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THE WATER FOOTPRINT. KEY CONCEPTS AND SOME CONSIDERATIONS IN AGRICULTURAL APPLICATIONS

LA HUELLA HÍDRICA. CONCEPTOS PRINCIPALES Y ALGUNAS CONSIDERACIONES EN APLICACIONES AGRÍCOLAS

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Summary

Water is an essential natural resource. Human activities consume and pollute large quantities of water. On a global scale, the greatest use of water occurs in agricultural production, although significant volumes of water are also consumed and polluted in the industrial and domestic sectors. The concept of Water Footprint acts as a multifaceted indicator of human water consumption and serves as a platform for decision-makers with a view to the sustainable and equitable use of water. This indicator provides the basis for knowing the impact from a social and economic point of view. Its determination at an international level is broad, however, in Cuba there are few applications in the agricultural sector, which is the largest consumer. This work introduces the concepts of Water Footprint, as well as its types, that is, the blue, green and gray Water Footprints. It also introduces the way in which it can be calculated in the hypothetical case of a crop.

Resumen

El agua es un recurso natural esencial. Las actividades humanas consumen y contaminan grandes cantidades de agua. A escala global, el mayor uso del agua acontece en la producción agrícola, aunque también se consumen y se contaminan importantes volúmenes de agua en los sectores industrial y doméstico. El concepto de Huella Hídrica actúa como un indicador multifacético del consumo humano del agua y sirve como plataforma para los decisores con vistas al uso sustentable y equitativo del agua. Este indicador proporciona la base para saber el impacto desde el punto de vista social y económico. Su determinación a nivel internacional es amplia, sin embargo, en Cuba son pocas las aplicaciones en la rama Agrícola siendo la mayor consumidora. En este trabajo se introducen los conceptos de Huella Hídrica, así como sus tipos, es decir, las Huellas Hídrica azul, verde y gris. También se introduce la forma en que puede calcularse en el caso hipotético de un cultivo.

Introduction

Water is an essential natural resource. Human activities consume and pollute large quantities of water. On a global scale, the greatest use of water occurs in agricultural production, although significant volumes of water are also consumed and polluted in the industrial and domestic sectors. Water is a scarce resource; however, the demand for water is increasing, in fact, there are many places in the world where there is serious water depletion or pollution: rivers drying up, lake and groundwater levels falling, and species in danger of extinction due to contaminated water (Guide to calculating the Water Footprint, n.d.).

Deepa et al., 2021, point out that water security is considered a prominent theoretical framework for sustainability in environmental policies and resource management and that the United Nations identifies water availability, its sustainable management and access as one of the goals for sustainable development (No. 6,https://www.un.org/sustainabledevelopment/sustainable-development-goals/, last access October 1, 2024.

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Therefore, to understand the impact of excessive water use and its sustainable use, the concept of "Water Footprint" (WF) has emerged (Allan, 1997, Hoekstra and Hung, 2002, Hoekstra, 2003) to consider water use along supply chains. The water footprint is an indicator of freshwater use that not only looks at the direct use of water by a consumer or producer, but also at indirect water use.

The WF concept acts as a multifaceted indicator of human water consumption and serves as a platform for decision-makers to achieve sustainable and equitable water use. This indicator provides the basis for determining the impact from a social and economic perspective (Hoekstra et al., 2011).

At an international level, there have been numerous investigations related to the determination of the water footprint, the indicators to evaluate it and the factors that influence it in different geographical areas (Vázquez del Mercado and Buenfil., 2012; Vanham and Bidoglio,, 2013; Chenoweth et al., 2014; Lovarelli et al., 2018; Hossain et al., 2020; Ibidihi and Salem., 2020; Wang et al., 2023).

In Cuba, Cabello et al. (1915) calculated the water footprint for potato cultivation in Cuba, García (2015) estimated the WF of livestock consumption in the Naranjo River basin in the province of Las Tunas, Montalvan et al. (2019) calculated the grey footprint in a tannery in Camagüey; Arias et al. (2023) determined the WF for the Hatuey complex in Santiago de Cuba and Nuñez et al. (2023) studied indicators to evaluate the operational water footprint in city hotels at the tourist destination in Havana. However, agricultural applications are still very few, with Agriculture being the largest consumer of water, so it is considered necessary to promote these topics for their application in agricultural areas of the Mayabeque province and the Agrarian University of Havana.

This paper introduces the main concepts associated with HH, the methodology generally used to calculate it and some considerations in the agricultural case.

Development

Main concepts

The water footprint (WF) of a product is the volume of fresh water used to produce that product, measured along the entire supply chain. It is a multidimensional indicator that shows the volumes of water consumption by source and the volumes polluted by type of pollution. All components of a water footprint are specified geographically and temporally. That is, the WF assesses water consumption considering different sources and also the quality of the water. Accordingly, there are three types of water footprints; the green and blue ones (based on the sources) and the grey one (based on the impact of water quality).

The green water footprint refers to the water that is stored in the soil as a result of precipitation (Bocchiola et al., 2013; Dekamin et al., 2018). In other words, it is the water stored in the soil available to plants. In other words, it is the volume of rainwater that evaporates and evapotranspires through plants and therefore does not become runoff. This indicator becomes more relevant in sectors such as agriculture.

The blue water footprint It is the water that flows in rivers and lakes or is groundwater. It is not the water that comes directly from precipitation during the growing season (Fader et al., 2011, Rost et al., 2008; Hoff et al., 2010). In other words, it is the volume of surface or groundwater consumed. It is an indicator of consumptive water use, referring to water losses produced when water evaporates, is returned to another watershed or the sea, or is incorporated into a product or service.

The gray footprint As a trend in recent years (Lovarelli et al., 2018; Esmaeilzadeh et al., 2020), it specifically focuses on ecotoxicity taking into account the amount of water needed for the pollutants to be in a dilution that can be consumed by humans or that does not harm the biodiversity of an ecosystem at different trophic levels (Marzullo et al., 2018). That is, the volume of fresh water required to dilute the pollutant load contained in a discharge given the natural background concentrations and environmental quality standards. If the discharge does not exceed the quality values or background concentrations, it is considered a normal return, so it would not count as a water footprint.

Furthermore, the Water Footprint can be direct or indirect. The direct water footprint refers to the consumption of fresh water and the pollution associated with the use of water directly in the development of an organization's activity, in the provision of a service or in all phases of production of a product, while the indirect water footprint refers to the consumption of fresh water and the pollution associated with the production of goods and services (except water) consumed in the system analyzed.

As an indicator of "water use", the water footprint differs from the classic measure of "water withdrawal" in three aspects: 1) the concept of water footprint only takes into account consumptive water use, i.e. it does not include the use of blue water to the extent that this water returns to the same basin from which it is withdrawn in the same period. It therefore differs from the traditional concept of water use which does include all water withdrawn from surface and groundwater, considering both consumptive (water consumed) and non-consumptive uses (water returned in discharge to the same basin and in the same period); 2) it is not restricted to the use of blue water, but also includes green and grey water; and 3) it is not limited to direct water use, but also considers indirect water use.

The unit of measurement of the water footprint is the volume of fresh water consumed in a period of time expressed in m3.

Water Footprint Calculation. Accepted methodologies for calculation

There are mainly two standards and methodologies of great international recognition:

- Water Footprint Network: Hoekstra and Hung (2002), from the UNESCO-IHE Institute for Water Education, created the water footprint as a metric to measure the amount of water consumed and contaminated to produce goods and services throughout the supply chain. As a result of the growing interest, they founded the Water Footprint Network platform for collaboration between companies, organizations and individuals to solve the world's water crises by promoting fair and intelligent use of water. From this initiative, the Manual for the evaluation of the water footprint (Hoekstra et al., 2011) emerged, in which the calculation methodology created by Hoekstra is developed.
- UNE-ISO 14046:2014: The concept of water footprint was born and continued to develop, giving rise to other methodologies such as the ISO 14046 standard. The standard specifies the principles, requirements and guidelines related to the evaluation of the water footprint. ISO 14046 uses the term water footprint in its translation into Spanish, and refers to the environmental impacts on water resources throughout the life cycle of products. Therefore, the water footprint methodology is also based on the life cycle analysis methodology standardized by ISO 14040 and ISO 14044.

In this study we will refer to the first methodology and we have taken as a reference the “Guide for the calculation of the Water Footprint”, prepared by the Department of the Environment of the Generalitat Valenciana specifically as an aid for water management. This in turn is based on the manual prepared by Hoekstra (2003).

Phases for a complete study of the Water Footprint

The phases for a complete water footprint study are:

1. Define the objectives and scope of the study, 2) Analysis of the water footprint inventory, 3) Evaluation of the impact of the water footprint and 4) Interpretation of results.

In phase 1, from the outset, you must specify what type of water footprint you want to work on, that is, whether it is for a product, a service, an organization, and once this is defined, you must indicate the intended applications, the reasons for carrying out the study, what public the water footprint is aimed at, whether the results are going to be communicated and by what means you plan to do so.

On the other hand, to define the scope, it is necessary toSelect the time period to be considered, establish a base year, determine the functional unit and all the inputs and outputs of the system analysed must be related to the selected functional unit. In addition, establish the cut-off criteria, that is, up to what level of information will be taken into account, as well as the allocation criteria since, in most cases, there is not a simple production line, where the raw materials are transformed into a single product, but rather more than one product is generally produced. A very important aspect is to establish what is included and what is not included in the study. To do this, the stages, processes and flows to be considered in the evaluation of the water footprint must be detailed. Finally, the indicators or the impact indicator that have been used in the evaluation of the water footprint must be indicated.

In phase 2 All relevant inputs and outputs of the system analysed that may contribute significantly to the environmental impacts related to water use must be quantified. This includes determining the direct water inputs and outputs, the types of water resources used (precipitation, sea water, surface water, etc.), the parameters and characteristics that describe water quality, the ways in which water is used: evaporation, transpiration, integration into the product, etc., the geographic location of the water use or of the water whose quality is affected, the temporal aspects of water use, raw material and process inputs, energy inputs (electricity and fuel), product outputs, transport, waste generation, and emissions to the atmosphere, water, and soil that may alter water quality. The decision to include or not include any of the above information must be justified. Obviously, the quality of the results of the water footprint study will be directly related to the quality of the inventory used. Primary data should be used whenever possible. If primary information is not available, the estimation of this value will be chosen. It is recommended that data be obtained from reliable reports whenever possible.

In phase 3 lWater footprint impact assessment must comply with ISO 14044 and ISO 14046. Water-related impacts can be represented by one or more parameters that quantify the potential environmental impacts of a product system, process or organization.

The term water footprint should only be used to describe the outcome(s) of a comprehensive water footprint assessment. If potential water-related impacts are not comprehensively assessed, the term water footprint should only be used as a qualifier. It is therefore necessary to determine which of these parameters are to be studied.

The first step is to select the impact categories and category indicators to be studied. The selection of impact categories and indicators should be consistent with the defined objective and scope, taking into account the potential environmental impacts caused by changes in water quantity and/or quality.

Finally, phase 4 involves the interpretation of the results and is based on identifying significant issues and conclusions from the results obtained in the impact assessment phase.

Calculation of the blue water footprint:

The blue water footprint will be given by Equation 1

$$Water\ \ footprint\ \ blue + Evaporated\ \ blue\ \ water + Blue\ \ water\ \ consumed + Water\ \ flows\ \ not\ \ returned\ \ to\ \ the\ \ basin \tag{1}$$

In the case of a crop, for example, if it is irrigated from a lagoon or pond, evaporated water will occur, which will be calculated by multiplying the evaporation by the area of the body of water in question.

The blue water consumed will be all the water directly used for cultivation as well as the drinking water that was used for the workers.

In order to estimate indirect water consumption, the water used to obtain all those products used in the production of a given crop, such as fertilizers, fuel, electricity, containers used for harvesting, or others, must be considered. The indirect water consumption associated with the use of these materials is obtained by multiplying the annual consumption data (if this period of time is considered for the crop) by a conversion factor that must be found in national or international literature.

In the case of water flows not returned to the basin, it is assumed in most cases that they do not take place since they are considered local agricultural production.

Calculating the green water footprint:

In this case, it is necessary to know the millimetres of rainwater that are being used in the stages considered for the calculation of the water footprint. In the case of greenhouse crops, the green water footprint would be zero.

Calculation of the grey water footprint:

According to water footprint calculation manuals, the grey water footprint in agriculture is associated with the use of fertilizers and not insecticides, and the one that is the majority in the formula applied to the crop in question is taken into account. If it is a nitrogen mixture, nitrogen is considered the main component. The grey water footprint is then calculated according to Equation 2:

$$Huella\ \ hídrica\ \ Gris\ \ = \frac{L}{C_{max} - \ C_{nat}} = \frac{a\ \ \times Apl}{C_{max} - \ C_{nat}} \tag{2}$$

Where:
L, is the pollutant load (mass/time)
a, is the fraction of the chemical that reaches surface or groundwater
Apl, is the amount of chemical applied (mass/time)
Cmax is the maximum permitted concentration (mass/volume)
Cnat is the natural concentration of the receiving medium (mass/volume)

It is necessary to take into account only the most critical pollutant, that is, the one that produces the largest volume of water according to the formula above. In the NPK formula, Nitrogen is considered to be the majority with around 22%.

For this calculation there are two variables that stand out due to the complexity of their determination. In the case of Cnat, there is generally no information and it is considered to have a value of zero, and the fraction “a” which must be estimated is also not measured. According to Chapagain et al. (2006), it is assumed that there is 10% of Nitrogen leaching into the aquifer.

Pollutant loading refers to the total amount of pollutants introduced into a specific environment (in this case, leaching Nitrogen), while chemical quantity applied refers to the specific amount of a chemical used in a particular process or application. Pollutant loading considers the total impact that pollutants may have, while chemical quantity focuses on the specific use or dose without necessarily reflecting the total environmental effect.

At this point, it is necessary to know what the concentration of the contaminant is that is suitable and from there the quantity of water necessary to bring the contaminant load calculated in the case analyzed to the level that is environmentally suitable is calculated.

Finally, the analysis of the results consists of comparing the values obtained for the three types of water footprints and making a plan of measures that favor the sustainable and efficient use of available water.

Conclusions

In this work, the concepts of Water Footprint and its types, i.e. the blue, green and grey water footprints, have been defined. In addition, the phases that must be taken into account for its determination have been presented, being very important to define the objectives and the scope, as well as for which system the water footprint will be determined. Something that must be highlighted is the importance of the data collected in the inventory stage since the validity of the results obtained will depend on the quality of these. Once the water footprint has been determined, the results will be analysed and strategies will be established with a view to the efficient use of water. Finally, it is outlined how to calculate it in the case of a hypothetical crop.

References

Allan, J.A., 1997. 'Virtual water': A long-term solution for water short Middle Eastern economies? : School of Oriental and African Studies. University of London, London, pp. 24-29.

Arias, L. Telma., Vazquez, M.E., Loforte, Q.L. 2023. Determinación de la huella hídrica en el Complejo Hatuey de Santiago de Cuba. Tecnología Química Vol.43, no. 3, sept.-dic., 2023

Bocchiola, D., Nana, E., Soncini, A., 2013. Impact of climate change scenarios on crop yield and water footprint of maize in the Po valley of Italy. Agric. Water Manag. 116, 50-61.

Cabello, J.J., Sagastume, A., Lopez, B.E., Vandecasteele, C. Hens, L. (2016) Water Footprint from Growing Potato Crops in Cuba. Tecnología y Ciencias del agua Vol. VII No. 1 Enero-Febrero 2016, pp 197-116

Chapagain, A.K., Hoekstra, A.Y., Savenije, H.H.G., Gautam, R. (2006). The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. Ecological Economics 60 No. 1 (2006), 186-203.

Chenoweth, J., Hadjikakou, M., Zoumides, C. 2014. Quantifying the human impact on water resources: a critical review of the water footprint concept. Hydrol. Earth Syst. Sci., 18, 2325-2342, 2014.

Deepa, R., Aavudai Anandhi y R. Alhashim (2021) Volumetric and Impact-Oriented Water Footprint of Agricultural Crops: A Review Ecological Indicators 130 (2021) 108093

Dekamin, M., Barmaki, M., kanooni, A., 2018. Selecting the best environmental friendly oilseed crop by using Life Cycle Assessment, water footprint and analytic hierarchy process methods. J. Cleaner Prod. 198, 1239-1250.

Esmaeilzadeh, S., Asgharipour, M.R., Khoshnevisan, B., 2020. Water footprint and life cycle assessment of edible onion production: a case study in Iran. Sci. Hortic. 261, 108925. https://doi.org/10.1016/j.scienta.2019.108925.

Fader, M., Gerten, D., Thammer, M., Heinke, J., Lotze-Campen, H., Lucht, W., Cramer, W., 2011. Internal and external green-blue agricultural water footprints of nations, and related water and land savings through trade. Hydrol. Earth Syst. Sci. 15 (5), 1641-1660.

García, H.Y., Estimación de la huella hídrica de consumo pecuario en la cuenca hidrográfica del río Naranjo, provincia Las Tunas, Cuba Rev. Protección Veg. Vol. 30 Número Especial (diciembre, 2015): 175 ISSN: 2224-4697

Guía para el cálculo de la Huella Hídrica. Huella Hídrica de Productos, Servicios y Organizaciones. Generalitat Valenciana, Conselleria de Medi Ambient, Aigua, Infraestrutures, (s.f.)

Hoekstra AY. 2003. Virtual Water. An Introduction. En: Virtual Water Trade. Proceedings of the International Expert Meeting on Virtual water Trade. Value of Water Research Report Series No.12. Delft, The Netherlands:UNESCO-IHE Institute for Water Education. p. 13-23.

Hoekstra, A.Y., Chapagain, A.K., Mekonnen, M.M., Aldaya, M.M., 2011. The Water Footprint Assessment Manual: Setting the Global Standard. Earthscan Ltd, London, UK.

Hoekstra, A.Y., Hung, P.Q., (2002) Virtual water trade: A quantification of virtual water flows between nations in relation to international crop trade, Value of Water Research Report Series No. 11, UNESCO-IHE, Delft, The Netherlands.

Hoff, H., Falkenmark, M., Gerten, D., Gordon, L., Karlberg, L., Rockstrom, J., 2010. Greening the global water system. J. Hydrol. 384 (3-4), 177-186.

Hossain, I., Imteaz, M., Khastagir, A. 2020. Water footprint: applying the water footprint assessment method to Australian agriculture. J. Sci Food Agric 2021. DOI 10.1002/jsfa.11

Ibidihi, R., Salem, B,H. 2020. Water footprint of livestock products and production systems: a review. Animal Production Science, 2020, 60, 1369-1380.

Lovarelli, D., Ingrao, C., Fiala, M., Bacenetti, J., 2018. Beyond the Water Footprint: A new framework proposal to assess freshwater environmental impact and consumption. J. Cleaner Prod. 172, 4189-4199.

Marzullo, R.D.C.M., Matai, P.H.L., Morita, D.M., 2018. New method to calculate water ecotoxicity footprint of products: a contribution to the decision-making process toward sustainability. J. Cleaner Prod. 188, 888-899.

Montalván,E., Aguilera, C.Y., Brigido, F.O., Veitía, R.E. Rodriguez, L. L.(2019) Procesos de contaminación-purificación en aguas superficiales afectadas por el vertimiento de efluentes de una teneríaRev Cub Quim vol.31 no.1 Santiago de Cuba ene.-abr. 2019

Nuñez, T.E., Alvarez, A.A., Hechavarria, D.L. 2023. Estudio de indicadores para evaluar la huella hídrica operacional en hoteles de ciudad del destino turístico La Habana. Retos Turísticos, Vol. 22, No. 1: e-5985, enero-diciembre, 2023.

Rost, S., Gerten, D., Bondeau, A., Lucht, W., Rohwer, J., Schaphoff, S., 2008. Agricultural green and blue water consumption and its influence on the global water system. Water Resour. Res. 44 (9) https://doi.org/10.1029/2007WR006331.

Vanham, D., Bidoglio, G. 2013. A review on the indicator water footprint for the EU18. Ecological Indicators 26 (2013) 61-75.

Vázquez del Mercado, Rita, Buenfil, R. M.O. 2012. Huella Hídrica de América Latina: Retos y Oportunidades. Aqua-LAC - Vol. 4 - Nº 1 - Mar. 2012. pp. 41 - 48.

Wang, Q., Huang, K., Liu, H., Yu, Y. 2023. Factors affecting crop production water footprint: A review and meta-analysis. Sustainable Production and Consumption 36 (2023) 207-2016