Environmental Impact Assessment Review 72 (2018) 126–136

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

Applicability and relevance of water scarcity models at local management scales: Review of models and recommendations for Brazil

Ana Lídia de Almeida Castro[a], Edilene Pereira Andrade[a], Mateus de Alencar Costa[a], Tayane de Lima Santos[c], Cássia Maria Lie Ugaya[b], Maria Cléa Brito de Figueirêdo[c,*]

[a] Federal University of Ceará (UFC), Av. Mister Hull, s/n - Pici, 60455-760 Fortaleza, Brazil
[b] Federal Technology University of Paraná (UTFPR), Av. Sete de Setembro, 3165 - Rebouças, 80230-901 Curitiba, Brazil
[c] Embrapa Agroindústria Tropical, Dra. Sara Mesquita Street, 2270 - Pici, Brazilian 181, 60020 Fortaleza, Brazil

ARTICLE INFO

Keywords:
Life cycle impact assessment
Water scarcity footprint
Freshwater use
Regionalization
Characterization factors
Water stress

ABSTRACT

With water shortages increasing worldwide, several Life Cycle Impact Assessment (LCIA) models have been developed for assessing the potential impacts of water consumption (deprivation) on ecosystems and human health. Each model uses different water scarcity concepts, measurement scales, and indicators, resulting in distinct characterization factors (CFs) available for the same region over time. However, to date, no previous work has compared water scarcity models to identify those more suitable for countries outside of Europe, considering national hydrological divisions and environmental conditions. Furthermore, no previous studies have investigated the sensitiveness of background hydrological data, applied to calculate water scarcity CFs, in regions that historically experience water scarcity, such as the Brazilian semiarid region. This is important because global hydrological data may present high uncertainty and indicate low scarcity in regions that suffer with water scarcity issues. Therefore, this work initially evaluated midpoint models for water scarcity and recommended the most appropriate models for application at the Brazilian hydrographic division level, defined by the Brazilian Water Agency (ANA). A critical review of twelve midpoint models was performed based on four main criteria: (i) indicator broadness; (ii) scientific robustness; (iii) availability of CFs for Brazil; and (iv) regionalization potential of CFs for ANA geopolitical hydrographic divisions, considering the availability of national data. Each criterion was given a score of 1 to 5 for each analyzed model and a recommendation was made based on the final score, obtained by averaging the scores of each criterion. Results showed that the best-rated models were those that adopted the monthly Water Stress Index (WSI) and the AWARE index. Both models were robust, presented CFs at a monthly scale, and could be partially regionalized by applying national monitoring data available in national databases. Nonetheless, none of these models applied a broad water scarcity concept that encompassed both physical and economic water scarcities, nor presented CFs for the Brazilian hydrographic divisions. Furthermore, a case study was performed, comparing the CFs provided by AWARE and WSI with the regionalized values, which were calculated using national hydrological data. This case study focused on the São Francisco watershed and on the Rio Verde Grande, a smaller watershed belonging to the São Francisco, known for its historical water scarcity problems. The results of this case study showed that a finer regionalization scale and the use of local data allow to represent better the local water scarcity for sub-regions in comparison with the original watershed level, especially for semiarid regions. The approach proposed in this study for evaluating life cycle impact models at country level is new and may be applied in other studies, aiming to indicate models for specific world regions.

1. Introduction

Water is a basic resource for almost all living things. For humans, hydric resources are essential for not only drinking and cooking, but for most economic activities. In the natural environment, water is needed to maintain most forms of life in aquatic and terrestrial ecosystems. Due to its key role for both humans and ecosystems, monitoring and managing water deprivation worldwide is of the utmost importance.

According to the World Water Assessment Programme (WWAP), water demand is expected to grow in all production sectors over the next few years (WWAP, 2015). A report written by the 2030 Water Resources Group (2030 WRG) estimates a global water shortage of 40%

* Corresponding author.
E-mail addresses: cassiaugaya@utfpr.edu.br (C.M. Lie Ugaya), clea.figueiredo@embrapa.br (M.C. Brito de Figueirêdo).

https://doi.org/10.1016/j.eiar.2018.05.004
Received 22 September 2017; Received in revised form 7 May 2018; Accepted 7 May 2018

by 2030 in a business-as-usual scenario, based on projections of changes in global demand and availability of water between 2009 and 2030 (2030 WRG, 2009).

This growing water scarcity has two main causes: high demand and low availability. Water demand is increasing, mainly due to population growth and economic development, which leads to the creation of new industries and irrigated districts (WWAP, 2015). In addition, water availability can be reduced in certain areas due to the effects of climate change, which causes extreme weather events and variations in the seasonality and amount of rainfall, whereas water pollution may compromise population needs for clean water. Added to this problem is the reduced access or lack of access to clean water or facilities for supplying suitable water for drinking, industrial and agricultural purposes in many developing regions.

Therefore, water scarcity can be defined as the imbalance between water availability and demand in a region, both of which vary according to the environmental and socioeconomic conditions of that region. This imbalance may be assessed by considering only the quantitative aspects of water (physical scarcity as the amount of consumed water) as defined by the ISO 14046 standard for water footprint assessment (ISO, 2014), or it can encompass water quality aspects as well as access to appropriate water distribution and treatment facilities (economic water scarcity), as defined by the Food and Agriculture Organization (FAO) of the United Nations (Steduto et al., 2012).

The increasing concern regarding water scarcity worldwide has led to the development of different assessment models that aim to improve water management at global and regional perspectives. In the framework of Life Cycle Impact Assessment (LCIA), various models have been proposed since 2006 to assess the impacts of products on water scarcity (Kounina et al., 2013; Boulay et al., 2015).

Each water scarcity model follows a particular water scarcity concept and spatial and temporal coverage, and also applies different indicators, which results in distinct characterization factors (CFs) available for the same region over time. Therefore, the AWARE (available water remaining) index (Boulay et al., 2017) was recently recommended by scientific consensus as the midpoint level global model by the Life Cycle Initiative and has been promoted by the United Nations Environment Programme (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC). However, to date, comparative evaluations of characterization models have been performed for models for European countries (EC-JRC, 2011; EC-JRC, 2016), but none have looked at countries outside Europe, considering their particular hydrographic divisions and environmental conditions.

Furthermore, no previous studies have investigated the sensitiveness of background hydrological data, applied to calculate water scarcity CFs, in regions that historically experience water scarcity, such as the Brazilian semiarid region. This is important because global hydrological data may present high uncertainty and indicate low water scarcity in such regions.

Brazil is currently one of the world's major food producers and exporters and this is expected to continue in the future (OECD and FAO, 2015), which means that overseas LCA studies are also affected by the Brazilian agricultural production chain. Appropriate water scarcity models should be selected to assess and reduce the impacts of water scarcity on crops and crop-based products produced in this country.

In this context, this study evaluated midpoint models for water scarcity footprint studies of production processes occurring in Brazil and recommended the most appropriate models for application at the Brazilian hydrographic division level, which has been established by the Brazilian National Water Agency (ANA). Consideration at the national hydrographic division was important because all national water data resulting from monitoring and modeling was available for this division and most of the water management initiatives and research studies developed in the country also follows this division.

Furthermore, the application of national background hydrological data was investigated through a case study focused on the São Francisco watershed, located in the Brazilian semiarid region. This region has an area of 969,589 km^2, a population of over 23,000,000, > 1,000,000 ha of irrigated farms, and > 650 reservoirs, which are managed to meet urban and ecosystem water needs throughout the year and during drought periods, which typically last several years (ANA, 2016).

The results of this study were part of the research activities developed under the Brazilian Research Network in Life Cycle Impact Assessment (RAICV), which includes experts from Brazilian research, educational, and private institutions. Furthermore, this network is supported by the Brazilian National Program of Life Cycle Assessment of the Ministry of Industry, Foreign Trade and Services (Ugaya et al., 2016).

2. Material and methods

2.1. Models selection

Water scarcity models were chosen following a literature review of scientific articles and reports published in the Web of Science database to June 2017. The following keywords were used: "life cycle impact assessment", "water scarcity", "water footprint", and "characterization model". In this study, only midpoint models were considered.

2.2. Criteria and grading definitions for model evaluation

Assessment of the selected models was based on the ranking of the following criterion, defined by the members of the RAICV, adapted from EC-JRC (2011): (i) indicator broadness; (ii) scientific robustness; (iii) availability of CFs for Brazil; and (iv) regionalization potential of CFs for Brazilian geopolitical hydrographic divisions, applying available national data.

Indicator broadness referred to the level of coverage of each model related to the concept of scarcity used, the geographical coverage (watersheds globally or only in specific regions), and the elementary flows considered (surface, groundwater, and soil moisture). The models were scored high if: (i) they adopted a broad definition of water scarcity that encompassed quantitative (pure physical and volumetric approach), qualitative (accounting for the level of water degradation), and economic aspects (assess to water facilities) as proposed by the FAO (Steduto et al., 2012); (ii) CFs were available globally; and (iii) the model considered the flows from surface, groundwater, and soil moisture (Table 1).

Although the change in soil moisture was considered by Pfister et al. (2016) an aspect to be included in land use impact assessment, in this study it was considered that the soil moisture available in a region was part of the total water availability in that region, and thus was a flow to be accounted for in water scarcity models. Regarding water quality, some authors argue that this aspect is already analyzed in impact categories related to water degradation (Berger et al., 2014; Loubet et al., 2013; Milà i Canals et al., 2009; Pfister et al., 2009). However, in this study, water quality was recognized as an important parameter for water scarcity because in many Brazilian regions water is available in sufficient quantity but not in the required quality, and thus is considered a scarce resource by users. Water quality refers to the physical, chemical, and biological characteristics that make water suitable for the different human users and ecosystems (ISO, 2014).

Scientific robustness is related to the model's reliability within the scientific community and to the transparency of the modeling (equations) employed to calculate the CFs. Model reliability was evaluated if there was a positive analysis of the model available in scientific review publications and if there was a detailed description of the aspects considered in the impact pathway. Model transparency and accessibility were considered by evaluating the description of equations used to derive CFs, and of databases and hydrologic models applied. The highest score was given to those models that were reliable and transparent in all evaluated aspects (Table 1).