Water Footprint

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The water footprint (WF) is a widely recognised and comprehensive indicator of both the direct and indirect appropriation of freshwater. It has been utilised for diverse functions, including as a key indicator of the planetary boundaries and United Nations Sustainable Development Goals. (draft for definition)

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1. Introduction

The water footprint (WF) measures the consumptive and degradative freshwater appropriations of human activities, which can be attributed to production, consumption, and trade[1]. As a comprehensive water consumption indicator, WF has played increasingly diverse roles in the fields of hydrology, environmental science, and sustainability. Green (rainwater consumption) and blue (surface and groundwater consumption) WF accounting enable the identification and mapping of green and blue water scarcity in time and space[2][3][4][5][6]. The grey WF (the water required for water pollutant dilution) assessment has inspired the creation of new water scarcity indicators, such as the blue water scarcity index as the ratio of sectoral water withdrawals of acceptable water quality to the overall water availability proposed by Van Vliet et al. [7]. The environmental impact analysis of water consumption has been improved by incorporating WF indicators in multiregional input–output (IO) modelling[8][9] [8,9] and life cycle assessments (LCAs)[10]. As a part of the "footprint family"[11], the WF has become one of the key indicators for planetary boundaries[12] and for measuring the United Nations Sustainable Development Goals (SDGs) at various scales[13][14]. Therefore, it is not surprising that the cumulative number of published articles on WFs expanded from 80 by December 2010 to 1775 by August 2020 in the Web of Science (WoS) database.

Most WF studies have been conducted at the country or regional scale[15]. China has the largest total WF for national production[16], and it ranks fourth in the groundwater footprint for food production[17]. One in four people facing moderate to severe water scarcity for at least one month in a year live in China . Given the spatial and temporal heterogeneities of water resource endowments, the climate, the soil, economic structures, production, and consumption patterns within China, studying the Chinese WF at various intranational geographical scales has been a popular undertaking. Searching for the keyword "water footprint" in journal article titles in the WoS, 31% (i.e., 215 of 702) concern China. Additionally, there are approximately 100 articles (in Chinese) in the China National Knowledge Infrastructure (CNKI) database on WFs. Several review papers [18][19][20][21] focused on WF studies in China. Wu et al.[19] and Qian et al. [20] summarised the primary methodologies and algorithms used in the WF assessment for Chinese products. Sun and Shen[19] reviewed Chinese literature on ecological, carbon, water, and energy footprints and concluded that research on WFs was less developed than that on ecological and carbon footprints. Zhu et al.[21] provided a systematic bibliometric review on WFs in China regarding trends in research region distributions, keywords, and methods. However, aside from the conventional bibliometric analysis, an in-depth summary of Chinese WF research is lacking in terms of study content and achievable implementations for practical water resource management.

Based on the bibliometric analysis of articles published from January 2003 to June 2020 in English (WoS) and Chinese (CNKI), this study explores state-of-the-art WF accounting, driving force analyses, and environmental impact assessments. The implementations and limitations of Chinese water management strategies and possible future study directions are also discussed.

2. Implementations and Limitations

Implementations of WF concepts in practical water resources management strategies and policies depend on robust measurements, comprehensive impact assessments, feasible reflections, and widespread awareness. All these are subject to the spatial resolution of analysis and the quality of data. Adding information to WF figures by comparing WFs to benchmarks or local environmental or economic conditions helps to display their grades and impacts[22]. According to the current analysis in terms of keywords in considered publications as well as trends in WF accounting for China, existing

WF estimations and research for China were primarily on WF magnitudes, components in terms of water colours, and variation in time and space, while little information was available for WF benchmarks and viable action manuals. The WF spatial and temporal heterogeneities in agricultural production under varied climatic conditions and crop yield levels have been largely reported in[21]. Industrial WF datasets, especially for the textile industry and energy production, have been developed. Blue and green water scarcity levels from agricultural production and consumption in northern China have been revealed in finer spatial and temporal units[6]. According to the driving factor assessment, utilising water-saving technologies in crop fields, industrial restructuring, trade network optimisation, consumption pattern (diet) adjustments, and water price reformation have largely been recommended theoretically in the reviewed literature for reducing WFs in China. However, as previously mentioned, there is little information on the robustness of these WF values based on the algorithm used, and the spatial-temporal resolutions lack sufficient quantitative uncertainty analyses. Additionally, operable measures for reducing WFs were not found. Therefore, it is not surprising that WF research has not been widely incorporated by local water policies in China. Only 23 projects have been funded with "water footprint" in their titles, as compared to the over-1600 projects with words "water resources consumption" and to the over 2300 projects with words "water productivity", by the National Natural Science Foundation of China at the end of August 2020[23]. The only two existing governmental actions related to the WF include the issue of the Chinese version of ISO 14046 as a national standard (GB/T 33859-2017/ISO 14046:2014)[24] and the Water Supplies Department of Hong Kong introduction of global average WF values, using term "virtual water", of common food and industrial products on their website[25].

3. Future Directions

Due to its ability to measure different water consumption sources at any spatial or temporal scale and be integrated with other environmental impact indicators [90], the WF has been widely highlighted as an effective metric for constructing evaluation frameworks for the water–food–energy nexus[26][27], determining the water planetary boundary[28], and measuring the progress of SDGs related to water security[13][14]. However, four primary knowledge gaps must be remedied before using WF assessments to identify and resolve the increasingly complex water issues in China. First, as shown in current results, multiple methodologies exist for WF accounting and impact analysis. In choosing one or multiple proper methodologies and taking advantages of each, the most important step is clarifying the purposes of the WF accounting or impact analysis. Each kind of methodology has its own unique advantages and scope of application. Regarding WF accounting, the Water Footprint Network bottom-up approach, especially for agricultural products, can directly record the WF of producing a specific kind of product, whereas the multiregional IO-based WF modelling is able to show the appropriation of water resources by the entire supply-chain of a sector[29]. Regarding WF impact analysis, the Water Footprint Network framework shows WF inventory and tends to assess its impacts on local water resources physically; whereas the LCA-based ISO framework focused on the level of impacts on human health, ecosystems, and resource depletions by using indexes in unit of H_2O equivalent[30]. Second, for each water-use sector, WF accounting standards with unified measurements of uncertainties by verified algorithms are urgently needed. There is only one study currently available on the quantification of uncertainties in WF accounting for crops in the Yellow River Basin[31], and it is limited to certain tested crops, models, and scales. Although there is information in ISO 14046 on the principles of uncertainty analysis (see Section 3.6.3 in the ISO 14046 standard), case studies are scarce. Validations of existing WF algorithms and modelling in field experiments for the agricultural sector, enterprise monitoring for the industrial sector, and large sampling social surveys for households should be performed. At the same time, we should always keep in mind and try to answer the questions of how representative the field trials are, and of what level/scale—having in mind that water use/requirements can be very diverse from one field to the other. Of course, the balance between the complexity and efficiency in dealing with the abovementioned knowledge gaps should be taken into account. Third, widely valid and tested methodologies for setting WF benchmarks must still be developed. For industrial sectors, WF benchmarks can be set according to the optimal production techniques and supply chains[32]. Finally, assessments of the social and economic effects of WFs must be developed as WFs are generated by social and economic activities. Many studies have demonstrated how regional WFs affect local water resources or water quality; however, they lack information on the social and economic effects of the WFs. The next step is to distinguish between the green and blue water economic values to determine the associated economic effects (e.g., [33]).

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