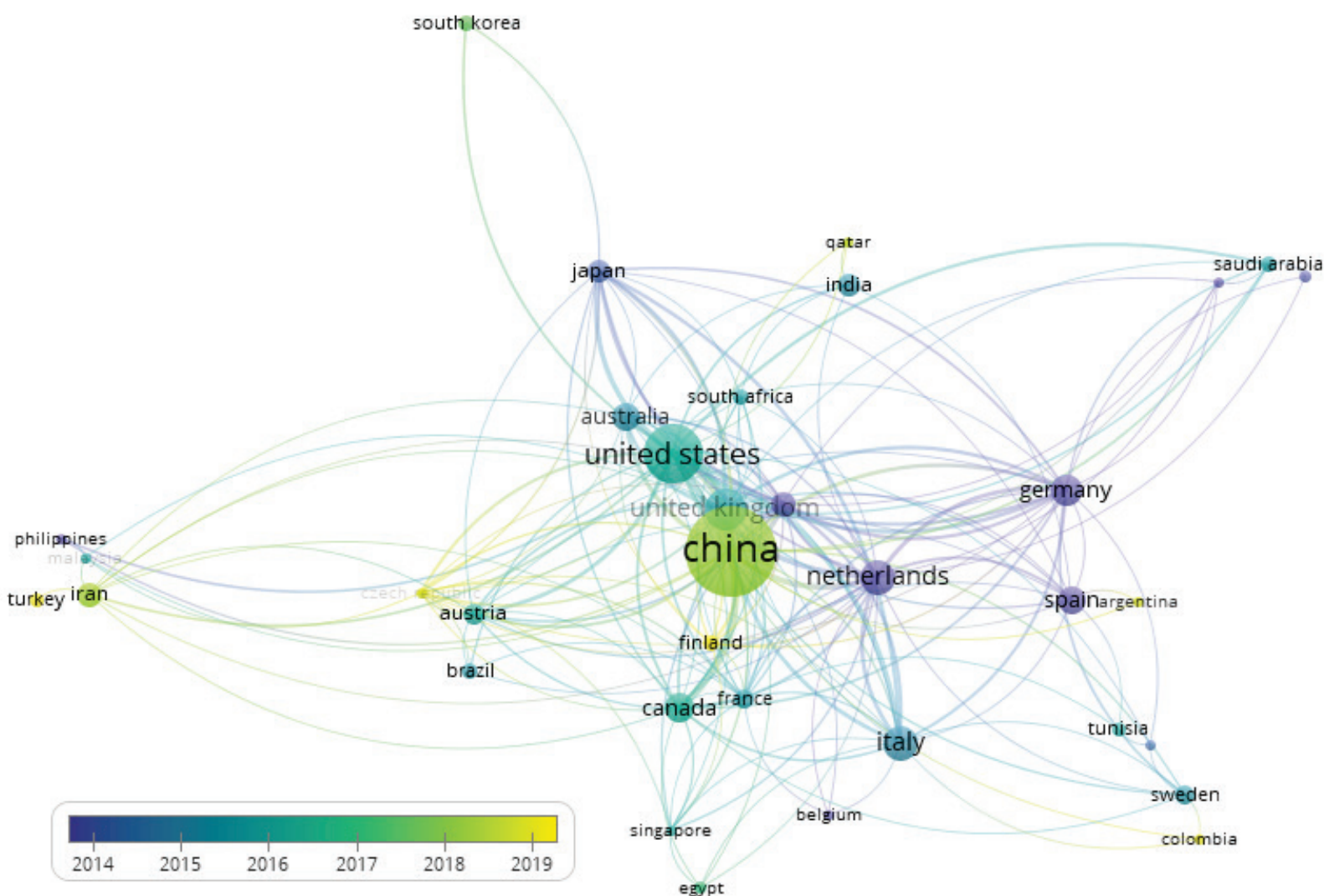


Figure 5. Networks of countries with publications on virtual water, 2005–2023. Source: Own elaboration with Scopus data & VOSviewer 2024.

In relation to the global output of analyses on the water footprint concept, the participation of 19 countries with contributions of more than 1 % is documented. Their contributions account for 76.9 % of the documents recorded up to 2023 (Figure 3). In this configuration, China contributes 22.1 % of the publications, followed by the United States (10.2 %), The Netherlands (6.0 %), Italy (5.0 %), Spain (4.2 %), the United Kingdom (4.2 %), Germany (3.3 %), and India (3.1 %). In addition, 11 countries with shares greater than 1 % but less than 3 % of the total publications detected are included in the group.

The mapping of networks of countries with publications on water footprint confirms China's leadership (Figure 6). Its positioning comprises a complex of interactions with the United States, the Netherlands, Italy, Spain, the United Kingdom and Germany. The network has increased with contributions from countries that, until then, had no relevant participation in water footprint research, such as Brazil (2.2 %), Iran (2.0 %), South Africa (1.8 %), Switzerland (1.6 %), Japan (1.2 %), Thailand (1.2 %), Singapore (1.2 %), Turkey (1.1 %).

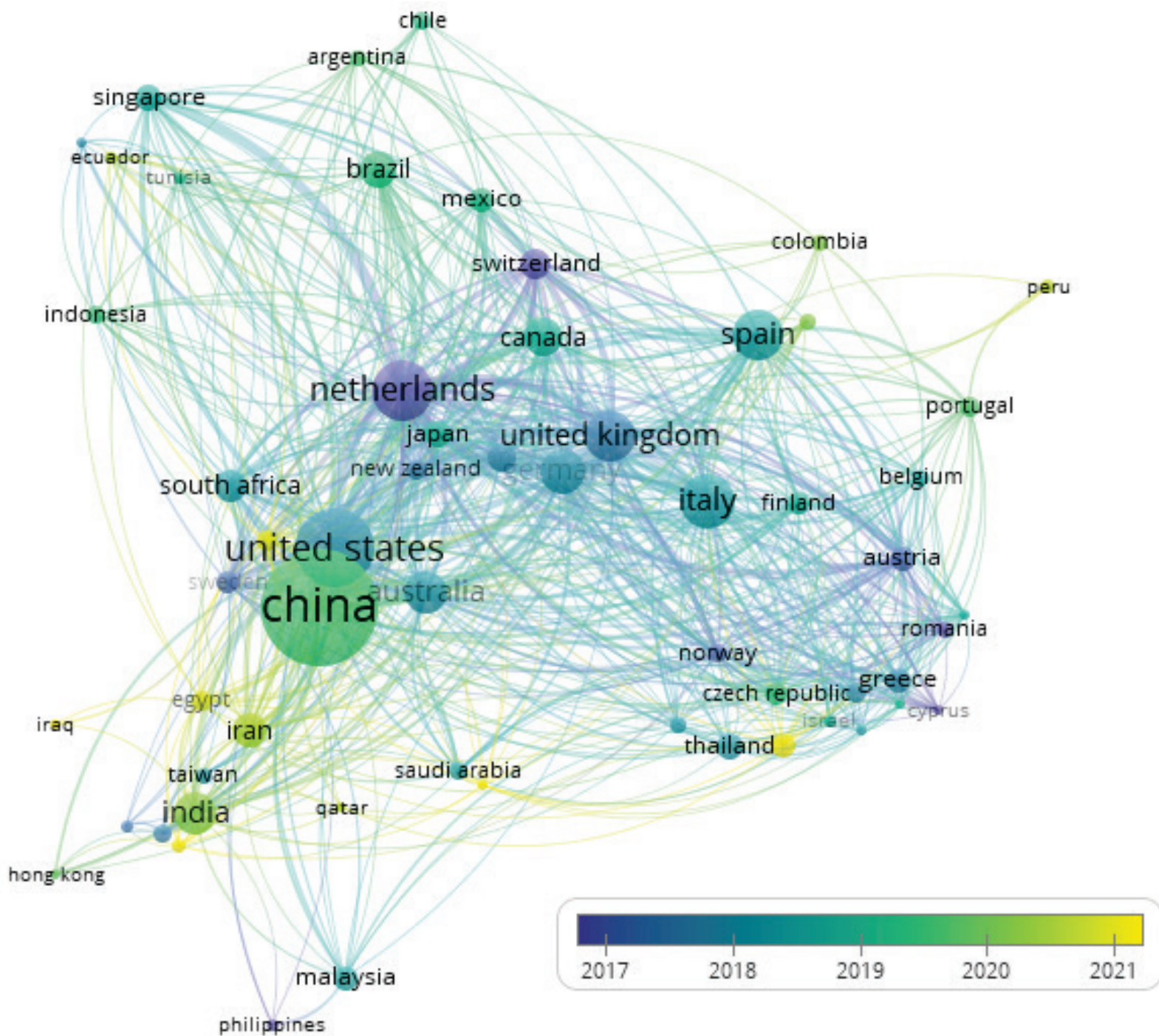


Figure 6. Networks of Countries with Publications on Water Footprint, 2005–2023. Source: Own elaboration with Scopus data & VOSviewer 2024.

Source and institutional affiliation of the thematic areas virtual water and water footprint

Journals that issue at least 0.97 % of publications on water topics account for 57.12 % of the virtual water topic and 63.9 % of the water footprint (Figure 7). The journals *Journal of Cleaner Production*, *Science of the Total Environment*, *Water Switzerland* make up the first three places in these topics with the predominance of water footprint.

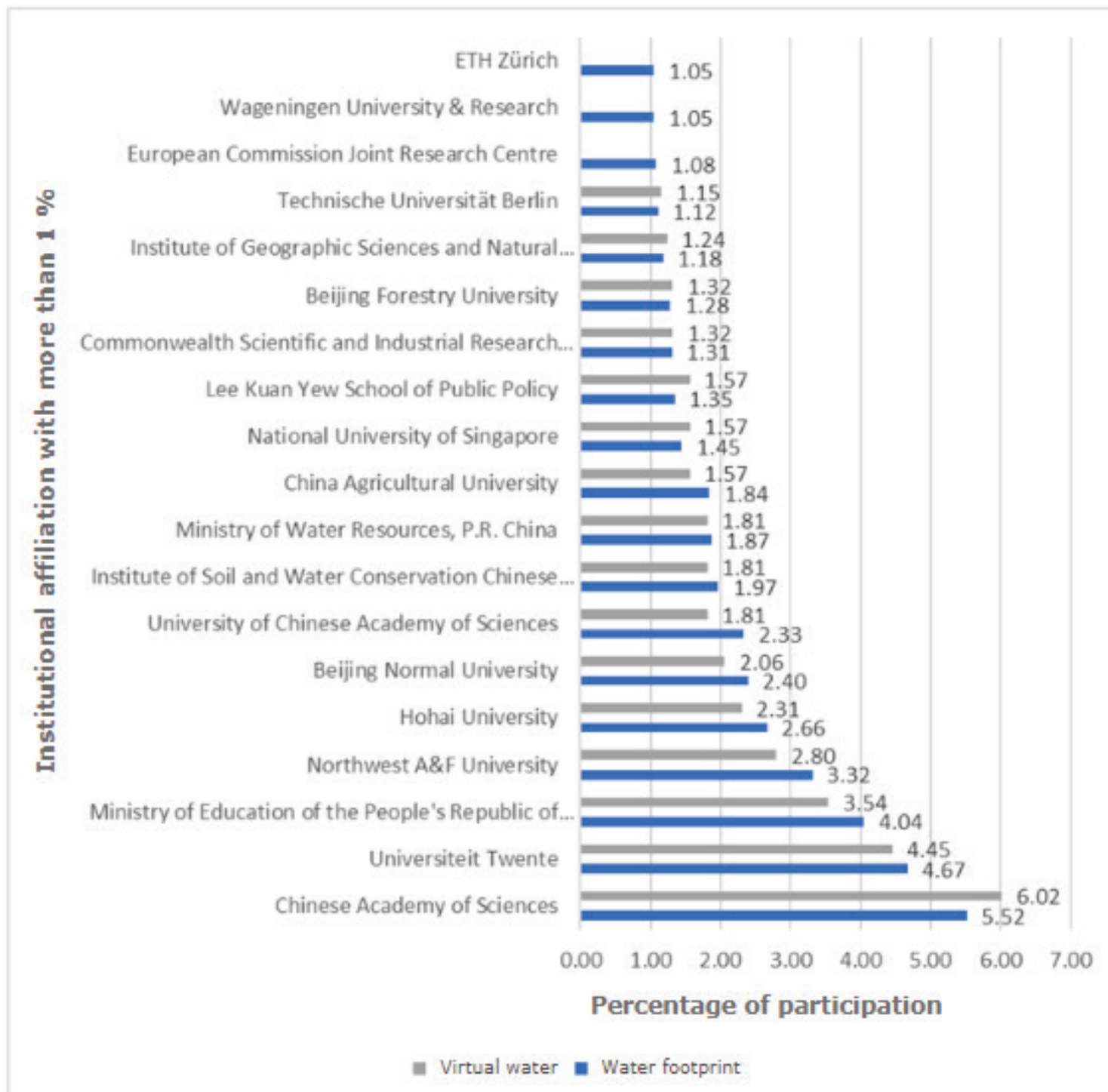


Figure 7. Institutional affiliation of individuals related to the concept of virtual water and water footprint. Source: Own elaboration with Scopus data 2024.

Leading journals in the publication of water footprint and virtual water products

This confirms the leadership and specialization in this area of knowledge by the People's Republic of China, as well as the institutional interest in water issues of those who lead the efforts of the Chinese Academy of Sciences, the Beijing Normal University and the University of Chinese Academy of Sciences (Figure 7).

Funding

Funding for global water research comes mainly from the People's Republic of China, whose institutions jointly support 91 % of research on virtual water and 92.5 % on water footprint. In the field of virtual water, the contributions of the National Natural Science Foundation stand out, which supports 49 % of the research. It is followed by the National Key Research and Development Program (12.3 %); Fundamental Research Funds for the Central Universities of China (8.5 %) and the National Science Foundation of the United States (7.9 %), among the most important.

Global water footprint research is mainly funded by Chinese institutions. The National Natural Science Foundation of China (426) and the National Key Research and Development Program (119) alone have together sponsored 50 % of this century's research. For the United States, the National Science Foundation (70), and for the European community, the Fundamental Research Funds for the Central Universities (68),

Horizon 2020 Framework Program (4.8 %), European Commission (4.8 %), and the European Regional Development Fund (3.0 %).

Country co-authorship

The international networks of co-authorship in virtual water analysis position China as the central node of collaboration, with the concurrence of the United States and the United Kingdom (Figure 8). The mapping of interconnections is evidence of intense collaboration and interdependence in the construction of specialized work between these countries.

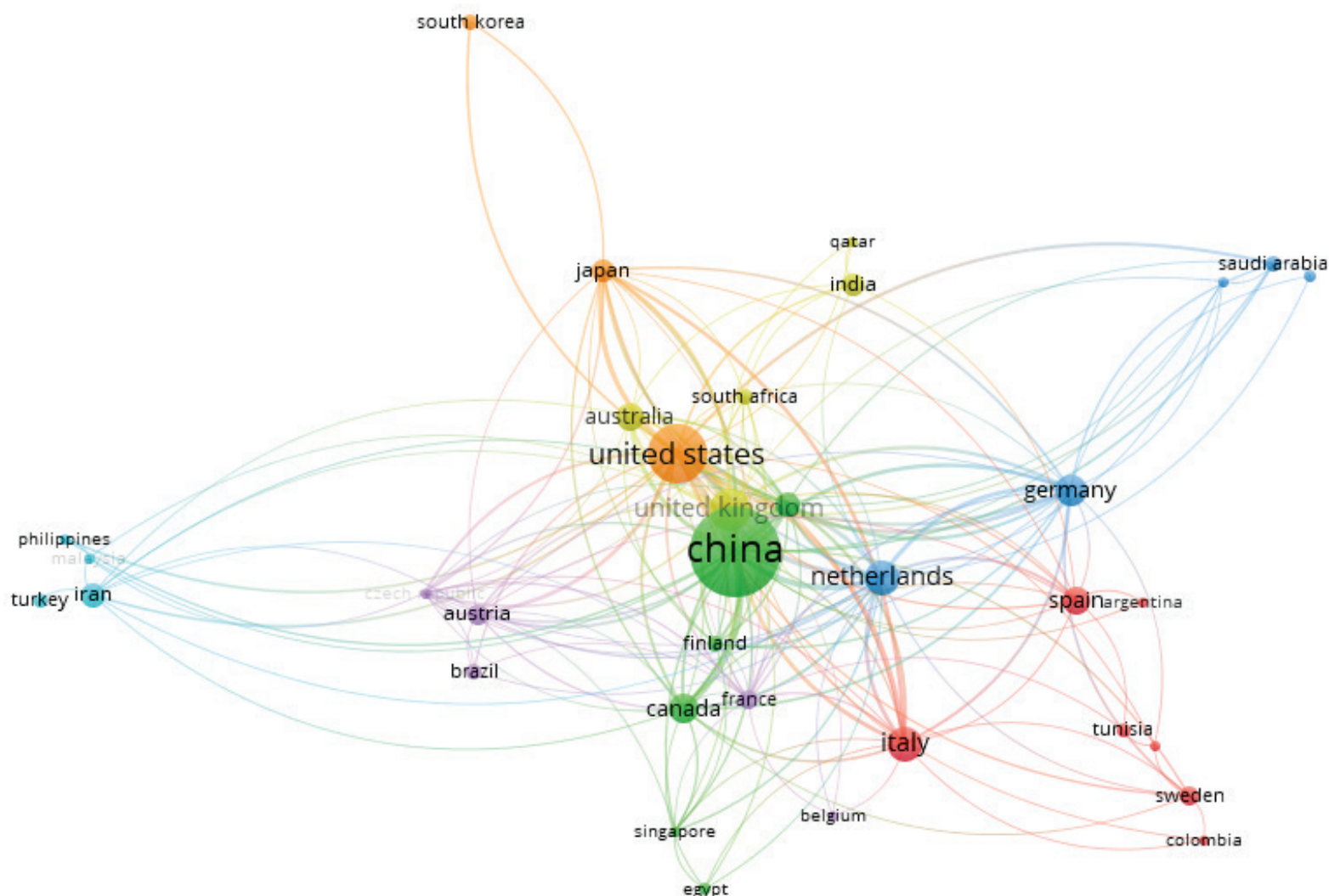


Figure 8. Co-authorship network of countries on the topic of virtual water. Source: Own elaboration with Scopus data & VOSviewer 2024.

Figure 9 describes a network co-authorship collaboration between countries with China as the central node, which confirms its collaborative and knowledge management leadership. Its variety of connections with the United States, United Kingdom, Germany, Japan and other countries confirm the global reach of this topic.

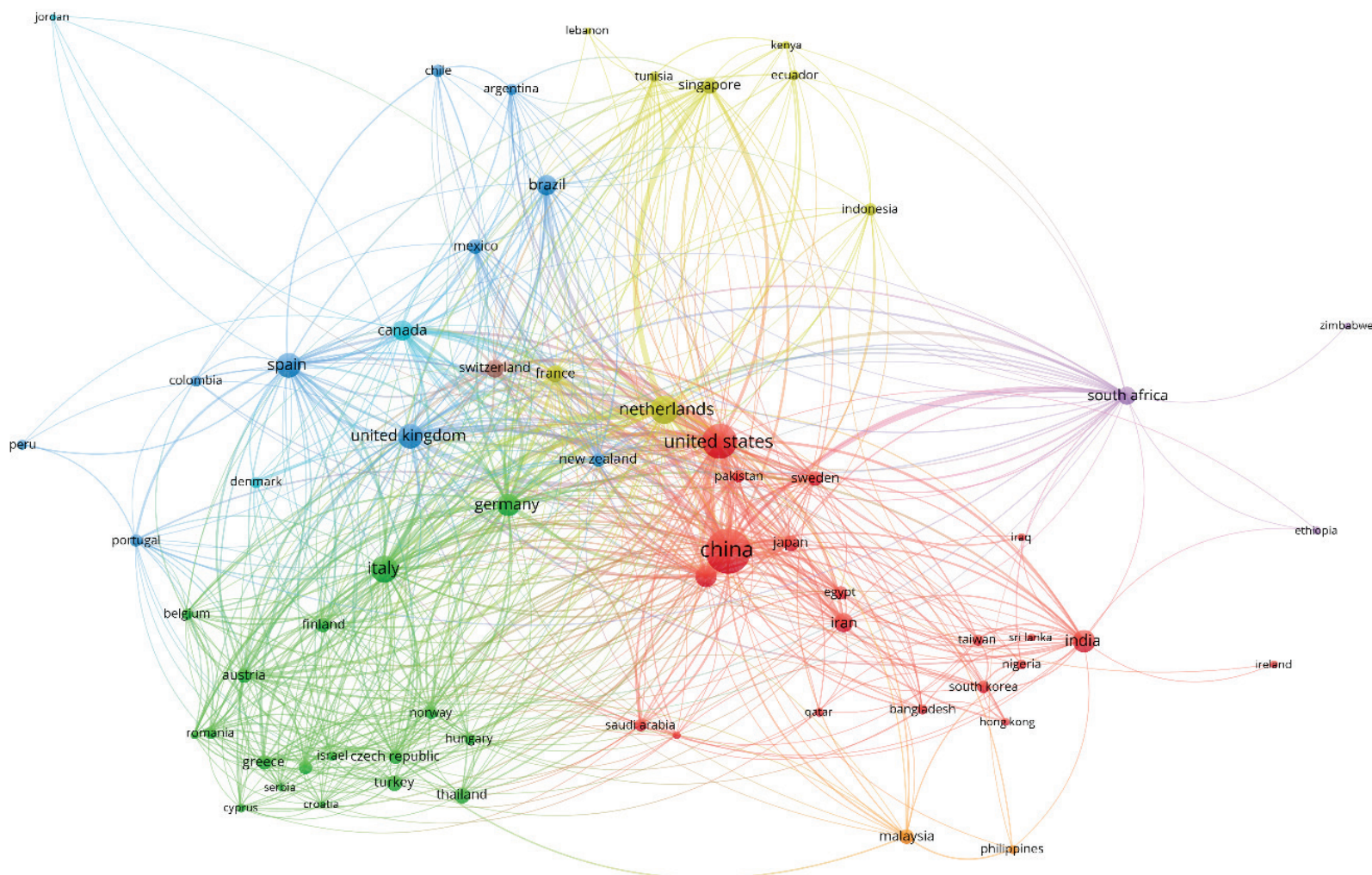


Figure 9. Co-authorship Network of Countries on the Topic of Water Footprint. Source: Own elaboration with Scopus data & VOSviewer 2024.

Discussion

Scientific production on the concepts of virtual water and water footprint displayed similar trends during the first decade of the 21st century. During this period, the academic community emphasized the complementary potential of the water footprint concept, introduced in 2002, in relation to virtual water, proposed in 1993. The water footprint offered a multidimensional and flexible approach to assess the sustainability of a product or system within a spatial and temporal framework (Briones-Cabrera *et al.*, 2024). By contrast, virtual water was limited to quantifying the amount of water required to produce a good or service, without considering spatial or temporal variations. These limitations reduced its capacity to analyze pollution and water sustainability, particularly in the context of massive transfers of virtual water across regions, which undermined water security by disrupting the Water-Energy-Food (WEF) nexus, a critical element for sustainable development (FAO, 2015). Following the identification of this nexus at the 2011 World Economic Forum, and the recognition of the relevance of the water footprint for its analysis, a significant increase in specialized literature was observed.

The surge of water footprint research during the second decade of the 21st century did not displace interest in virtual water studies. On the contrary, two academic communities with substantive contributions emerged around each concept, alongside a group of scholars exploring their complementarities and leading global research networks on water issues. Prominent authors include A. Y. Hoekstra, Wu, P., Wang, Y., Gao, X., Zhuo, L., and Wang, S., with Hoekstra being the most prolific and widely cited in both areas. Chapagain and Pfister stand out in virtual water studies, whereas Mekonnen, M. M. is highly regarded in water footprint

research, according to citation averages.

Bibliometric analyses of co-authorship networks reveal structural differences: Research on virtual water exhibits less cohesive academic communities with fewer central nodes, while water footprint studies show greater interconnectedness, fostering methodological convergence and the consolidation of analytical standards. This cohesion may partly explain the growth and visibility of the water footprint concept.

Regarding disciplinary composition, environmental and Earth sciences predominate, with a strong ecological orientation. Some perspectives have criticized the fact that more effort has been devoted to methodological development and dissemination of both concepts than to the analysis of power relations underlying such flows (Beltrán & Velázquez, 2021). From the mid-2010s onwards, the incorporation of transdisciplinary approaches based on mixed methods has become more visible, with contributions from the social sciences, environmental economics, and, to a lesser extent, ecological economics. The limited participation of the latter is striking, given the high relevance of virtual water and water footprint indicators in making visible the distributive ecological conflicts generated by the social metabolism of the economy (Beltrán & Velázquez, 2021). These debates are consistent with the growing interest of global public policy in the face of climate change and population growth, considering the strategic role of water in sustainability and development (Chaparro & Leguizamón, 2022).

Nevertheless, despite the increased global interest in water-related phenomena, the dominant channel of dissemination remains scientific journal articles, highlighting a production profile more oriented toward the academic community than toward public outreach or policymaking.

In this context, international collaboration networks are emerging to manage water issues in agriculture, the environment, human settlements, industry, health, and climate change. China leads in knowledge production and dissemination, as well as in supporting academic institutions through funding for specialists in virtual water and water footprint research. The United States and several European countries follow in importance. Conversely, the limited participation of developing countries reflects a structural bias in knowledge generation, potentially restricting the inclusion of local perspectives on water-related challenges in vulnerable regions. Such is the case in Latin America, where, according to CEPAL (2021), there are persistent gaps and imprecisions in water consumption data at the subnational scale.

Conclusions

The global water reserves available for human use are finite and unequally distributed; more than 60 % of these reserves are concentrated in just 10 countries. The amount of usable freshwater per person in the Middle East and North Africa is only a fraction of what is available in Latin America. Even in countries with abundant water reserves, some regions can experience severe water scarcity. Furthermore, future water availability is subject to significant changes due to climatic variations, seasonal changes, droughts, and floods.

These phenomena highlight the importance of prioritizing environmental education and building values that support the sustainable use of water resources. Raising awareness about the consequences of irrational resource use should be an integral part of human education and development. Undoubtedly, this requires a massive interdisciplinary

effort, supported by all scientific fields contributing to environmental discourse (Caycedo & Trujillo, 2020).

Review analyses help researchers synthesize and construct scientific assumptions, identify trends, patterns, and statistical inferences to formulate hypotheses, characterize the state of the art in the field, and highlight new knowledge gaps. This research specifically aimed to examine the bibliometric characteristics of the concepts of virtual water and water footprint. The results reveal the relevance of these topics, not only through the continuous increase in publications but also through the growing collective awareness regarding the importance of managing water sustainability. This is reflected in the expansion of research coverage across different regions, which increasingly subscribe to the study of these concepts.

The analysis of publications related to virtual water and water footprint reveals a significant shift over time. Initially, both topics emerged in the early 21st century, growing almost in parallel until 2010, with virtual water leading in publications. However, from 2011 onward, publications on Water Footprint have seen continuous growth up to 2023. This shift reflects the increasing need to understand, measure, and manage water sustainably across various human activities.

Similarly, the data analysis helps explain how virtual water and water footprint concepts have grown together but have diverged over time due to the need for specialization and in-depth research. Despite their differences, both concepts serve as essential tools for educating, measuring, and illustrating to the general public the impact of mass consumption of goods and services on water resources.

Thus, the importance of studying virtual water and water footprint lies in reassessing the value of water and recognizing its significance in fostering collective action for its protection. Ensuring responsible water management is essential to preserving this invaluable resource, securing a sustainable and equitable future for future generations, and maintaining the balance of ecosystems and life itself.

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