
AI translation · View original & related papers at
chinaxiv.org/items/chinaxiv-201806.00052

Postprint of Bibliometric Analysis of Water Footprint Using CiteSpace

Authors: Zhang Cancan, Sun Caizhi

Date: 2018-06-09T00:00:00+00:00

Abstract

Using journal papers from 1993-2016 in the Web of Science database and the China National Knowledge Infrastructure (CNKI) Academic Journal Network Publishing Database as data sources, a literature search was conducted with “water footprint” OR “virtual water” as keywords. The CiteSpace visual literature analysis tool was employed to analyze keywords, authors, publishing institutions, and source journals of the retrieved literature, and to construct relevant knowledge maps, thereby exploring the development status and future research hotspots in the water footprint research domain. The results indicate:

The number of research publications in the water footprint field continues to grow, with water footprint research receiving increasing attention from scholars both domestically and internationally; International water footprint research primarily focuses on virtual water and water footprint, with relatively high attention to water rights issues, whereas domestic water footprint research mainly concentrates on virtual water trade and virtual water consumption, with applied research becoming a hotspot. Future water footprint research hotspots may revolve around the coupling of water-food-energy nexus, and research efforts integrating water footprint with socio-economic issues will gradually intensify; Authors of both Chinese and foreign-language literature in the water footprint field are concentrated among a limited number of researchers, and the studies of the main authors have laid the foundation for water footprint research; Major publishing institutions include Univ Twente, Chinese Academy of Sciences, etc., and major source journals include ECOL ECON, HYDROL EARTH SYST SC, WATER RESOUR MANAG, as well as Resources Science, China Population, Resources and Environment, Acta Ecologica Sinica, etc. Based on the current status of water footprint research, recommendations for the future development of the water footprint field are proposed.

Full Text

Bibliometric Analysis of Water Footprint Literature Based on CiteSpace

Zhang Cancan¹, **Sun Caizhi**¹ ¹School of Urban and Environmental Sciences, Liaoning Normal University; Marine Economy and Sustainable Development Center, Liaoning Normal University

Abstract: This study employs the CiteSpace visualization tool to conduct a bibliometric analysis of water footprint literature retrieved from the Web of Science and CNKI databases using “water footprint” and “virtual water” as keywords. The analysis covers 2000–2016 for foreign literature and 2003–2016 for Chinese literature, examining publication volumes, keywords, authorship, institutions, and journals to map the knowledge structure of this research field. Results indicate that water footprint publications have grown continuously since the concept’s introduction. Foreign research primarily focuses on virtual water and water footprint theory with considerable attention to water rights issues, while domestic Chinese research emphasizes virtual water trade and consumption. The coupling of water footprint with socioeconomic problems represents an emerging hotspot. Authorship is concentrated among a small group of researchers whose work has laid the foundation for the field. Major publishing institutions include the University of Twente and the Chinese Academy of Sciences, with key journals being *Ecological Economics* and *Resources and Environment*. Based on current research trends, we propose directions for future water footprint studies.

Keywords: water footprint; CiteSpace; bibliometric analysis

1 Introduction

Water resources are intimately linked to human survival and socioeconomic development. However, irrational water use during societal progress has led to water scarcity and pollution, making water resources an increasingly limiting factor for economic growth worldwide. This has created an urgent need to accurately measure humanity’s actual water consumption. The concept of “virtual water” was introduced by British scholar Tony Allan in 1993, defined as the volume of water required to produce goods and services—the amount of water virtually embedded in products and services [1]. Building upon this, Dutch scholar Hoekstra and colleagues proposed the “water footprint” concept in 2002, referring to the total freshwater volume needed to produce the goods and services consumed by a country’s or region’s population [2]. Similar to the ecological footprint concept introduced by Canadian scholar William E. Rees in the early 1990s [3], water footprint measures the water resources needed to produce goods and services for a given population, representing the real water volume required to sustain human consumption patterns. By calculating humanity’s true appropri-

ation of water resources from a consumption perspective and linking water use to consumption patterns, water footprint expands problem-solving approaches into the socioeconomic domain, becoming an effective indicator for assessing environmental impacts of human activities on water systems.

Over the past decade since its introduction, water footprint has attracted widespread attention from scholars globally. Research has concentrated on single-product water footprint analysis [4-5], influencing factor studies [6-9], and regional or national-level water footprint assessments [10-13], along with structural analyses [14]. While literature reviews have been conducted [15-18], most rely on subjective statistical analysis rather than quantitative methods. Bibliometrics applies mathematical and statistical techniques to quantify literature volume and terminology, while knowledge mapping visualizes these results. CiteSpace, developed by Dr. Chen Chaomei at Drexel University's College of Computing and Informatics, has become a popular tool for visualizing scientific research data [19], widely applied in bibliometric analysis since its inception [20-24]. This study employs bibliometric methods to quantitatively analyze water footprint literature, using CiteSpace to generate knowledge maps that reveal research patterns and objectively illuminate trends in this field, aiming to identify emerging frontiers and hotspots.

2 Data Sources

We utilized CiteSpace 5.0.R2.SE for data processing and analysis. The water footprint definition is clear: the total freshwater volume required to produce goods and services consumed by a population. Considering that virtual water constitutes an important component of water footprint and water footprint research builds upon virtual water theory, we established foreign literature search terms as “water footprint” OR “virtual water”. Data were retrieved from the Web of Science Core Collection (SCI-EXPANDED) for 2000-2016, limited to article-type publications. After deduplication and removal of irrelevant entries, we obtained 1,520 relevant documents distributed across 2000-2016.

For Chinese literature, search terms were similarly set as “water footprint” OR “virtual water”, with data sourced from CNKI's China Academic Journals Full-text Database. Using advanced search with precise matching for 2003-2016, we retrieved and refined 1,248 relevant documents, all distributed across 2003-2016.

3 Temporal Analysis of Publication Volume

3.1 Foreign Literature Publication Trends

Foreign water footprint publications showed an overall upward trend from 2000–2016, with minor fluctuations. The growth can be divided into three phases: (1) **2000–2006**: Low-volume 徘徊 period. Following the concept’s introduction, water footprint—a novel offshoot of virtual water—was still under discussion, with limited publications. However, interest grew through conferences like the 2002 Third World Water Forum in Japan, 2005 Expert Meeting on Virtual Water Trade in Germany, and 2006 Fourth World Water Forum in Mexico. (2) **2006–2013**: Fluctuating ascent. Water footprint gained international attention, though research scope remained undefined, resulting in slower growth. (3) **2013–2016**: Rapid expansion. The 2015 Paris Climate Conference highlighted climate change as a critical planetary issue. Since the hydrosphere’s three-state changes significantly impact climate, water research became vital for global climate response, ushering water footprint into a new era. Despite ongoing debates and imperfections, these discussions accelerated concept refinement, establishing water footprint as a prominent research field.

3.2 Chinese Literature Publication Trends

Chinese water footprint publications (except for minor annual declines) showed overall growth, divided into three phases: (1) **2003–2005**: Explosive growth from 2 to 22 articles. China’s vast territory and diverse industries, combined with extremely uneven spatiotemporal water distribution, created urgent demand for new research methods. As a novel concept, water footprint quickly attracted expert attention. (2) **2005–2012**: Fluctuating ascent. Research focused on regional and product water footprint calculations. Despite continued growth, the field encountered bottlenecks requiring new methods and content. (3) **2012–2016**: Steady high-volume growth. Research shifted toward spatiotemporal variation analysis, regional water resource evaluation, and other expanded applications, marking a new stage where water footprint became widely applied as an effective water problem-solving tool.

[Figure 1: see original paper] shows foreign and Chinese publication numbers from 2000–2016.

4 Keyword Analysis

Keywords represent authors’ core arguments. Visualizing them helps identify research hotspots. We imported foreign and Chinese literature data separately into CiteSpace, setting the timeframe to 2000–2016 (foreign) and 2003–2016 (Chinese) with one-year slices. Clustering sources included titles, abstracts, author keywords, and keywords-plus, with burst terms selected and node type set to keyword. Selection criteria used the top 50 most-cited items per slice.

4.1 Foreign Literature Keyword Analysis

The foreign literature keyword map (network density: 0.0223) shows larger nodes for more frequent keywords. The largest node is “water footprint”, with related terms including “footprint”, “green”, “consumption”, and “blue”. The second major node, “virtual water”, indicates this remains a key focus. High-frequency keywords include “water footprint”, “virtual water”, “consumption”, “resource”, “trade”, and “footprint”. In foreign water footprint research, water resources are examined not merely as natural resources but also in economic trade and water rights contexts. The two largest nodes represent absolute hotspots with highest centrality and frequency, whose branches indicate future research directions.

[Figure 2: see original paper] displays the foreign literature keyword knowledge map. lists high-frequency keywords (frequency > threshold), revealing concentrated research on water consumption and trade, mostly related to socioeconomic life. High attention to virtual water trade is evident. Keywords like “land use” and “environmental impact” show water footprint’s interdisciplinary connections. As research deepens, lifecycle assessment and input-output analysis have gained prominence, reflecting sustainability’s growing importance.

4.2 Chinese Literature Keyword Analysis

The Chinese literature keyword map (network density: 0.0065) shows “virtual water trade” as the largest node, followed by “virtual water strategy” and “sustainable development”. Related research includes water resource carrying capacity and security. Chinese water footprint research extends beyond natural resource studies into socioeconomic domains, broadening solution approaches and diversifying sustainability applications. Keyword rings show “virtual water consumption” and “water resource carrying capacity” as early hotspots, with “sustainable development” gradually replacing “virtual water trade” and “ecological footprint” as the emerging focus.

[Figure 3: see original paper] shows the Chinese literature keyword map. lists high-frequency keywords. Compared to foreign literature, Chinese research emphasizes food security and water resource evaluation—understandable given China’s large population, agricultural prominence, and severe water imbalance. Foreign keyword citation frequencies are more evenly distributed, creating cohesive clusters, while Chinese keywords show greater disparity.

5 Author Group Analysis

5.1 Foreign Literature Author Analysis

CiteSpace analysis of foreign authors (network density: 0.0093) shows node size proportional to publication count. The most prolific author is Mekonnen

MM (23 papers), followed by Hoekstra AY (22 papers), the concept's originator. Other authors with 10+ papers include Wang YB, Wu PT, Pfister S, Sun SK, Zhao XN, Yang H, Konar M, Liu J, and Ridoutt BG. Three core author groups emerge: (1) University of Twente cluster centered on Hoekstra AY and Mekonnen MM; (2) Northwest A&F University cluster including Wang YB, Wu PT, Sun SK, and Zhao XN; (3) Swiss Federal Institute of Technology cluster with Yang H and Pfister S. Foreign author collaboration is tighter than among Chinese scholars.

[Figure 4: see original paper] shows the foreign author knowledge map. ranks authors by publication count. The 12 authors with 10+ papers account for 23.7% of total publications, indicating high concentration. Hoekstra's foundational work guides international water footprint research, with other studies building upon his framework.

5.2 Chinese Literature Author Analysis

Chinese literature author analysis (network density: 0.0029) reveals Sun Caizhi as the most frequent author (19 papers), followed by Qin Lijie (11 papers). Only these two authors exceed 10 publications, together accounting for 14.8% of Chinese water footprint literature, showing even greater concentration. Their pioneering work established China's water footprint research foundation. Other notable contributors include Tian Guiliang, Wang Xinhua, Yang Yurong, Wu Pute, and Han Yuping.

[Figure 5: see original paper] shows the Chinese author knowledge map. lists prolific authors. The dendritic pattern indicates China's water footprint field is in a "school-based" stage: tight intra-team collaboration but limited inter-team communication. Major teams include Sun Caizhi's, Wang Xinhua's, Yang Yurong's, Wu Pute's, Qin Lijie's, Han Yuping's, and Tian Guiliang's groups. This fragmentation hinders scientific development.

6 Institution Analysis

6.1 Foreign Literature Institution Analysis

Analysis of foreign institutions (network density: 0.0147) shows node size proportional to publication volume. Geographic distribution is uneven, with top institutions concentrated in coastal countries: Netherlands, Japan, and Europe—these nations possess advanced technology and urgent water demand, demonstrating how research capacity and water scarcity drive water footprint studies. The University of Twente (Netherlands) leads with 89 papers (28.39% of total), followed by the Chinese Academy of Sciences. Twente's location in Enschede and Hoekstra AY's affiliation explain its dominance. China's vast territory and severe water imbalance also motivate deep water research.

[Figure 6: see original paper] shows the foreign institution knowledge map. lists top institutions.

6.2 Chinese Literature Institution Analysis

Chinese institution analysis (network density: 0.0049) reveals the Chinese Academy of Sciences as the top publisher, followed by Hohai University and Liaoning Normal University. Geographic distribution is uneven, concentrated in coastal universities and water-scarce northwest inland regions, suggesting water stress correlates with research intensity. Ten institutions published 10+ papers. As China's premier academic institution, the Chinese Academy of Sciences provides scientific support for national decision-making. Hohai University, specializing in water conservancy with state key laboratories, is a traditional water research powerhouse. Institutions with high water footprint output typically have dedicated research teams.

[Figure 7: see original paper] shows the Chinese institution knowledge map. lists top institutions.

7 Journal Analysis

7.1 Foreign Literature Journal Analysis

CiteSpace statistics show *Ecological Economics* (Elsevier, Netherlands) published the most water footprint articles during 2000–2016. The journal focuses on natural resource evaluation, sustainable agriculture, and ecological integration technology. Other high-volume journals include *Environmental Science & Technology*, *Global Environmental Change*, *Journal of Environmental Management*, *Journal of Industrial Ecology*, and *Energy Policy*, indicating water footprint's relevance to environmental change, security, and economic development. Specialized water resources journals demonstrate the field's maturity.

lists top foreign journals.

7.2 Chinese Literature Journal Analysis

Chinese journal analysis shows *Resources and Environment* published the most water footprint articles, followed by *Journal of Northwest A&F University*, *China Rural Water and Hydropower*, and *Resource Development & Market*. Core journals with high impact factors (e.g., *Journal of Natural Resources*, *Resources and Environment in the Yangtze Basin*, *Journal of Arid Land Resources and Environment*) represent the field's core and frontier. Water footprint research spans resource science, environmental science, and geophysics, forming a multi-disciplinary intersection.

lists top Chinese journals.

8 Discussion and Outlook

This bibliometric analysis using CiteSpace identifies water footprint research hotspots, core author groups, major institutions, and key journals. Since the concept's introduction, related publications have grown continuously. Analysis of international literature through 2016 reveals water footprint and virtual water's increasingly prominent role in water resource management. Changing international conditions and mounting water scarcity pose new challenges. Future research should focus on:

1. **Shifting research emphasis:** Water footprint introduces new perspectives to water management, transforming pure natural resource issues into socioeconomic problems. The research focus is shifting from virtual water trade and strategy to more practical applications, reflecting scholars' orientation toward utility.
2. **Coupling with major issues:** Water scarcity, food security, and energy issues are three major challenges to global socioeconomic stability. Their coupling represents a future hotspot. Researchers should leverage water footprint's unique advantages to address water problems.
3. **Theoretical system development:** Despite abundant achievements since 2002, water footprint lacks a unified theoretical system. Research content and direction remain unsettled. Strengthening basic theory is urgent to establish unified evaluation systems, as current disparate systems yield inconsistent regional water resource assessments.
4. **Expanding research scope:** Current regional studies concentrate on urban areas, neglecting rural regions with substantial water resources and consumption. Establishing water footprint archives for rural and marginal industries is essential. As social division of labor refines, water footprint accounting should extend beyond mainstream industries to marginal sectors.
5. **Enhancing academic collaboration:** Both international and Chinese water footprint research shows high author concentration, with work centered on few researchers. While these scholars laid the foundation, sustainable development requires cultivating successor generations through graduate training and specialized forums. Currently, intra-institutional collaboration is strong but inter-team cooperation is weak, hindering long-term progress. Academic forums should facilitate exchange and integration.
6. **Developing specialized journals:** As a critical natural resource research area, water resources lack sufficient specialized journals, limiting timely dissemination and discussion of findings. Organizing high-quality,

dedicated journals would accelerate water footprint development by providing platforms for rapid, accurate transmission of latest results.

References

- [1] Allan J A. Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible. In: ODA, Priorities for Water Resources Allocation and Management. London: ODA, 1993. 13-26. [2] Chapagain A K, Hoekstra A Y. Value of Water Research Report Series (No.16). IHE Delft, 2004. 1-80. [3] Wackernagel M, Rees W E. Our ecological footprint: reducing human impact on the earth [M]. Gabriola Island: New Society Publishers, 1996. [4] [5] [6] [7] [8] [9]. 1998-2012 South Xinjiang cotton consumption water footprint and its ecological impact. Research of Soil and Water Conservation, 2009, 16(02): 176-180+185. [10] Temporal evolution analysis of cotton production water footprint [D]. Northwest A&F University, 2012. [11] Analysis of water footprint evolution and influencing factors in China' s industrial sectors. Journal of Natural Resources, 2014, 29(12): 2114-2126. [12] Study on water footprint changes and driving mechanisms in Wuwei Oasis agriculture. Journal of Natural Resources, 2013, 28(03): 410-416. [13] Impact of affluence and technology on China' s water footprint, 2006, 26(10): 3358-3365. [14] Measurement and driving pattern analysis of provincial grey water footprint efficiency in China, 2016, 38(06): 1179-1191. [15] Spatiotemporal differences of water footprint in Hebei Province based on virtual water theory. Journal of Natural Resources, 2012, 27(06): 1022-1034. [16] Water footprint calculation and analysis, 1999-2009. Arid Land Geography, 2013, 36(02): 364-370. [17] Water resources evaluation in Anhui Province based on water footprint theory. Resources and Environment in the Yangtze Basin, 2014, 23(02): 220-224. [18] Water resources evaluation of Jiulong River Basin based on water footprint theory, 2012, 34(10): 1905-1912. [19] Agricultural water footprint and structural change characteristics, 1980-2012. Journal of Arid Land Resources and Environment, 2015, 29(06): 133-138. [20] Water footprint research progress, Upmanu Lall, 2013, 33(18): 5458-5466. [21] Comparison of virtual water and water footprint. Resources and Environment, 2013, 33(04): 78-83. [22] Review of China' s water footprint research. Journal of Tongji University (Social Science Edition), 2012, 23(04): 43-49. [23] Progress in water footprint theory, accounting methods and applications. Advances in Science and Technology of Water Resources, 2013, 223(11): 73-80. [24] Methodological functions of CiteSpace mapping knowledge domains. Studies in Science of Science, 2015, 33(02): 242-253. [25] Knowledge mapping analysis of China' s marine economy research, 2016, 36(01): 89-96. [26] Spatial association pattern analysis of China' s provincial water footprint intensity. Journal of Natural Resources, 2013, 28(04): 571-582. [27] Spatial econometric analysis of provincial water footprint intensity convergence in China, 2012, 32(08): 1020-1025. [28] Analysis of relationship between economic growth and water footprint intensity convergence based on spatial effects, 2014, 30(07): 810-812+820. [29] Water

fairness evaluation and spatiotemporal evolution analysis from water footprint perspective, 2013, 38(10): 63-68. [30] Study on water footprint of corn production in western Jilin Province, 2015, 31(08): 978-981+1025. [31] Green water footprint of corn under different irrigation conditions in Jilin Province, 2014, 34(05): 1085-1093. [32] Study on water footprint of corn growth process in Jilin Province, 2013, 35(11): 2224-2231. [33] Study on dietary water footprint of Changchun residents, 2014, 36(09): 1799-1809. [34] Dietary water footprint of urban residents with different income levels in Jilin City. Journal of Northeast Normal University (Natural Science Edition), 2013, 45(04): 135-140.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv –Machine translation. Verify with original.