THE WATER FOOTPRINT PROJECT WITHIN A GEOGRAPHICALLY DELINEATED AREA: THE STATE OF THE ART

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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 first 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, countries, river basins etc.

The aim of the paper is a review of the most important WF studies with a special focus on applications within geographically delineated areas (e.g. a river catchment). The review 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. WF approach provides quantitative data relative to spatial and temporal boundaries, concerning freshwater consumption and pollution of each process taking place in the defined area. Furthermore, it can take into account imports and exports of the virtual water within the area of interest. Thus, WF applications within geographically delineated areas could be a useful tool in the hands of administrations and could contribute significantly to proper water resources management and sustainable regional development in every scale (from local to international level).

Keywords: Water Footprint, review, water resources management, geographically delineated area

1. Introduction

The water footprint (WF) is an indicator closely correlated with virtual water (Allan, 1993) 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 (Hoekstra *et al*., 2011). The WF of business is mainly useful to the private sector (hotspots in supply chains, benchmarking of products etc.) while the WF of individuals 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 for example a hydrological unit such as a catchment area or a river basin or an administrative unit like a municipality, province, state or nation (Hoekstra *et al*., 2011). National and global scales are not included in the current review.

2. Methodologies

There are two main standard WF methodologies: a stand-alone method according to international Water Footprint Network (WFN), (Hoekstra *et al*., 2011) which is the most widespread so far and Life Cycle Assessment (LCA) based methods. The first one provides volumetric WF on the aspect of water resources management while the second one is an impact oriented approach.

According to Hoekstra method WF can be separated into the three components of blue, green and grey water that refer to the consumption of surface and groundwater water resources, rainwater as it does not become run-off and the volume of freshwater that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards, correspondingly. The four phases of the method are: setting goals and scope, WF accounting, WF sustainability assessment and WF response formulation. Recently Hoekstra proposed three pillars under wise freshwater allocation: WF caps per river basin, benchmarks per product and fair shares per community (Hoekstra, 2014).

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, while in the top-down approach, WF is calculated as the total use of water resources in the country, if we add to this the imported virtual water and subtract 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 (Hoekstra *et al*., 2011). 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 (van Oel *et al*., 2009).

Several papers have been published in an effort to propose various ways to integrate WF into LCA inventories (Pfister *et al*., 2009), (Bayart *et al*., 2010), (Boulay *et al*., 2011), (Milà i Canals *et al*., 2008), (Ridoutt and Pfister, 2010). 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 (Rebitzer *et al*., 2004). Ridoutt and Pfister (2012) 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 (Berger, 2014). Furthermore, the International Organization for Standardization has recently launched ISO 14046 2014 project 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 (Ridoutt and Pfister, 2010). 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*. (2009). According to Ridoutt and Pfister (2010), it is misleading to sum different forms of water consumption with different opportunity costs as blue water has higher opportunity cost than green water (Chapagain *et al*., 2006), in areas that differ in their water shortages because impacts associated with all forms of consumption differ. They also disadvantage that the methodology by Hoekstra - Chapagain has developed independently from LCA and therefore there is no clear relationship between WF and probably caused social or environmental damage. On the other hand Hoekstra *et al*. (2009) 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. Literature review

3.1. River 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 (Arévalo *et al*., 2012), (Dumont *et al*., 2013), (Zeng *et al*., 2012), (Aldaya and Llamas, 2010.), (Aldaya and Llamas, 2008). 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. In the river basin level few papers include grey WF (Vanham and Bidoglio, 2014a), (Aldaya and Llamas, 2010). 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 (Aldaya and Llamas, 2008), Heihe Basin (Zeng *et al*., 2012), Guadalquivir basin (Dumont *et al*., 2013) and 365 European basins (Vanham and Bidoglio, 2014a). Multi-regional input–output (MRIO) models (top down method), have been used for the Yellow river basin (Feng *et al*., 2012) and the Haihe basin (White *et al*., 2015). Yet Zhi *et al*. (2014) and Zhao *et al*. (2010) used a Generating Regional IO Tables (GRIT) method to bridge the gap in quantitative knowledge from the perspective of a river basin. Some of the studies apart from surface water also estimate groundwater in WF accounting (Dumont *et al*., 2013), (Zhi *et al*., 2014), (Schreier *et al*., 2007), (Hoekstra *et al*., 2012). Zhuo *et al*. (2014), 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. Orr *et al*. (2012) 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 (EC, 2012), 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 (Zhang *et al*., 2011), (Zhang and Anadon, 2014), (Cazcarro *et al*., 2010), (Wang *et al*., 2013). Vanham and Bidoglio (2014b), Ene *et al*. (2012), Bulsink *et al*. (2010) and Zang *et al*. (2014) included the grey water component. Aldaya *et al*. (2009) and Garrido *et al*. (2010) distinguished between surface and groundwater. Some studies divided countries in sub-catchments, mostly at provinces level, to examine interactions within countries (Ma *et al*., 2006), (Bulsink *et al*., 2010), (Garrido *et al*., 2010). Bocchiola *et al*. (2013) evaluated the impact of climate change upon WF and VW trade and benchmarked objectively adaptation strategies for agricultural systems. Zang *et al*. (2014) 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.

4. Limitations and future challenges

Some analysts support that WF alone, contain too little pertinent information to guide policy makers who should also consider the social, political, and economic aspects of water use in any setting and that water related problems should be solved locally and not through global governance schemes or trade barriers (Perry, 2014), (Wichelns, 2010), (Gawel and Bernsen, 2011). Besides Hoekstra *et al*., (2011) 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 to be further standardized (Vanham and Bidoglio, 2013a) and there is an absence of an agreed water quality standard to use when estimating dilution requirements (Perry, 2014). More research need to be done on sustainability assessment with an emphasis on integration of social and economic factors. Of particular concern is relating WF to more qualitative indices of water scarcity, quality and impacts to environments and livelihoods (Hoekstra and Mekonnen, 2012b). The incorporation of climate change, uncertainties and economic concequences 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 compination with other tools.

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