SUPPLEMENTARY INFORMATION

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# Freshwater consumption and domestic water deprivation in LCIA: revisiting the characterization of human health impacts

Laura Debarre[1], Anne-Marie Boulay[2],Manuele Margni[1,3],

[1]CIRAIG, Polytechnique Montréal, Department of mathematical and industrial engineering, Montréal, QC, Canada

laura.debarre@polymtl.ca, +33669236719

[2]CIRAIG, Polytechnique Montreal, Department of chemical engineering, Montréal, QC, Canada

[3] HES-SO, University of Applied Sciences and Arts Western Switzerland, Institute of Sustainable Energy, Sion, VS, Switzerland

**Sanity check - Comparison of WASH DALYs values**

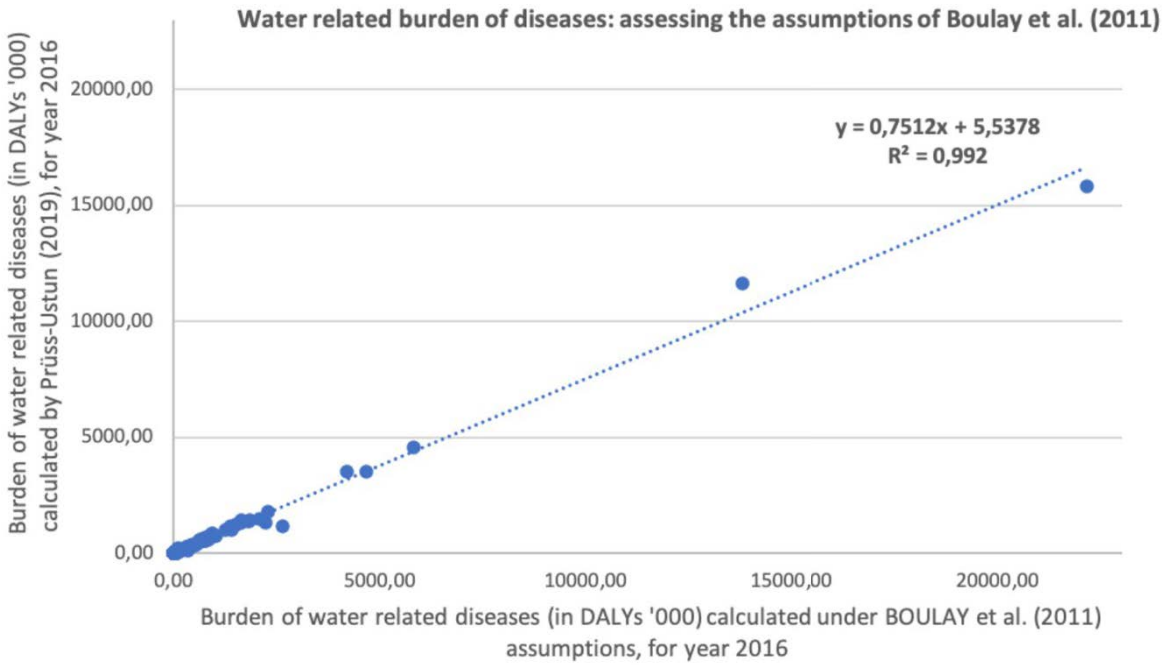



*Figure 1: Sanity check comparing Pruss-Ustun et al. (2019) results with Boulay et al. (2011)'s assumptions regarding water-related DALYs*

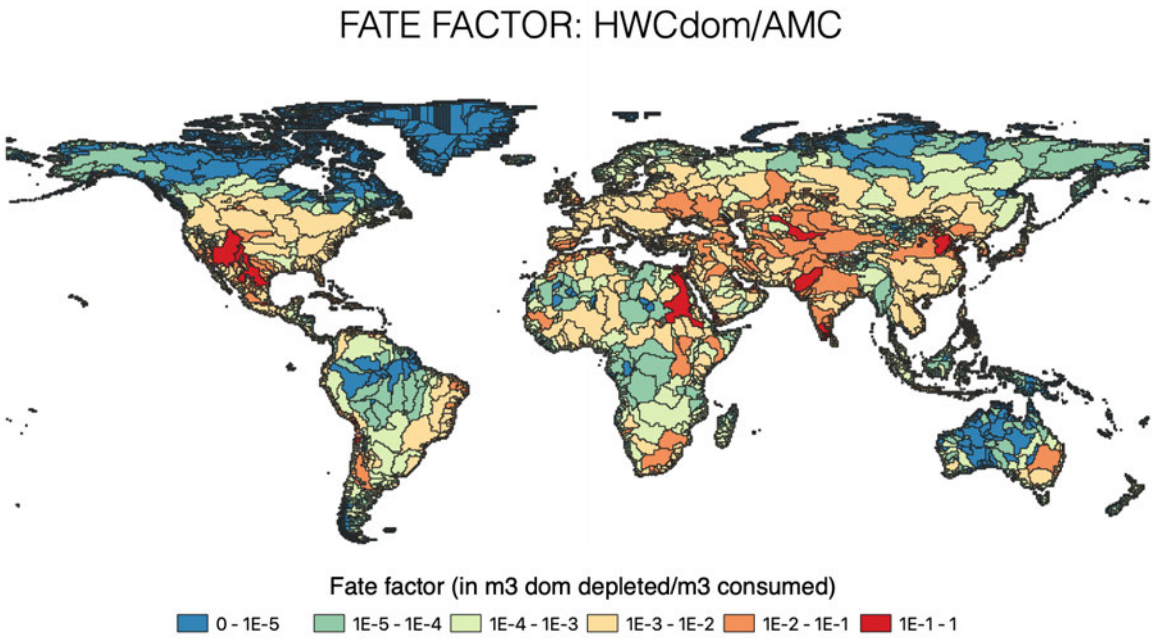
Although the values proposed by Boulay et al. (2011) are 25% higher, the correlation is strong between the latest model's assumptions and data regarding the water related burden of diseases. Considering its expertise and accuracy, we chose the data proposed by Prüss-Ustün et al. (2019) to be integrated in this work.

**Insights on the fate factor**

The fate factor developed in this work results from the multiplication of two ratios: HWCtotal/AMC (where AMC accounts for *Availability Minus Water Consumption*) which can be linked to *water scarcity*, and HWCdom/HWCtotal, accounting for *water distribution among users*.

| | |
|---|---|
| $$FF_{dom} = \frac{HWC_{total}[m^3]}{AMC[m^3]} \times \frac{HWC_{dom}[m^3]}{HWC_{total}[m^3]}$$ | Eq1 |

Their multiplication (and the simplification of the term HWCtotal) allows the calculation of the fate factor as the ratio of HWCdom to AMC, as presented in the main text.



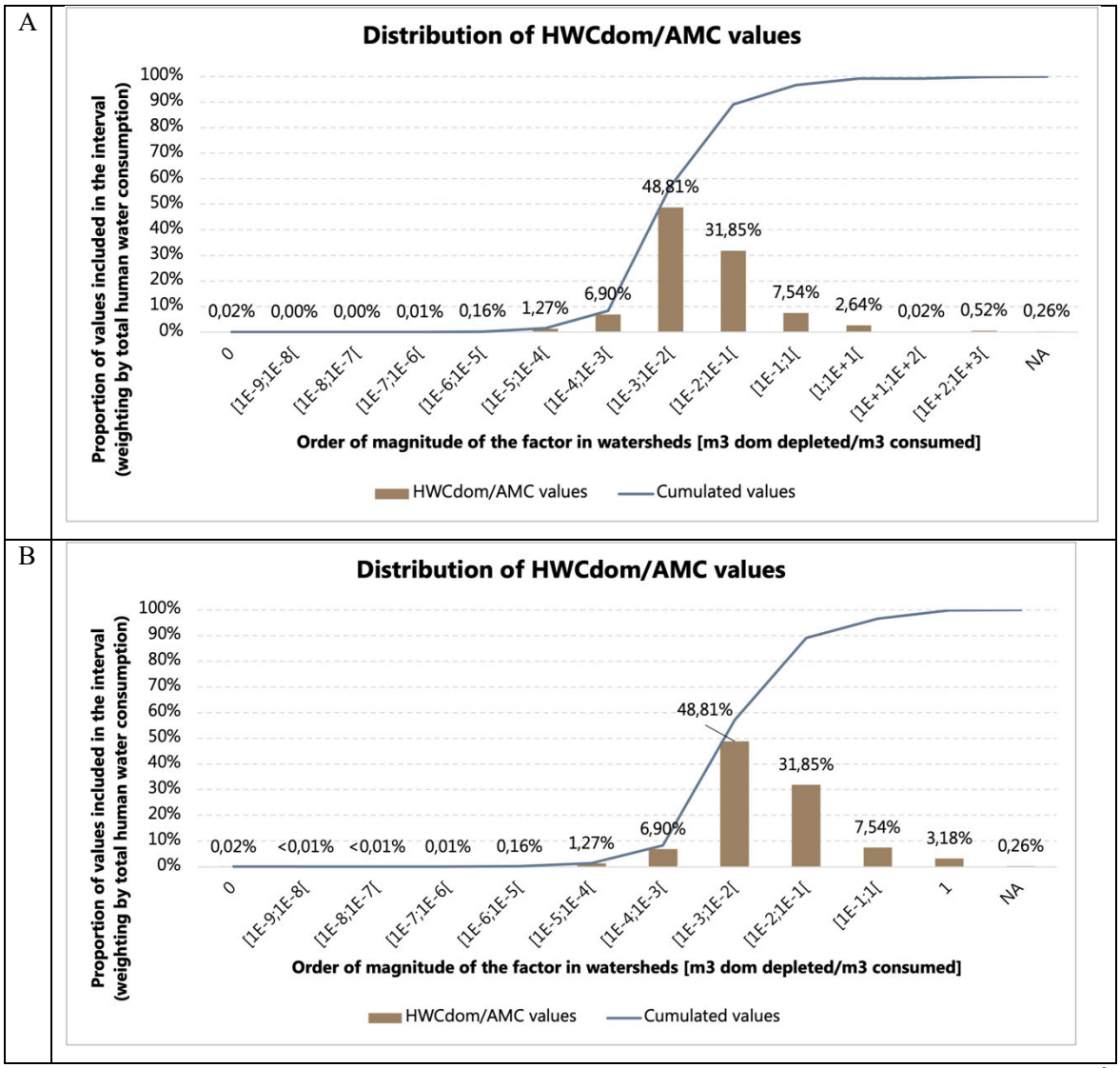



***Figure 3: Distribution of fate factors values according to their order of magnitude. Fate factors are expressed in $m^3$ dom depleted/$m^3$ consumed. Proportions are calculated based on the total human water use intensity in each watershed. Values above 1 are not limited to 1 in A but are in B.***

Fate factors as defined in the model (i.e. limited to 1, see figure B) range from 0 to 1 m3 dom depleted/m3 consumed. Those results are aggregated by percentage of water consumption amount in watersheds to assess the distribution of the values in line with LCA inventories (Figure 3). More than 99% of the values (99.55%) are superior to 1E-5, and almost 81% (80.66%) are included between 1E-3 and 1E-1 $m^3$ dom depleted/$m^3$ consumed.

In order to provide better insights on the modeling and to understand the characteristics of watersheds, the following paragraphs offer discussion on the differences of both *water scarcity (HWCtotal/AMC)* and *users distribution (HWCdom/HWCtotal)* within watersheds.

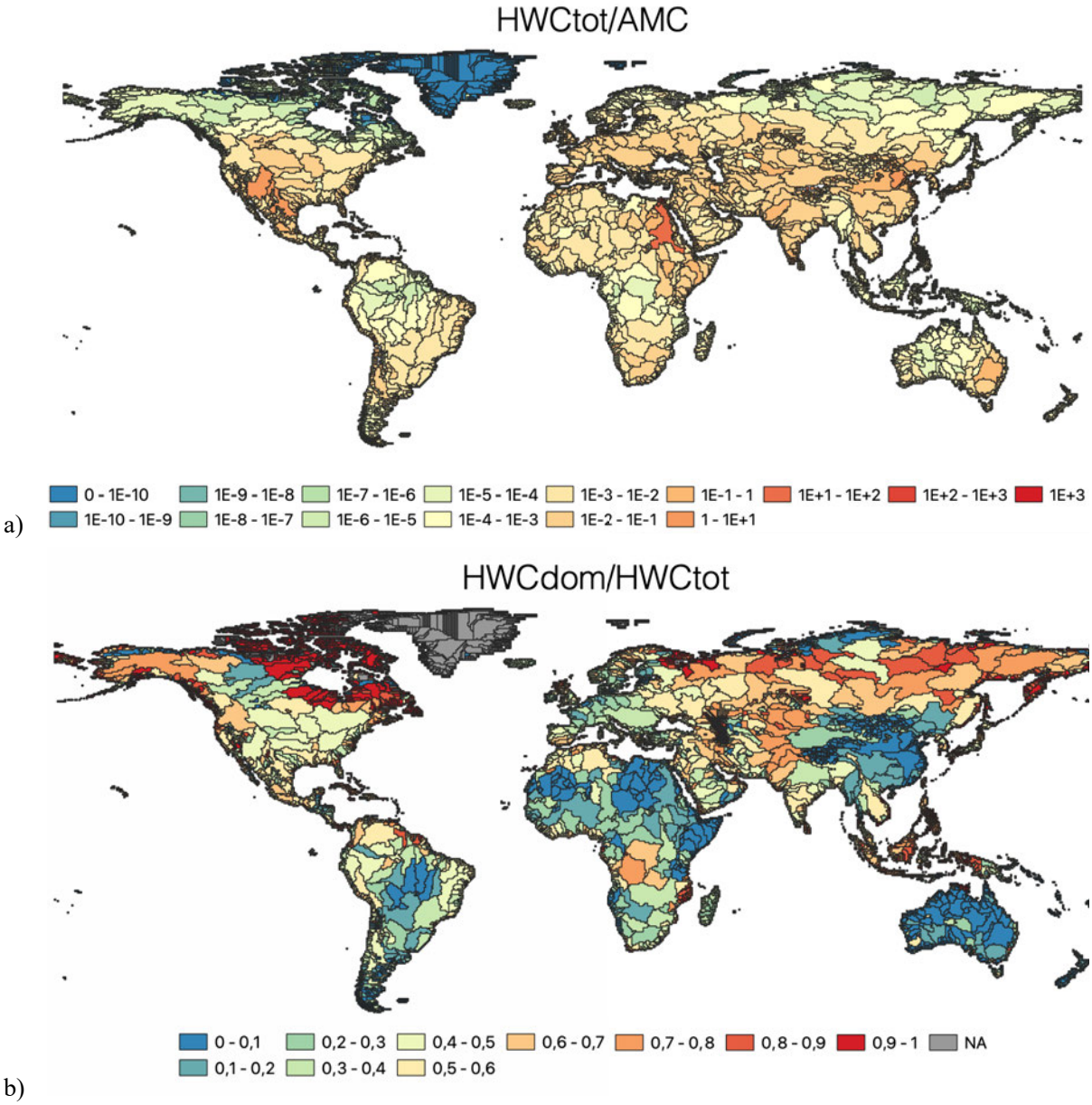
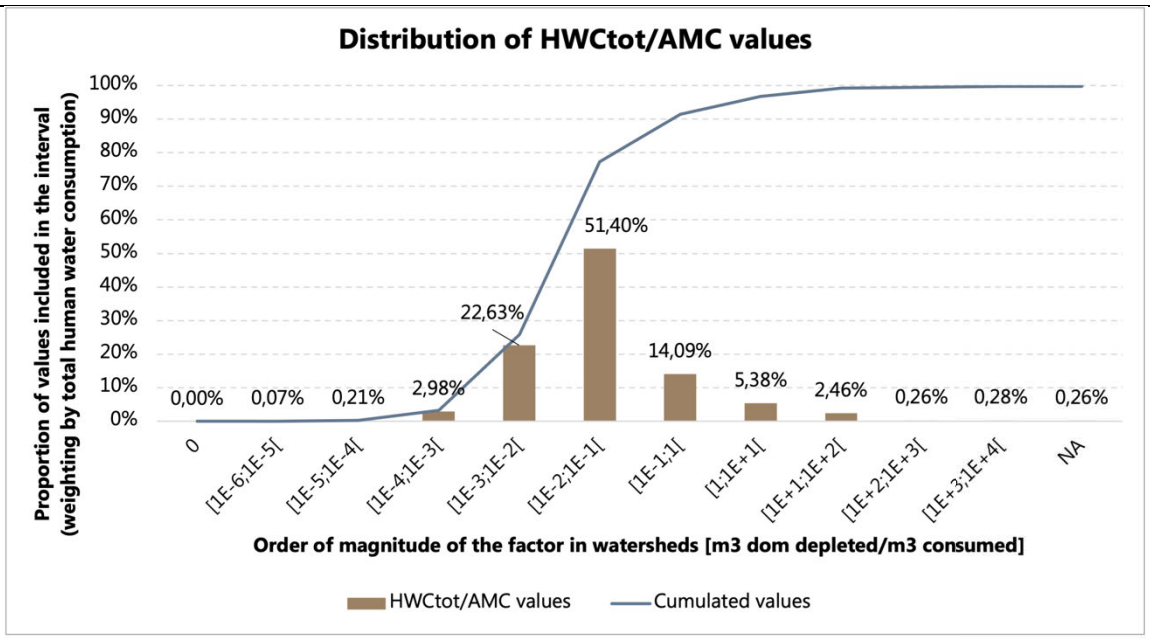



***Figure 4: Geographic representation of A- water scarcity (unitless) and B-water distribution among users in watersheds (in % water consumption). Obtained by manipulating WaterGAP data*** *(Flörke et al. 2013)* ***through QGIS. Caution is required in the interpretation of the maps giving the non-uniformity of the legends with the Fate factor map's one (Figure 1).***

***Water scarcity (HWCtotal/AMC) echoes the physical water depletion potential we define within the text. Figure 4.a evidences the regions where water scarcity is high, such as the Nile valley, California, Nevada or Arizona. In low population areas such as central Australia, northern Canada, the Amazon rainforest, northern Russia or Saharan Africa, low values of Hwtotal/AMC can be explained by low water demand. Water distribution among users (Figure 4.b) allows to see water competition between users through the lens of domestic water. Domestic water use intensity is particularly high in northern Canada and in some Eastearn Europe regions.***

A




B

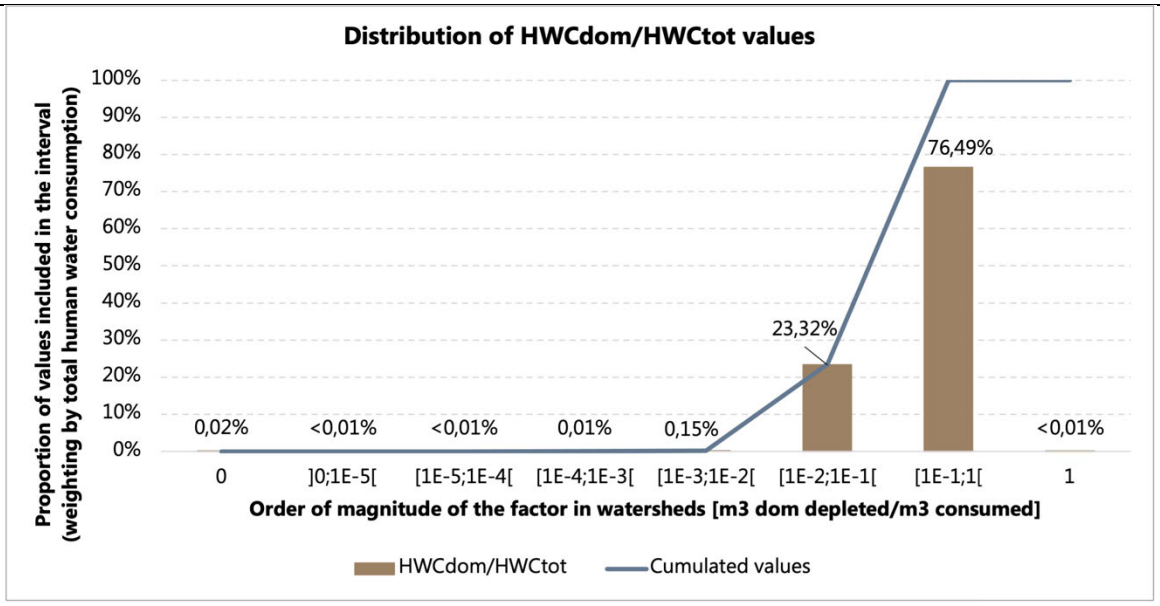
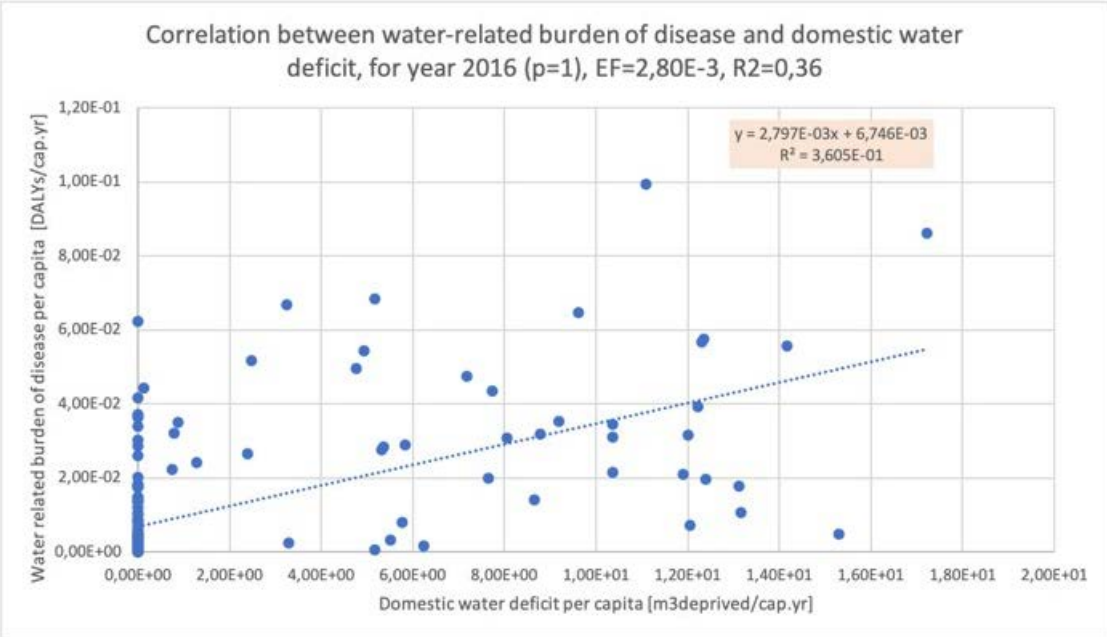


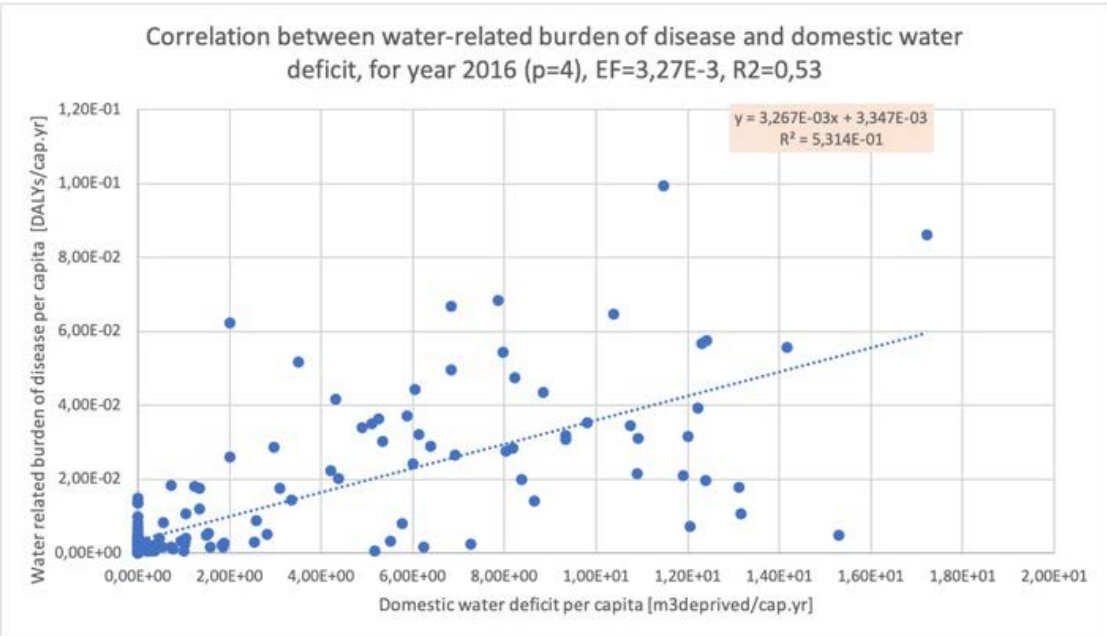

Figure 5: Distribution of values A- for HWCtot/AMC, assessing water scarcity, and B- for HWCdom/tot assessing domestic water share in total water use

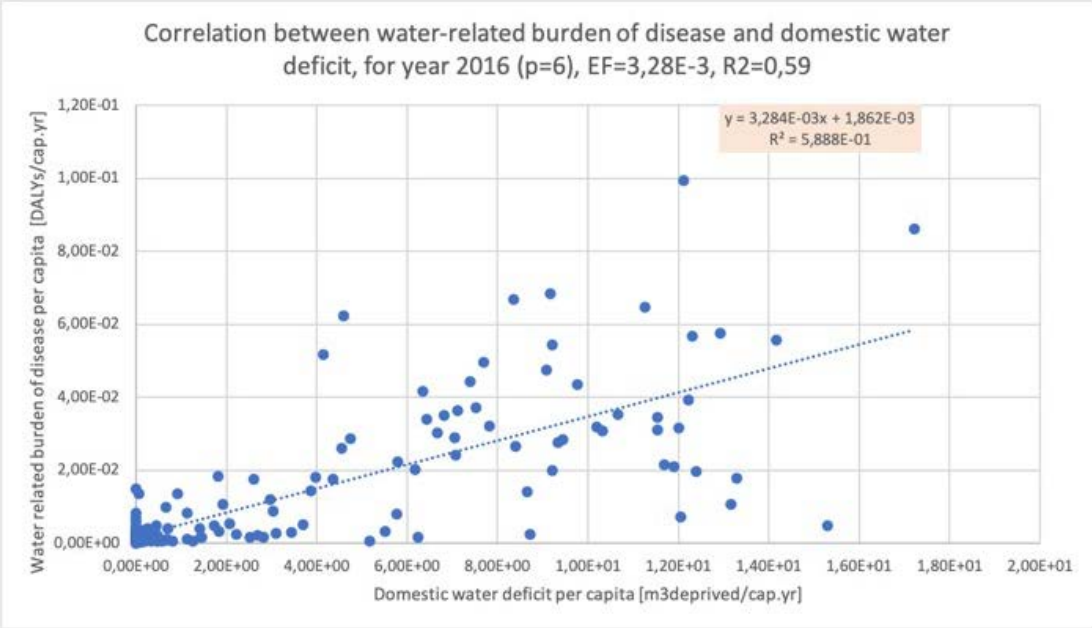
Figure 4 and Figure 5 show the wider distribution of HWCtot/AMC values compared to HWCdom/HWCtot. While nearly ninety nine (98.93) percent of the values of the ratio HWCtot/AMC are distributed between 1E-4 and 1E+2 (6 orders of magnitude), 99.81% of the values of the ratio HWCdom/HWCtot are included between 1E-2 and 1 (2 orders of magnitude). That highlights the important sensitivity of the fate factor to water scarcity (HWCtot/AMC).

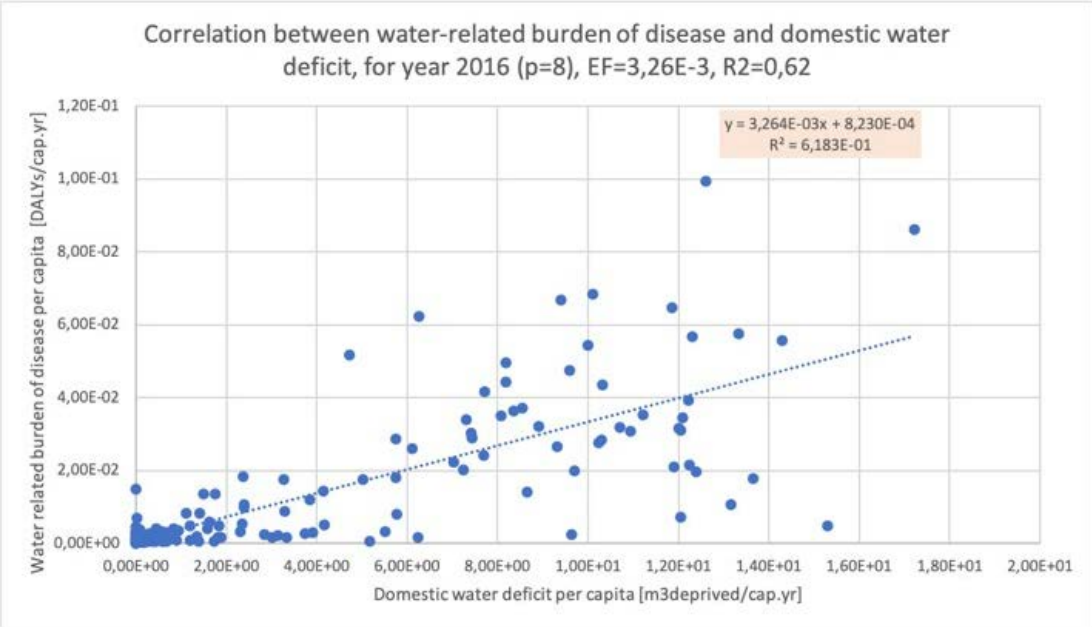
**Sensitivity analysis of p**

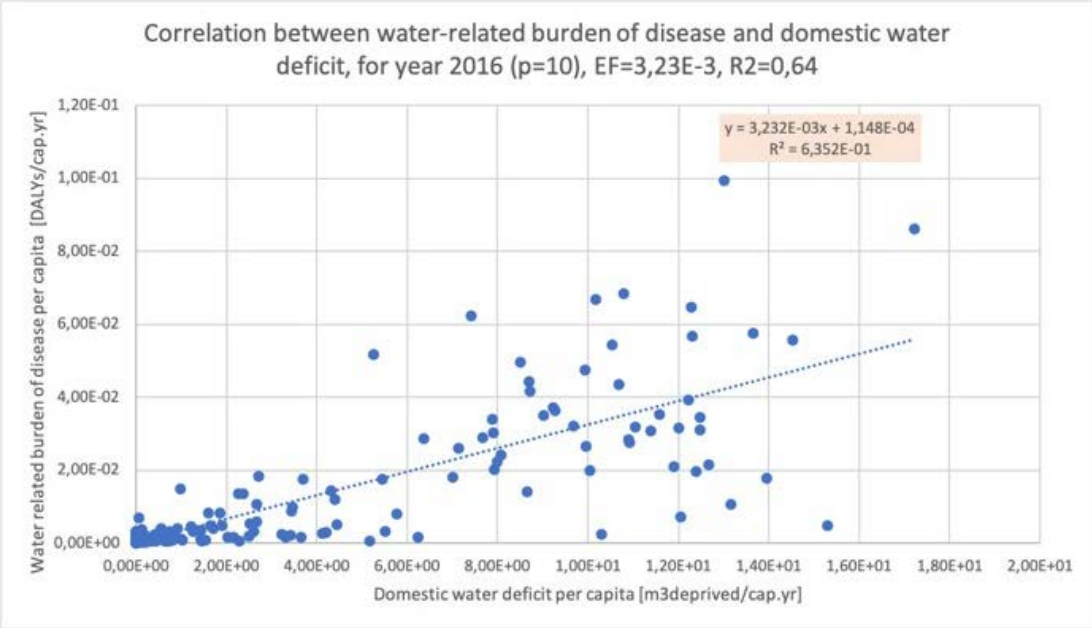
A sensitivity analysis is carried out on the value p to assess its influence on the effect factor value. The relevance of the correlation between the water-related burden of disease and the domestic water deficit is considered as a basis to this analysis. The inconsistency of the results when p=1 confirms the relevance of the integration of a factor p to discriminate domestic water use between households with and without water access on premise: the high number of countries suffering from water-related diseases with no domestic water deficit is considered inadequate. The correlation between water related burden of diseases and domestic water deficit shows great results for values of p superior to 4. The value used in this work is set to 6,3 in respect to these results and to the work of Larson, Minten, and Razafindralambo (2006). Nonetheless, the sensitivity analysis shows that a change of the value has little influence on the value of the effect factor and its order of magnitude [2.80E-3 DALY/$m^3$ – 3.07E-3 DALY/$m^3$].

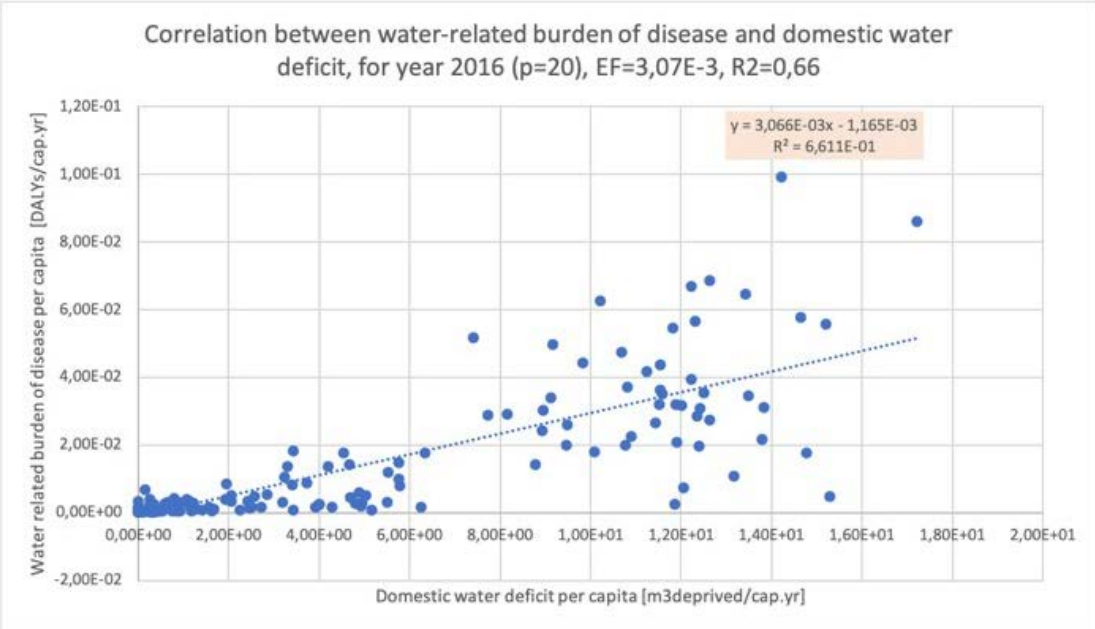


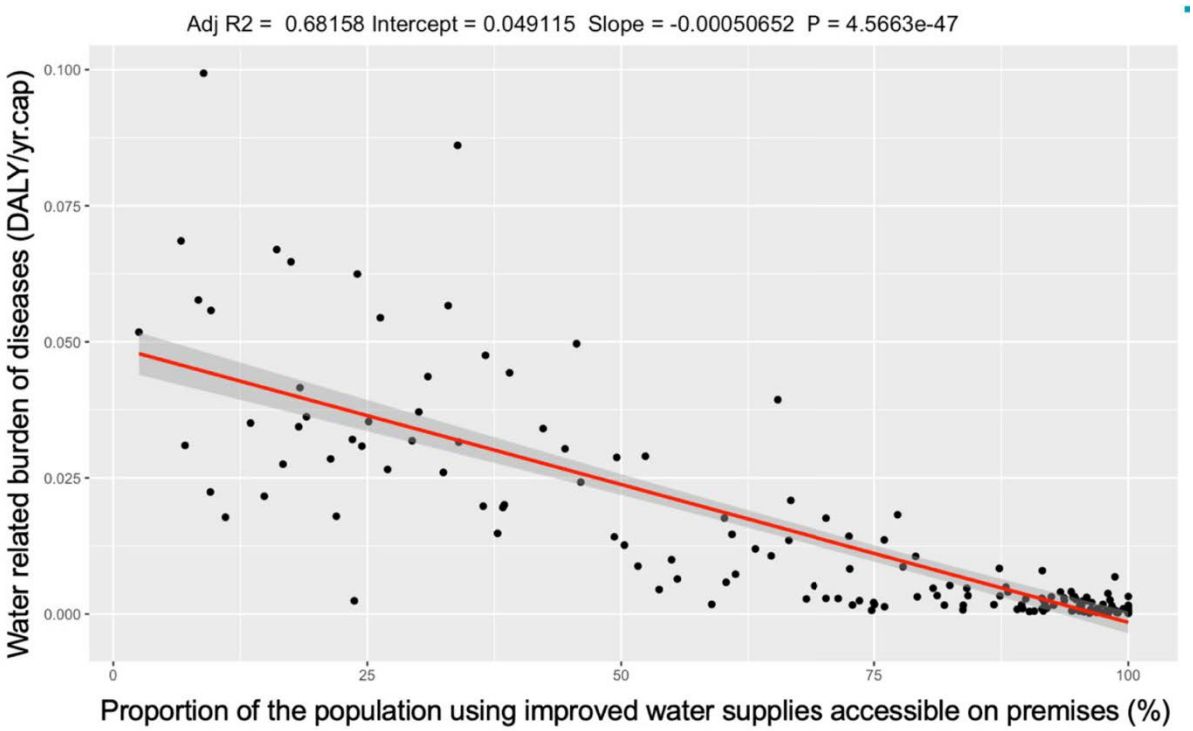

Correlation between water-related burden of disease and domestic water deficit, for year 2016 (p=6), EF=3,28E-3, R2=0,59
y = 3,284E-03x + 1,862E-03
R² = 5,888E-01
Water related burden of disease per capita [DALYs/cap.yr]
1,20E-01
1,00E-01
8,00E-02
6,00E-02
4,00E-02
2,00E-02
0,00E+00
0,00E+00
2,00E+00
4,00E+00
6,00E+00
8,00E+00
1,00E+01
1,20E+01
1,40E+01
1,60E+01
1,80E+01
2,00E+01
Domestic water deficit per capita [m3deprived/cap.yr]


Correlation between water-related burden of disease and domestic water deficit, for year 2016 (p=8), EF=3,26E-3, R2=0,62
y = 3,264E-03x + 8,230E-04
R² = 6,183E-01
Water related burden of disease per capita [DALYs/cap.yr]
1,20E-01
1,00E-01
8,00E-02
6,00E-02
4,00E-02
2,00E-02
0,00E+00
0,00E+00
2,00E+00
4,00E+00
6,00E+00
8,00E+00
1,00E+01
1,20E+01
1,40E+01
1,60E+01
1,80E+01
2,00E+01
Domestic water deficit per capita [m3deprived/cap.yr]


Correlation between water-related burden of disease and domestic water deficit, for year 2016 (p=10), EF=3,23E-3, R2=0,64
y = 3,232E-03x + 1,148E-04
R² = 6,352E-01
Water related burden of disease per capita [DALYs/cap.yr]
1,20E-01
1,00E-01
8,00E-02
6,00E-02
4,00E-02
2,00E-02
0,00E+00
0,00E+00
2,00E+00
4,00E+00
6,00E+00
8,00E+00
1,00E+01
1,20E+01
1,40E+01
1,60E+01
1,80E+01
2,00E+01
Domestic water deficit per capita [m3deprived/cap.yr]


Correlation between water-related burden of disease and domestic water deficit, for year 2016 (p=20), EF=3,07E-3, R2=0,66
y = 3,066E-03x - 1,165E-03
R² = 6,611E-01
Water related burden of disease per capita [DALYs/cap.yr]
1,20E-01
1,00E-01
8,00E-02
6,00E-02
4,00E-02
2,00E-02
0,00E+00
-2,00E-02
0,00E+00
2,00E+00
4,00E+00
6,00E+00
8,00E+00
1,00E+01
1,20E+01
1,40E+01
1,60E+01
1,80E+01
2,00E+01
Domestic water deficit per capita [m3deprived/cap.yr]

**Correlation between water related burden of diseases and private access to water supplies**




A strong correlation is demonstrated between the coverage of private access to domestic water supply and the water-related burden of disease per capita (R2=0,68, P=4,57e-47).

**Boulay et al. (2011) « general » and "unknown" models**

Several sub-models were developed building on Boulay et al. (2011) in order to be implemented in life cycle assessment applications. They differ mainly by the specificity of the data used to calculate the fate factor. The "Unknown" model was developed to be integrated into the IMPACT World+ (Bulle et al. 2019) life cycle assessment methodology, while the "General" model data is used in this work to compare the results with the revised model. The following section summarizes how they differ.

The fate factor used in the **Unknown model** discriminates between groundwater and surface water scarcity. It defines a final scarcity indicator as the weighted mean of the scarcity factors: $\alpha_{surface}$ and $\alpha_{groundwater}$. They are each the result of the application of a logarithmic function to their corresponding "raw" scarcity indices ($\alpha^*_{surface}$ and $\alpha^*_{groundwater}$). The surface $\alpha^*_{surface}$ "raw" scarcity indicator is calculated as a consumption to availability (CTA) ratio, where consumption refers to surface water consumption and availability as the statistical low flow Q90. The groundwater $\alpha^*_{groundwater}$ "raw" scarcity indicator is also calculated as a consumption to availability (CTA) ratio, where consumption refers to ground water consumption and availability as the renewable groundwater resource available.
In Boulay et al. (2011), a logarithmic function is applied to these "raw" factors (CTA ratios) to obtain the fate (named scarcity) factors $\alpha_{surface}$ and $\alpha_{groundwater}$. It is defined by thresholds based on exisiting international recommendations on the definition of stress at the time developed for WTA and converted for CTA use: ratios are set equal to 0 if inferior to 0,0022 and to 1 if superior to 0,196. Then, $\alpha_{unknown}$ is calculated as the consumption-weighted sum of $\alpha_{surface}$ and $\alpha_{groundwater,}$ as per:

$$\alpha_{unknown} = \alpha_{surface} \times (1 - fg) + \alpha_{groundwater} \times fg$$

where fg is the fraction of usage dependent on groundwater.

The **General** model calculates $\alpha_{general}$ by applying the same logarithmic function to a "general" CTA ratio that does not discriminate between water source (surface or ground), but is defined as the ratio between total water consumption and total water availability ($\alpha_{general*}$= CU/(Q90+GWR)). The logarithmic function thresholds are the same (0,0022 and 0,196).

Since the thresholds remain the same and that $\alpha^*_{surface}$ values are globally higher than $\alpha^*_{groundwater}$ and $\alpha^*_{general,}$ the application of the logarithmic function on these "raw" scarcity indices result in a higher proportion of zero values for $\alpha_{general}$ values (compared to $\alpha_{unknown}$ calculated as the weighted sum of $\alpha_{surface}$ and $\alpha_{groundwater}$). This translates into a "general" water stress being generally lower (because of more resources available for all uses) than a surface-specific or groundwater-specific water stress where the water use may not necessarily be optimized with the most abundant source

**Fate factor comparison**

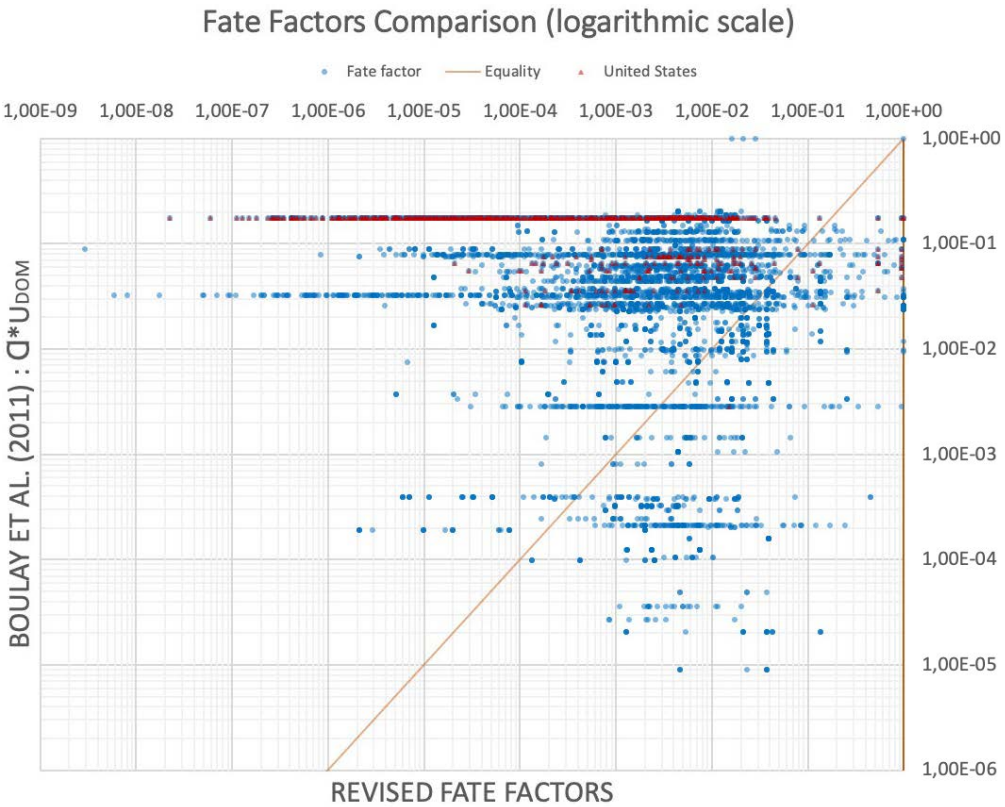
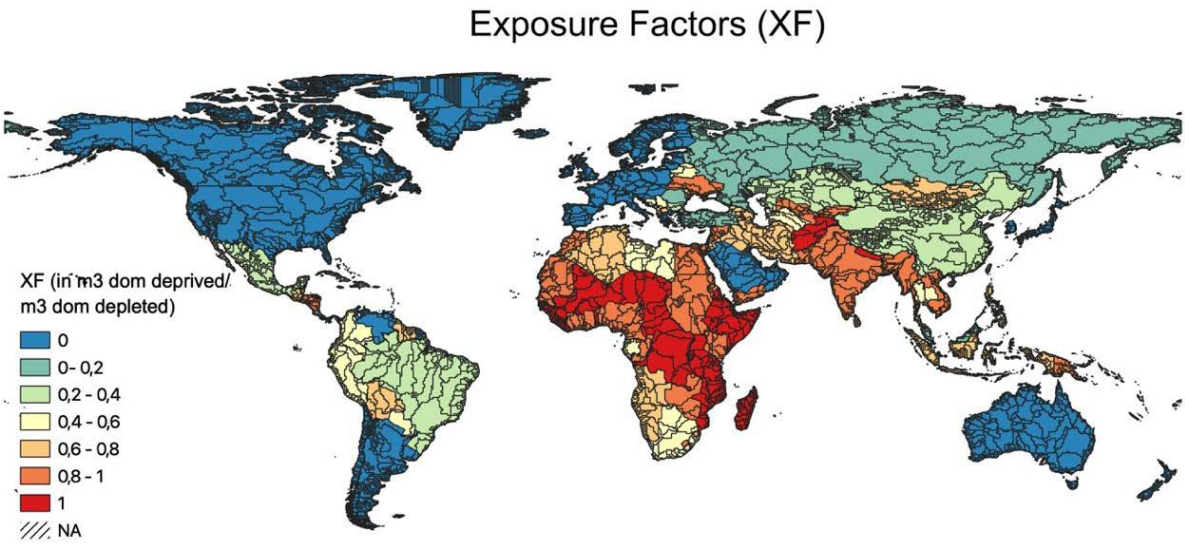


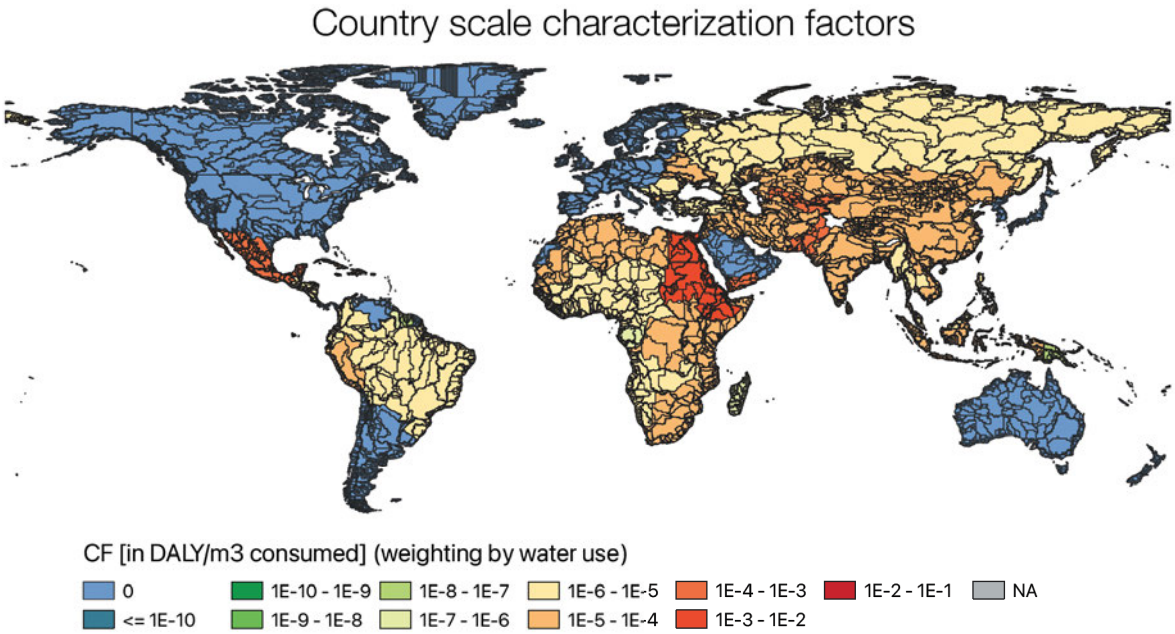

***Figure 7: Comparison of revised (this study) vs Boulay et al. (2011)'s non zero fate factors [in m3 dom depleted/m3 dom used]. Blue points abscissa (ordinate respectively) coordinates account for sub river basin fate factors values in the revised model (the combination of fate factors α and the proportion of use by domestic users $U_{dom}$ in Boulay et al. (2011)). Due to the use of a logarithmic scale, null values are not represented; they are the only truncated values of the graph. The orange equality line represents coordinates for which revised and Boulay et al (2011)'s fate factors are equal for a sub river basin cell. Red points account for United States fate factors.***

Figure 7 represents the revised fate factors in comparison with the combination of non null Boulay et al. (2011)'s fate factors α and the proportion of use by domestic users. Dots aligned on a horizontal line illustrate the variability of fate factors due to a higher spatial resolution of this research work versus the single value of a lower resolution of Boulay et al. (2011). For instance, Boulay et al. (2011) provides 37 different fate factors in the United States, compared to 721 in the revised model. 69.7% of the points are located at the left of the equality line, showing an overall decrease of non null fate factors values in the revised model. For instance, in the United States, 79.9%, (0.92% and 19.1%) of the revised fate factors present lower (equal and higher respectively) values compared to Boulay et al. (2011).

**Revised exposure factors**




**Country scale CF**




Country scale CFs (annual) are calculated considering a domestic water use weightening.

**Sensibility analysis: Variation of minimum water requirements**

To assess the sensibility of the results to the value of minimum human water requirements (MWR), we calculated the effect factors by adjusting the value of the MWR from 10 to 500 liters per day per capita.

| **Minimum water requirements** | | | |
|---|---|---|---|
| In liters per day per capita (lpdc) | In m3 | EF (global, as the slope of the linear regression) | R2 |
| 10 | 0,01 | 2,50E-02 | 0,15 |
| 20 | 0,02 | 9,92E-03 | 0,34 |
| 30 | 0,03 | 5,97E-03 | 0,46 |
| 40 | 0,04 | 4,15E-03 | 0,51 |
| 50 | 0,05 | 3,13E-03 | 0,54 |
| 60 | 0,06 | 2,51E-03 | 0,56 |
| 70 | 0,07 | 2,07E-03 | 0,57 |
| 80 | 0,08 | 1,73E-03 | 0,57 |
| 90 | 0,09 | 1,49E-03 | 0,57 |
| 100 | 0,1 | 1,30E-03 | 0,57 |
| 110 | 0,11 | 1,15E-03 | 0,57 |
| 120 | 0,12 | 1,01E-03 | 0,56 |
| 130 | 0,13 | 9,30E-04 | 0,6 |
| 140 | 0,14 | 8,48E-04 | 0,55 |
| 150 | 0,15 | 7,77E-04 | 0,55 |
| 160 | 0,16 | 7,17E-04 | 0,54 |
| 170 | 0,17 | 6,65E-04 | 0,54 |
| 180 | 0,18 | 6,19E-04 | 5,28 |
| 190 | 0,19 | 5,79E-04 | 0,52 |
| 200 | 0,2 | 5,43E-04 | 0,51 |
| 500 | 0,5 | 3,37E-04 | 0,43 |

A rise of the minimum water requirements results in the increase of domestic water deficit. Since the effect factor is calculated as the ratio of water-related burden of diseases to the domestic water deficit, this trend leads to a decrease in the effect factor by an order of magnitude similar to the evolution of water requirements (EF=3.13E-3 DALY/m3 deprived for water requirements= 50lpcd, EF=3.37E-4 DALY/m3 deprived for water requirements= 500lpcd).

**Exposure factors**

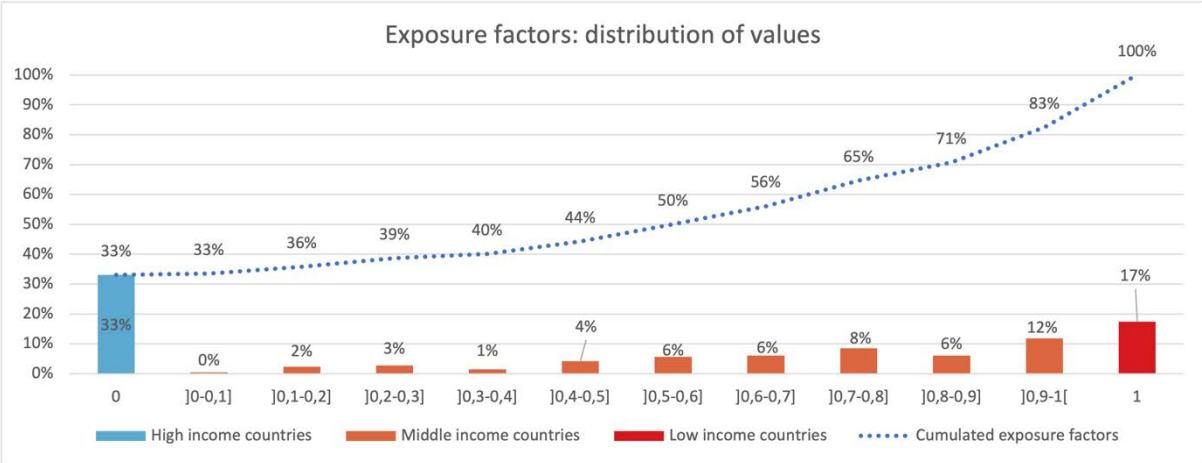



***Figure 8 : Distribution of exposure factor values. Each column represents the pourcentage of total countries whose exposure factors are included in the corresponding range. Blue dotted line represents the cumulative percentage of total countries whose exposure factors are equal or inferior to the corresponding range.***

Among the 212 updated factors, 70 countries are capable to fully adapt to water depletion (XF=0 for 33%, Figure 6's blue column) while 37 don't (XF = 1 for 17%) and exposure factor is included between 0 and 1 for 105 middle income countries (50%).

### a. Comparison with Boulay et al. (2011) CFs

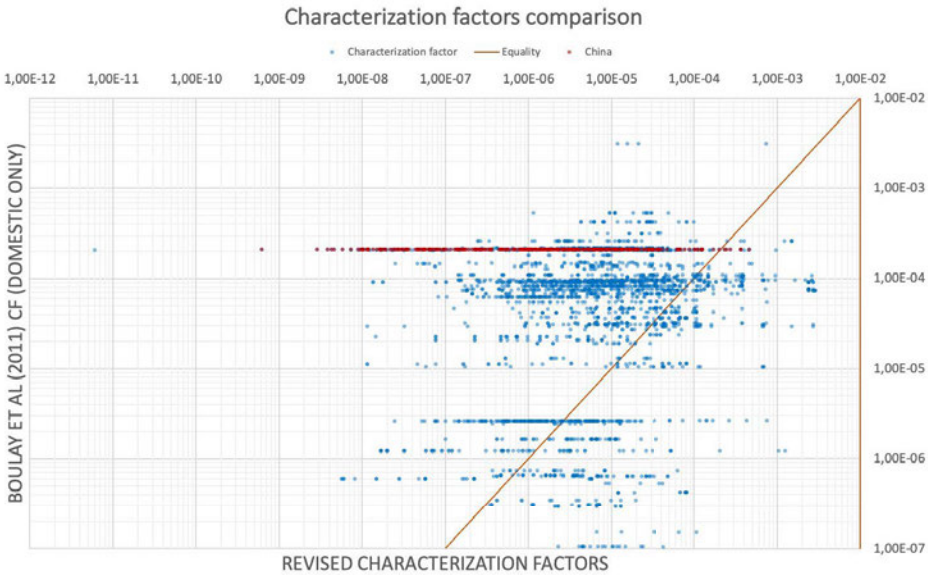



*Figure 9: Comparison of revised (this study) vs Boulay et al. (2011)'s non null characterization factors [in DALY/m3 consumed]. Due to the use of a logarithmic scale, null values are not shown. Red points account for one CF calculated in China by Boulay et al. (2011)*

Figure 9 shows the comparison between the non null revised CFs of this study and the ones developed by Boulay et al. (2011). These last CFs account for the domestic impact pathway only (excluding the agricultural and fisheries impact pathways) and consider a generic water quality level and without any specification related to the source of water. Overall, with points located above the line of equality, the non zero revisited CFs show lower values from the original CFs, directly linked with the changes in the fate factor, as described above. The lines of horizontal points show the relevance of the increased geographical resolution of the fate factor following the update of data from WaterGAP (Flörke et al. 2013; Müller Schmied et al. 2014). That allows a higher discrimination within a region, and a better representation of the local realities (current CFs) than single values obtained by Boulay et al (2011).