Agriculture Water Footprint: Approaches and Methodologies

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Abstract- Earth as a planet is known as the 'blue planet' because of the large capacity of stocks of water but only a small amount is easily available in accessible reserves of groundwater, lakes, rivers and the soil-water store. Water scarcity is becoming a widespread concern in many parts of the world because human usage is putting pressure on these limited water resources. The Agricultural sector is reported to be a major freshwater consumer globally and around 70% of the world's freshwater withdrawal is for irrigation. This justifies the need to develop standard indicators to evaluate human demand on natural resources. This paper aims to summarize the approaches of water footprinting with focus on the approaches suitable to assess water consumption of agricultural activities.

Index Terms- Water Footprint, Water Scarcity, Agriculture

I. INTRODUCTION

Freshwater is an essential resource requirement for the survival of all living organisms (both plants and animals), including humans in this planet. Earth as a planet is known as the 'blue planet' because of the large capacity of water stocks. However, only 2.5% of this capacity stock is fresh water (Oki et al., 2003). Most of that water is stored in glaciers and deep groundwater, and only a small amount is easily available in accessible reserves of groundwater, lakes, rivers and the soil-water store. Because of the great difference in availability, alongside human usage pressures on these limited water resources, water scarcity is becoming a widespread concern in many parts of the world (Oki et al., 2003).

The Agricultural sector is reported to be a major freshwater consumer globally and around 70% of the world's freshwater withdrawal is for irrigation (Gheewala et al, 2014.). This heavy exploitation of global water resource for food production is degrading global water resource (Bocchiola et al., 2013). Agriculture is a water consuming activity (Rost et al., 2008; Fader et al., 2011), and also most reliant on rainfall as one of its main source of water.

Producing crops under water stress conditions has necessitated the need to undertake analyses on water availability and to characterize water requirements (evapotranspiration losses and water use efficiency) (Lopez and Capetillo, 2015). This justifies the need to develop standard indicators to evaluate human demand on natural resources (Hoekstra et al, 2011).

Based on the concept of virtual water (VW) introduced in London in the mid-1990s (EL-Sadek, 2010), the concept of water footprint (WF) was established. This term can be defined as the total volume of freshwater used during the production and consumption of goods and services, measured at the place where the product was actually produced. Water Footprint (WF) has been established as an important tool to evaluate the contribution of goods and activities to water scarcity (Lopez and Capetillo, 2015). It is an indicator of human appropriation of freshwater resources and measures both the direct and indirect "water use" of consumers and producers (Mekonnen and Hoekstra, 2015). This concept is being used around the world to improve agricultural water management (Lopez and Capetillo, 2015). In Addition to that, Hoekstra *et al.* based on the studies of virtual water (VW) performed by Allan to lay out the concept of water footprint (WF). This term can be defined as the total volume of freshwater used during the production and consumption of goods and services, measured at the place where the product was actually produced.

Lamastra et al, 2014 categorized water footprint into three types namely; blue water footprint, which refers to the consumption of fresh surface water or groundwater that evaporates, it is incorporated in the product, it either does not return to the same catchment area, or it does return but in a different time period; The green water footprint refers to the total rainwater evapotranspiration plus the rainwater incorporated into the harvested crop or wood; and The gray water footprint which indicates the level of pollution of the water, expressed in terms of the freshwater volume required to assimilate the existing load of pollutants below the threshold value or eco-toxicological end-point. Methodologies and approaches have been developed to assess WF. For any well-defined group of consumers or producers, WF can be calculated as the sum of the water used along the full production chain.

a. An Overview of Water Footprint and related Studies

Hoekstra et al., 2011 defined the WF as an aggregate and multidimensional indicator of water use, showing different sorts of water consumption as a function of space and time and differs from the traditional concept of water balance. Water footprint (WF) has been introduced as a method to indicate the amount of water used and impacts of production process on water resources. Thus, it is measured as the total volume of freshwater used to produce a product (Gheewala et al., 2014). Quantification of water footprint is the first step in Water Footprint Analysis (WFA). This process demands the availability of accurate data and methods. WF studies have focused on the different implications of the water demand for industrial, agricultural, and other sectors (Tillotson et al, 2014). These researchers have defined WF and its types differently and so many methodologies have been employed. How to use the WF concept as a tool to solve practical problems in different sectors is still an issue (Tillotson et al, 2014). There is no agreement on robust methodology to have an impact on different water issues. Report by UN water 2012, revealed humans are consuming 54% of all of the earth's accessible freshwater (i.e. in rivers, lakes and underground aquifers). The continuous overconsumption and pollution of scarce freshwater resources, exasperates freshwater scarcity and quality issues around the world (Lamastra et al, 2014). This brings us to the term water use. Hoekstra et al., 2011 defined water use as a measure of water volumes consumed (evaporated or incorporated into a product) and/or polluted in the life cycle of a product. More recent studies have neglected to consider important elements especially when calculating water footprint using the Life Cycle Assessment (LCA) methodology. This has brought confusion to the understanding of the water footprint since researchers are defining it to suit their arguments. In the particular case of water resources, a struggle has been triggered among farmers, industries and households: these sectors require more and more water in order to satisfy increasing demands (Lopez and Capetillo, 2015). Wine industry for example, they use a lot of water from agriculture point of view in manufacturing of the final product and packaging. Therefore, for a well-defined group of consumers or producers, WF must be calculated as the sum of the water used along the full production chain (Lopez and Capetillo, 2015).

The number of water footprint studies and publications have increased rapidly in recent years (Hoekstra and Chapagain 2007; Liu and Savenije 2008; Ridoutt and Pfister 2009; Hoekstra et al. 2011; Hoekstra and Mekonnen 2012; Zeng et al. 2012; Chenoweth et al. 2013; Liu et al. 2013; Yang et al. 2013), and consequently, there is a need for a comprehensive review of the numerous tools and metrics developed for quantification and assessment (Tillotson et al., 2014). Therefore, in the next subheading will review the way some researchers assessed and calculated the WF in the Agriculture sector.

b. Agricultural Water Footprint

Bonamente et al, 2015, defined agriculture footprint as the total volume of surface and ground freshwater consumed for tillage. They included water used for irrigation, water used to dilute and apply treatments, and water used to wash the machinery. This shows that the researchers have wide knowledge in the Calculation of WF using LCA methodology and strongly agrees to what Lopez and Capetillo, 2015 proposed; that WF must be calculated as the sum of the water used along the full production chain in the LCA.

Agricultural footprint was calculated as

WF agricblue = WF agricblue, irr + WF agricblue treat + WF agricblue,wash

Water Footprint was established as a multi-dimensional indicator, allowing the geographical and temporal water consumption evaluation by source. Water consumptive use is measured in terms of the water volume consumed including evaporated water and/or polluted per unit of time.

In crop production, an accurate knowledge of crop water requirements during all seasonal stages is called for in order to reach optimal yields. For a specific crop, the crop water requirement mainly depends on the climatic conditions of the zone where the crop is established. Crop water requirement are usually computed from crop evapotranspiration and account for the net water depletion produced by the crop. Once crop evapotranspiration is calculated, it is possible to estimate the green and blue water components contribution to crop growing. Recognizing rainfall as the only source of water for dry land conditions, it is critical to identify the optimum growing period for the crop: when the expected water deficit is minimized.

II. METHODOLOGY

The consumption of goods and services often creates stress on the water resources of production sites. However, the dynamic between use and stress can be entirely different per location. The effect of local consumption on the water resources of other countries can be quantitatively analyzed in two ways. Firstly, one can look at the absolute volume of water imported (the size of the external WF) and the kind of virtual water imported (the quality of the WF). Secondly, one can consider the relative volume of water imported compared to the available resources in exporting countries. Though the size of the external WF can be large, it will exert less pressure in exporting countries if the kind of water used is abundantly available in those countries (e.g. export of rain-fed maize from the USA). Thus, before quantifying the WF of a product, we need to analyze the virtual water content of that product which distinguishes the kind of water used in the production process.

The virtual water content of a primary crop VWCc (m3/t) is calculated as the ratio of the volume of water used for crop production WUc (m3/ha), to the volume of crop produced, Yc (t/ha).

$$VWC_c = \frac{WU_c}{Y_c}$$

The volume of water used for crop production (WUc, m3/ha) is composed of two components

WUc=WUevaporative + WUnon-evaporative

Where WUevaporative is the volume of water evaporated and WUnon-evaporative is the volume of water unavailable for further use as a result of pollution, which is calculated as

WUevaporative=WUg+WUb

WUnon-evaporative=WUp

Building on the concept of Allan’s virtual water, 1998, Hoekstra, 2003 introduced the concept of water footprint which has been subsequently developed and refined as a method for quantifying water use by a product, service or nation (Chapagain and Hoekstra, 2008 and Hoekstra et al., 2009). The water footprint represents the sum of all the water used in a supply chain, comprising blue, green and grey water. Blue water is defined as the volume of freshwater abstracted from rivers, lakes and aquifers. The amount of rainwater used by plants is referred to as green water. Finally, grey water accounts for the impact of pollution on water resources and represents the volume of freshwater needed to dilute pollution so that the quality of the water remains above water quality standards set by regulations. This approach has been used for calculating the water footprints of various agricultural products; for example, the water footprint of beef has been estimated at 15,500 L/kg, sugar at 1,500 L/kg, wine at 120 L/glass and bioethanol (from corn) at 110 m3/GJ (WFN, 2010). It has also been used as a tool for developing corporate water reduction strategies (Ridoutt et al., 2009) and for water-footprint labelling of products (Sabmiller and WWF, 2009).

However, there are concerns that this approach could provide misleading results (Ridoutt et al., 2010 and Ridoutt and Pfister, 2009). The main concern relates to the fact that, unlike the carbon footprint, the water footprint represents just the quantity of the water used without an estimation of the related environmental impacts, such as due to water scarcity. Even the quantification of water use is controversial due to the inclusion of green water (rainwater as moisture in soils), which does not affect availability of blue water and therefore should not be accounted. Recently, some companies have adopted the concept of “net green” water – the difference between the water evaporated from crops and the water that would have evaporated from natural vegetation (Sabmiller and WWF, 2009).

Furthermore, water abstraction rather than consumption is often used in quantifying the blue water footprints (Hoekstra and Chapagain, 2008). This could be problematic, especially in the case of industrial water use where only a small part of the abstracted water is actually consumed (e.g. evaporated in cooling towers or embodied in the product) and the remainder is often discharged back to the water bodies (e.g. cooling water or industrial effluents from wastewater treatment plants). With respect to grey water footprint, it is argued that environmental impacts of grey water are more suitably addressed in other impact categories such as eutrophication or toxicity (Milà i Canals et al., 2009). Moreover, in the absence of an agreed method for the quantification of dilution volumes for assimilation, the estimation of grey water footprint is subjective.

a. The Milà i Canals et al. approach

This approach considers water use at the level of a river basin. According to this method, both the source of water and type of use of freshwater should be included in Life Cycle Inventory (LCI) (Milà i Canals et al., 2009). With respect to the source, it follows the Hoekstra et al. approach by classifying water sources as blue and green water. The blue water category is further differentiated into three types: flow (river/lake), fund (aquifer) and stock (fossil). The water use is split into two categories: evaporative and non-evaporative use. The latter is defined as water returned to the freshwater source after its use and available for further use. It is further suggested that the green water and the non-evaporative use of river, lake and aquifer water should be disregarded in Life Cycle Inventory Assessment (LCIA) because their use does not lead to relevant environmental impacts from a resource perspective (i.e. reduced availability of water for other users and effects on freshwater ecosystem). Instead, it is proposed to assess the land use effects on rainwater availability, which accounts for changes in infiltration and evapotranspiration in the production system relative to a reference land use. It is suggested that for high precipitation areas (rainfall > 600 mm/year), rainwater lost from arable land is 73%, whereas with forest as the reference (potential) land use, this is 67%; therefore, the additional loss due to arable land use is 6% of rainwater (Milà i Canals et al., 2009). For low precipitation areas (rainfall < 600 mm/year), the extra 10% of rainwater is lost due to similar change in land occupation.

b. The Pfister et al. approach

His approach considers water usage on a smaller scale than the Milà i Canals et al’s method, taking watershed as the area of focus. Unlike the previous mentioned approaches, this method considers only blue water. This method differentiates three categories of water use: in-stream water use, water consumption (where the water is no longer available in the watershed) and water-quality degradation (where the water is still available after use but with diminished quality). The main difference between the Milà i Canals et al. method and this approach is that the water discharged to another watershed is treated here as consumed while the Milà i Canals et al. approach considers the water discharged to any freshwater source as a non-evaporative use. Furthermore, unlike the Milà i Canals et al. approach, this method suggests that the wastewater discharge should be assessed for the loss of the water quality. However, Pfister et al. do not elaborate on how this could be done.

III. SOME OTHER MODELS OF WATER FOOTPRINT.

The section summarizes the approaches of water footprinting with focus on the approaches suitable to assess water consumption of agricultural products.

Hoekstra et al. provided a collective method on water footprinting and a specification on how to assess water consumption of agricultural products with the use of CROPWAT model are valuable in case no other data are available. The approach of the CROPWAT model can be used with high regional specification if the necessary parameter to enter in the model is available. The issue of water quality is addressed by water volume.

But, this approach does not factor water input quality and the concept is criticized for the mixing up of physical water consumption and virtual consumption. There is a method that considers the regional differences in water availability but conducting an impact assessment according to Hoestra et al. will not be easy because of restrictions in data availability.

Pfister et al. provided a comprehensive method to integrate water use into the life cycle assessment method. In the case for agricultural products, the approach of Hoestra et al to use the CROPWAT model is most suitable. Water quality is not explicitly differentiated but an approach outlined how this could be done. Inventory data is however not provided. Mila I Canals et al. for instance, refer to Hoekstra et al. for inventories, no additional specifications or data are provided. For impact assessment they consider regional water availability outlined similar to Hoekstra et al.

IV. CONCLUSION

The methods of water footprint have been applied in so many sectors with still new standardized methods emerging. On inventory level practitioners have a wide choice of methods. In compliance with the Life Cycle Assessment practice, verified primary data is preferable to use. It is very likely that comprehensive water use data will soon find their way into Life Cycle Assessment databases that will then simplify the compilation of inventories just as they do for all other material flows. Modeling water consumption with CROPWAT can be recommended if no other reliable data sources are available.

Life cycle impact assessment of fresh water use proves to be challenging. The method of Pfister et al. is the most suitable method so far that allows a comprehensive impact assessment of freshwater use to be integrated in the common Life cycle assessment approach. Life cycle assessment practitioners who aim to include the environmental effects of fresh water in Life cycle assessment studies are now provided with a tool to do so. For instance, a case study that uses the GaBi software and the approach of Pfister et al. to integrate water consumption into a LCA of cotton is given in Thylmann.

Much work on WF has been done on agricultural produce including rice, maze and beef. With an increase in the production in electronics and much attention on electronic waste disposal, focus should not be drawn in estimating only their LCA but also their WF.

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