Review of the Water Footprint Project within Geographically Delineated Area

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Abstract: During the last decade, there has been an intensive research activity concerning the concept of the Water Footprint (WF) approach, which was firstly introduced by Arjen Hoekstra in 2002. WF is an indicator of direct and indirect freshwater use of a consumer or producer that takes into account water consumption in every step (intermediate and final) along the production chain and services. The concept can be implemented in various levels such as products, consumers, producers, nations and river basins etc.. The water footprint within a geographically delineated area equals the sum of the process water footprints of all processes taking place in the area. The aim of current research is a review of the most important WF studies, with a special focus on applications within regional, basin and administrative unit level. National and global scales are not included in the current paper. The article presents the most widespread methodologies and approaches that attempt to evaluate water footprints of specific defined areas and highlights their recent advances as well as shortcomings in the constantly evolving research efforts.

Key words: Water footprint, review, water resources management, geographically delineated area.

1. Introduction

The Water Footprint (WF) is an indicator closely correlated with virtual water [1] that was introduced in an effort to relate fresh water use to human consumption. The difference between virtual water and WF is that the latter contains further information such as the type of water used (blue, green or grey) but also when and where it is used. The water footprint of an individual, community or business is defined as the total volume of freshwater used to produce the goods and services consumed by the individual or community or produced by the business [2]. The WF of business is mainly useful to the private sector (hotspots in supply chains and benchmarking of products etc.), while the WF of a given region provide stakeholders with helpful information. This paper discusses the WF within a geographically delineated area which is defined as the total freshwater consumption and pollution within the boundaries of

the area. The area can be a hydrological unit such as a catchment area or a river basin or an administrative unit like a municipality, province, state or nation [2]. This review summarizes research projects applicable at basin level or subnational administrative units and regions. National and global scales are not included in the current review because it is beyond the scope of this topic.

2. Materials

This paper analyses three WF methodologies: a stand-alone method according to international Water Footprint Network (WFN) [2] which is the most widespread so far, Life Cycle Assessment (LCA) based methods and Environmentally Extended Input-Output (EEIO) tables and models. The first one provides volumetric WF on the aspect of water resources management, the second one is an impact oriented approach and the third one evaluates the relationship between economic activities and downstream environmental impacts.

According to WFN method, WF can be separated

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into the three components of blue, green and grey water. Blue WF refers to the consumption of surface and groundwater water resources, green WF has to do with rainwater as it does not become run-off and grey WF is the volume of freshwater that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards. The four phases of the method are: setting goals and scope, WF accounting, WF sustainability assessment and WF response formulation. Recently, Arjen Hoekstra proposed three pillars under wise freshwater allocation: WF caps per river basin, benchmarks per product and fair shares per community [3].

A WF of a geographically delineated area can be assessed with the top-down or the bottom-up approach. The bottom-up approach computes WF by multiplying all goods and services consumed by the inhabitants of a country, with the corresponding water needs of those goods and services. On the other hand, in the top-down approach, WF is calculated as the total use of water resources in the country by adding to this the imported virtual water and subtracting the exported virtual water. The top-down approach is considered more convenient for quick calculation of nation WF, while the upward approach is more appropriate to calculate the WF of an individual, a company or a smaller geographical area where there are no available input-output data [2]. The bottom-up approach depends on the quality of consumption data, while the top-down approach relies on the quality of trade data. When the different databases are not consistent with one another, the results of both approaches will differ [4].

Over the past decades, one of the most frequent applications of input-output analysis has been the interaction of the economy and the environment [5]. Input-output analysis is a top-down economic technique, which uses sectoral monetary transactions data to account for the complex interdependencies of industries in modern economies [6]. The IO approach

to economic data was developed by Nobel prize winner Wassily Leontief [7-9], who also gave an introduction to the input-output method and its application to environmental problems. IO tables have been used widely to account for regional WFS and represent the economic interconnections of the transactions of virtual water among the examined economic sectors.

The Multi-Regional Input-Output (MRIO) model is a useful tool for tracing environmental impacts of consumption between sectors within an economic region and multiple regions [10]. Subnational applications of MRIO are more difficult to implement than international applications, because of inconsistent and misaligned data [11]. The ability to “geo-position” environmental pressure, and link it to regional environmental resource and socio-economic conditions, is vital for assessing sustainable scale and impacts for many environmental resources [12]. EIOA approaches are particularly useful when one wants to look at the direct and indirect water requirements of an entire final consumption pattern of a nation, a region, a lifestyle group or a household. Because such a final consumption pattern is comprised of so many different goods and services that bottom-up approaches have problems in providing all the required process-based descriptions of production and water consumption in their supply chains [13].

EEIO provides a simple and rapid method that can be used to evaluate the upstream environmental impacts associated with downstream economic consumption, as well as the embodied environmental impacts in traded goods [14]. EEIO research can contribute to the establishment of environmental, economic and social data inventories which can be used to inform about the monetary water transactions among economic sectors of the area of interest.

Due to the data intensive and bottom-up nature of traditional life cycle assessment, LCA can be excellent for measuring direct inputs, but presents difficulties when accounting for indirect inputs [15]. Hybrid LCA

and IO-LCA provide top-down approaches to LCA that accounts for both direct and indirect inputs. Hybrid approaches piecing together LCA and top down approaches are being implemented to address multi-scale issues in geographically delineated areas, by combining the advantages of both bottom-up and top-down approaches.

Several papers have been published in an effort to propose various ways to integrate WF into LCA inventories [16-20]. LCA is the investigation and evaluation of the environmental impacts of a given product or service and consists of four phases: goal and scope, life cycle inventory, life cycle impact assessment and interpretation [21]. Bradley Ridoutt and Stephen Pfister [22] have introduced a stand-alone LCA-based procedure. Water Accounting and Vulnerability Evaluation (WAVE) model has been developed to enable the accounting of water use and the analysis of the vulnerability of a basin to potential impacts resulting from it [23]. Furthermore, the International Organization for Standardization has recently launched ISO 14046: 2014 project [24], aiming at creating an international standard for WF.

The accounting of green water is controversial, since in LCA based methods, it is considered that the consumption of green water itself does not contribute to water scarcity and due to the inseparability of green water and land, the consumption of green water in agricultural product life cycles is better considered in the context of the land use impact category [20]. As well, there is a conflict about estimating water consumption without taking into account the type of water used and the local scarcity of the studied area. For that reason, the Water Stress Index (WSI) was introduced as a coefficient of the water pressure that weighs WF. WSI for various basins worldwide were calculated by Pfister et al. [16]. According to Bradley Ridoutt and Stephan Pfister [20], it is misleading to sum different forms of water consumption with different opportunity costs as blue water has higher opportunity cost than green water [25], in areas that

differ in their water shortages because impacts associated with all forms of consumption differ. They also mislead that the methodology by Arjen Hoekstra and Ashok Chapagain has developed independently from LCA and therefore, there is no clear relationship between WF and the potential caused social or environmental damage. On the other hand, Arjen Hoekstra et al. [26] maintain that volumetric WF contain highly relevant information, which disappears when translating volumes into arguable aggregated WF impact indices without physical interpretation, because it is completely meaningless in a water resources management context and that footprints were designed to show the pressure of humans on the environment, not the impacts.

3. Results and Discussion

3.1 Regional and Basin Level

As green water refers to agriculture sector which is also the main consumer of blue water, many WF studies deals with that sector. However, there is an effort to comprehend the majority of economic sectors of an examined area (Table 1). So far, owing to lack of data, studies which quantify grey WF are limited and mostly focused on nitrogen and phosphorus input from agriculture into water bodies [27-31]. In the case of bottom-up and top-down methods, both have been implicated in the river basin level. Bottom-up approach have been applied to Guadiana river basin, Heihe basin, Guadalquivir basin and 365 European basins [28, 32-34]. Multi-Regional Input-Output (MRIO) models have been used for the Yellow river basin and the Haihe basin [10, 35]. Yet Yuan Zhi et al. [4] and Xu Zhao et al. [36] used a Generating Regional IO Tables (GRIT) method to bridge the gap in quantitative knowledge from the perspective of a river basin. Alberto Garrido et al. [37] applied a top down approach to evaluate the Spanish water footprint variations from year to year, not only at a national but also at provincial and river basin taking into consideration economic aspects. The WWF combined

WF analysis and economic data for the horticulture and agriculture sectors in the lake Naivasha basin, in Kenya [38]. Some of the studies apart from surface water also estimate groundwater in WF accounting [4, 29, 32, 34, 39, 40]. Zhuo et al. [41] applied a sensitivity analysis method for the Yellow river basin to investigate the sensitivity of the WF of a crop to changes in input variables and parameters. Stuart Orr et al. [42] quantified additional land and water required to replace lost fish protein with livestock products, because of proposed dam construction in the lower Mekong basin.

3.2 Administrative Unit

Although WF accountings at river basin levels are more appropriate for decision making within water resources management than a traditional political unit [43], official data are not easily obtained at such a geographic region. In administrative scale, where trade data are more easily available, several papers are based on top-down approaches [44-47]. Huijuan Dong et al. [48] employed IO analysis method to evaluate not only the water footprint of the whole province but also water footprints of different economic sectors within this province. Yang Yu et al. [49] computed WFs of all sectors in the entire economy as well. Davy Vanham and Giovanni Bidoglio, Simona-Andreea Ene et al., Bultink F. et al., Guoping Zhang et al., and San Luis Agua S. E. [50-54] included the grey water component.

Some studies divided countries in sub-catchments, mostly at provinces level to examine interactions within countries [37, 49, 52, 55]. Julian Fulton et al. [56] compared the U.S. WF to California's WF and found that policy-relevant differences stand out, arguing that such findings demonstrate that WF assessments may find more policy relevance when scaled to analytical units where water-related decision making occurs. Stanley Mubako et al. [57] investigated the geographical patterns of water footprint and virtual water trade among U.S. states

and illustrated that the economic geography of the production of water-intensive products, and the institutions that link people to the sources of their WF is where the heart of the water scarcity issue lies.

Richard Rushforth and Benjamin Ruddell [58] were the first to comprehensively analyze water footprints and virtual water flows within a municipality in metropolitan area, intra-metropolitan area flows, and national scale flows simultaneously. They quantified water footprints and virtual water flows of the complete economy of the Phoenix metropolitan area's municipalities.

To link the spatially heterogeneous patterns of cities and ecosystem service production rates, Klaus Hubacek et al. [59] applied ascenario analysis based on input-output methodology and compared Beijing to China for the year 2020.

Daniele Bocchiola et al. [60] evaluated the impact of climate change upon WF and VW trade and benchmarked objectively adaptation strategies for agricultural systems. Guoping Zhang et al. [53] worked on a comprehensive project across 35 sub-catchments within the Hertfordshire and north London area that included blue, green and grey water footprints on surface and groundwater, for the domestic, industrial and agricultural sectors on a monthly basis and a climate change scenario for 2060. Table 1 presents a synopsis of the studies.

4. Conclusions

Some analysts support that WF alone, contains too little pertinent information to guide policy makers who should also consider the social, political, and economic aspects of water use in any setting. Furthermore, they claim that water related problems should be solved locally and not through global governance schemes or trade barriers [61-63]. Besides, Arjen Hoekstra et al. [2] stress that it is still a partial tool. It provides information for water consumption and water scarcity but it does not account for water aspects like flooding. The grey WF methodology needs

Table 1 Summary of studies that have evaluated the WF at the regional, basin and administrative unit level.

Geographical unit*	Authors	Year	Area of study	WF components	Multisector
RB	CTA et al. [27]	2013	Porce river basin (Colombia)	Blue, green, grey	✓
RB	Dumont, A. et al. [34]	2013	Guadalquivir basin (Spain)	Blue, green	✓
RB	Zeng, Z. et al. [33]	2012	Heihe river basin (China)	Blue, green	✓
R	Aldaya, M. M. [29]	2010	Doñana region (Spain)	Blue, green, grey	✓
RB	Aldaya, M., and Llamas, M. [32]	2008	Guadiana river basin (Spain)	Blue, green	✓
RB	Vanham, D. and Bidoglio, G. [28]	2014	European river basins	Blue, green, grey	
RB	De Miguel et al. [30]	2015	Duero river basin (Spain)	Blue, green, grey	
RB	Marini, E. et al. [31]	2015	Water district of western Peloponnese (Greece)	Blue, green, grey	✓
RB	Feng, K. et al. [35]	2012	Yellow river basin (China)	Blue, green	✓
RB	White, D. J. et al. [10]	2015	Haihe river basin (China)	Blue	✓
RB	Zhi, Y. et al. [4]	2014	Haihe river basin (China)	Blue	✓
RB	Zhao, X. et al. [36]	2010	Haihe river basin (China)	Blue	✓
LB	WWF [38]	2010	Lake Naivasha basin (Kenya)	Blue, green	✓
RB	Hoekstra, A. Y. [39]	2012	405 river basins	Blue	✓
RB	Zhuo, L. et al. [41]	2014	Yellow river basin (China)	Blue, green	
RB	Orr, S. et al. [42]	2012	Mekong river basin		
R	Aldaya, M. M. et al. [40]	2009	Mancha occidental region (Spain)	Blue, green	
A	Zhang, Z. et al. [44]	2011	Beijing (China)	Blue	✓
A	Zhang, C., and Anadon, L. D. [45]	2014	China provinces	Blue	✓
A	Cazcarro, I. et al. [46]	2010	Huesca (Spain)	Blue	✓
A	Wang, Z. et al. [47]	2013	Beijing (China)	Blue, grey	✓
A	Dong, H. J. et al. [48]	2013	Liaoning (China)	Blue	✓
A	Vanham, D., and Bidoglio, G. [50]	2014	Milan (Italy)	Blue, green, grey	✓
A	Ene, S. A. et al. [51]	2012	Iasi county (Romania)	Blue, green, grey	✓
A	Bulsink, F. et al. [52]	2010	Indonesian provinces	Blue, green, grey	
A	Zhang, G. P. et al. [53]	2014	Hertfordshire and north London area	Blue, green, grey	✓
A/RB	Garrido, A. et al. [37]	2010	Spain provinces and river basins	Blue, green	✓
A	Ma, J. et al. [55]	2006	North and south China	Blue, green	
A	Yu, Y. et al. [49]	2010	Southeast and northeast UK	Blue, green	✓
A	Fulton, J. et al. [56]	2014	California	Blue, green, grey	✓
A	Mubako, S., and Lant, C. L. [57]	2013	Interstate transfers in the U.S. States	Blue, green	✓
A	Rushforth, R., and Ruddel, B. [58]	2015	Phoenix, Arizona Metropolitan area	Blue	✓
A	Hubacek, K. et al. [59]	2009	Beijing and China	Blue	✓
A	Bocchiola, D. et al. [60]	2013	Po valley of Italy	Blue, green	
A	San Luis Agua S. E. Ministerio del Campo and Gobierno de la Provincia de San Luis [54]	2015	Province of San Luis	Blue, green, grey	✓

*A—Administrative unit, R—Region, RB—River Basin, LB—Lake Basin.

to be further standardized [64] and there is an absence of an agreed water quality standard to use when estimating dilution requirements [61]. More research needs to be done on sustainability assessment with an

emphasis on integration of social and economic factors. It is very important to take into account the environmental relevance and when accounting reduction targets regarding WFs within catchments, to

be formulated on the basis of relative water scarcity per catchment [65]. The incorporation of climate change, uncertainties and economic consequences to WF studies needs to be strained. Moreover, databases on water availabilities and environmental flow requirements especially at the river basin level need to be improved, since the success on an application lays on the availability of data. There is a big challenge to establish a widely accepted concept for all WF components and environmental impacts in water accounting. However, there is a big progress in methodological evolution that allows more sophisticated and elaborated quantifications. WF provides helpful information for allocating water more efficiently, improving land-use planning, developing a water-saving culture and can contribute significantly to water resources and sustainability management in combination with other tools.

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