Improvement of the AWARE model

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1. Introduction

The Available WAter REmaining (AWARE) model highlights the importance of considering consumption rather than withdrawal and takes into account spatial variability. It results from a massive and collective effort on behalf of the Water Use in LCA (WULCA) working group. The AWARE model provides a consensual, operational and recommended indicator for addressing and comparing water impacts, and fully succeeds in this purpose [1].The present work discusses the shape of the model, as well as associated limitations on its range of validity, which do not distinguish between regions that are more degraded than fair. A subsequent improvement is then proposed. This improvement follows the common practice in LCIA by (1) the definition of a relationship modelling the impact according to human intervention and (2) the use of marginal approach for determining the characterisation factor (CF). This improvement is mathematically sound, all the while satisfying the same expectations as the AWARE model.

2. Materials and methods

2.1. AWARE model

Using a more synthetic notation than that of the initial publication, the AWARE characterisation factor (CF_{AW}) defined in Boulay et al. (2018) is the following:

$$\frac{1}{AMD} = \frac{a}{A - D_E - C_H} \qquad (1)$$

$$CF_{AW} = \begin{cases} 0.1 \times \overline{AMD}, & AMD > 10\,\overline{AMD} \\ \frac{1}{AMD} \times \overline{AMD}, & 0.01\,\overline{AMD} \geq AMD \geq 10\,\overline{AMD} \\ 100 \times \overline{AMD}, & AMD < 0.01\,\overline{AMD} \end{cases} \qquad (2)$$

The CF is based on the inverse of the availability-minus-demand (*AMD*, m^3/m^2.month). The variable *a* is the area of the region ("area" in Boulay et al. (2018), m^2), *A* the availability ("Availability", m^3/month), D_E the environmental water requirements ("EWR", m^3/month), C_H the human water consumption ("HWC", m^3/month), and $\overline{AMD}$ the global average *AMD* of freshwater ecoregions where $C_H + D_E < A$ ("$AMD_{\text{world avg}}$", m^3/m^2.month).

A and C_H are estimations of current flows, and $C_H \leq A$. However when a too high human appropriation of water leads to a poor condition ecosystem (i.e. when $C_H > A - D_E$), equation (1) produces a negative result and obviously cannot be used. This is the case with 13% of the global area and up to 33% of world water consumption at a monthly level as indicated in [1]. In addition, when the ecosystem state reaches a fair condition (when C_H is close to $A - D_E$) equation (1) tends to infinity. Equation (1) therefore needs to be bounded in definition of the CF in equation (2). Due to these boundaries, the inverse of the *AMD* in CF_{AW} is only used for 87% of the world area and 62% of world consumption at a monthly level. The AWARE provides accurate information, expressing the remaining water with respect to the world average for most places. However, it is worth considering a way to overcome this limitation by proposing a relationship that maintains this validity over the whole world and not only for 62% of its water consumption.

2.2. New proposal

The $\frac{D_E}{A-C_H}$ ratio is defined as the demand (requested by the ecosystem) to availability (minus the effective human appropriation), more simply named the demand-to-remaining (DTR). This ratio, considering both ecosystem demand and human consumption, provides useful and straightforward information representing the current state. For a surface area twice as large, the corresponding impact should be twice more severe, and the DTR ratio therefore has to be multiplied by the area.This leads to $I_w = a\frac{D_E}{A-C_H}$ the water impact (I_w, m^2), which expresses an area degraded to fair conditions.Mainly two approaches have been used in LCA to derive CFs, representing a marginal or average change. The Life Cycle Initiative guideline recommends using marginal CF when the system under study concerns less than 5% of the issue, while the average CF addresses large changes. The marginal CF ($CF_{DTR,ma}$, m^2/m^3) is the partial derivative of a model of the relationship between the impact and the inventory flow (the marginal change of the impact with respect to a marginal change in the inventoried flow).

$$CF_{DTR,ma} = \frac{\partial I_w}{\partial C_H} = a \frac{D_E}{(A - C_H)^2} \quad (3)$$

3. Results and discussion

The significance of the approach is addressed by the sensitivity of the CFs according to the components of the model. It can be obtained by the partial derivative to highlight the shape of the relationship and the corresponding equations are available in the supplementary materials. As an illustration, the changes (Δ) in CF values can also be plotted with respect to changes in model parameters (Figure 1).

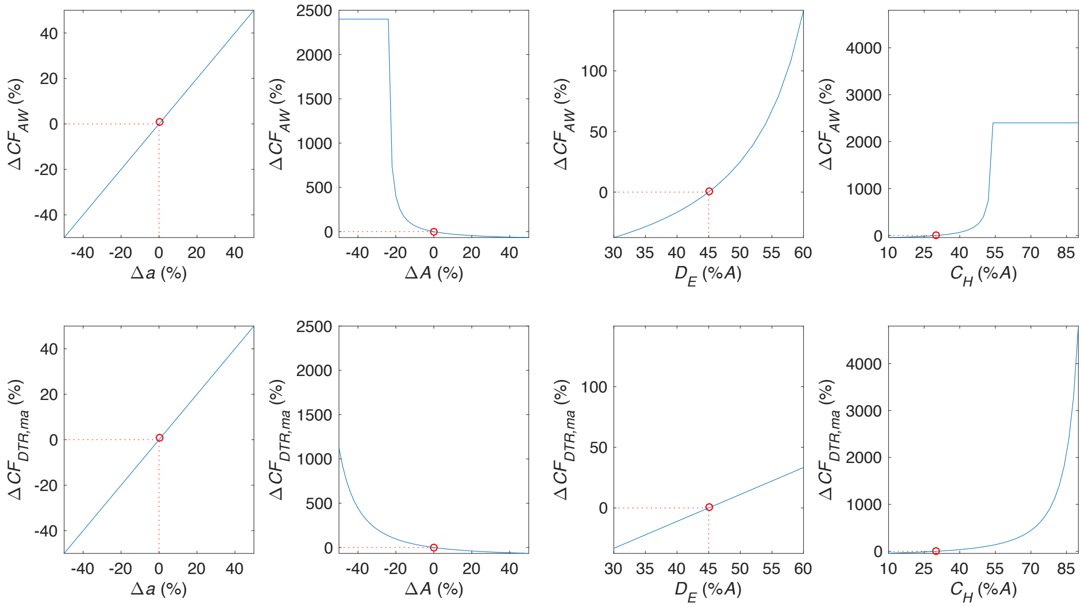

Figure 1. Illustration of the sensitivity of the characterization factors according to the model parameters. The circle is the arbitrary reference point.

As expected, the CFs of the AWARE and DTR models increase linearly with the area, in the same manner. In both situations, an increase in C_H produces the same result as a decrease in A. The increase grows faster when the AWARE model upper boundary is being reached, and when the complete human appropriation of water ($C_H = A$) is being attained for the DTR model. This implies that the relationships present similar features but at different intervals, without any discontinuities for DTR.

The CFs rise along with D_E, displaying a negative inverse relationship for AWARE and a linear relationship for DTR. The trends therefore differ in their shapes but, within the limits identified by [1], not particularly in their results. It is noteworthy that, due to the interval boundaries (30–60% of *A*), the changes in CFs led by D_E are about 10 times smaller than the changes induced by C_H and A.

4. Conclusions

AWARE consensus model brings a major benefit to the community by proposing a shared standard. However, AWARE relationship is only defined when human consumption has spared sufficient water for an ecosystem in fair condition and loses its validity for more severe situations. This leads to the introduction of cut-offs. By defining impact as the fraction of ecosystem demand on what is left by human activity, the DTR model proposed in the present work makes it possible to overcome this limitation.

5. References

1. Boulay A, Bare J, Benini L, Berger M, Lathuillière MJ, Manzardo A, Margni M, Motoshita M, Núñez M, Pastor AV, Ridoutt B, Oki T, Worbe S, Pfister S. 2018. The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). *Int. J. Life Cycle Assess.* 23:368–378.