A global analysis of the environmental cost of river water withdrawals

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1. Introduction

Over the years, much effort has been devoted to quantify **water withdrawals** at a global scale; however, comparisons are not simple because the uneven spatiotemporal distribution of surface water resources entails that the same amount of withdrawn water does not have the same **environmental cost** in different times or places.

In order to account for this spatiotemporal heterogeneity, this work proposes a novel **index** to assess the environmental cost of a reference amount of water withdrawn from a generic river section. The environmental cost of a withdrawal is equal to the **impact** that it has on the entire river ecosystem.

2. The impact index

2.1 The impact per unit length

We define the impact per unit length ($\boldsymbol{i_w}$) in a generic section of the river network proportional to the river discharge reduction caused by the water withdrawal (W) in the same section:

$$i_{max} : Q = i_w : W \rightarrow i_w = i_{max}\frac{W}{Q}$$

$\boldsymbol{i_{max}}$ is the maximum possible impact per unit length, which occurs when the entire river discharge (Q) in the river section is withdrawn (clearly, W ≤ Q). Since numerous studies have highlighted a power-law dependence of some significant river characteristics with river discharge (e.g., the width of the riparian belt, the habitat richness, the dilution capacity) we assess i_{max} as

$$i_{max} = k(\alpha)\, Q^{\alpha}$$

where $k(\alpha)$ is a proportionality constant and α is a parameter that depends on the river property studied and it varies from 0 to 1, this parameter allows one to consider **the relevance of a fluvial environment** (i.e., i_{max}) from different points of view.

A reasonable constrain is that the environmental cost of withdrawing all the world's surface water resources is unaffected by α and equal to a constant value, $\boldsymbol{I_{world}}$.

Thus, the impact per unit length of a water withdrawal in a generic river section is:

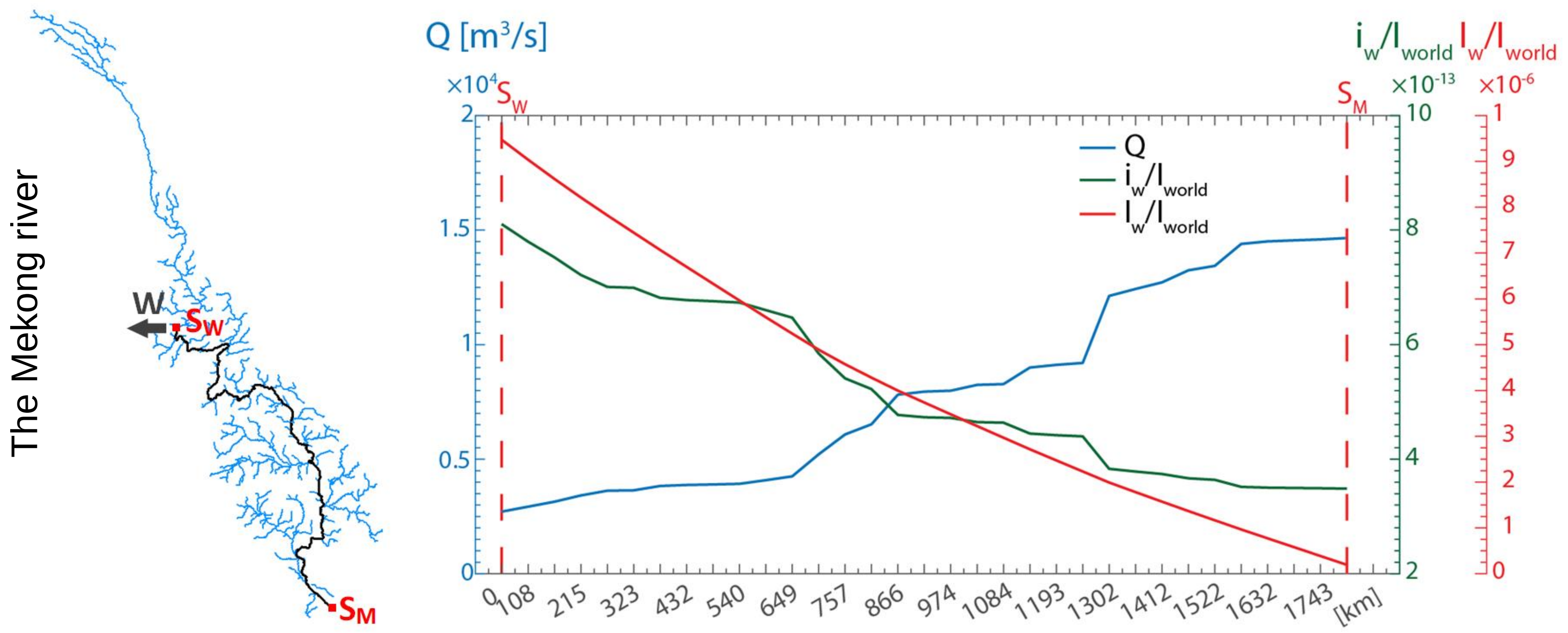
$$\boldsymbol{i_w = k(\alpha)\frac{W}{Q^{1-\alpha}}}$$

2.2 The overall impact

i_w estimates a local impact that does not take into account **downstream effects**, but the environmental cost of a withdrawal has to account for the impacts on the whole fluvial system.

Therefore, the overall impact of a water withdrawal has to be evaluated along the curvilinear abscissa of the river as the sum of the impacts per unit length from the section where water is withdrawn, S_W, down to the river mouth, S_M (see figure below). It follows that we can define **the environmental cost**, $\boldsymbol{I_w}$, of a water withdrawal in a river section of the river network as

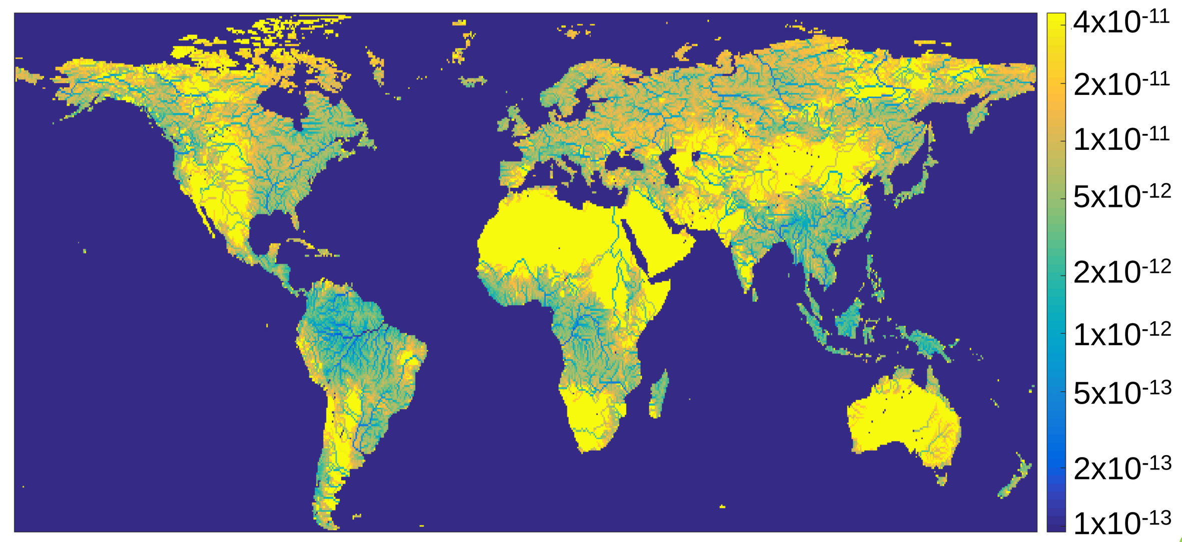
$$\boldsymbol{I_w = \int_{S_W}^{S_M} i_w(s)\, ds = k(\alpha)\int_{S_W}^{S_M}\frac{W}{Q(s)^{1-\alpha}}ds}$$



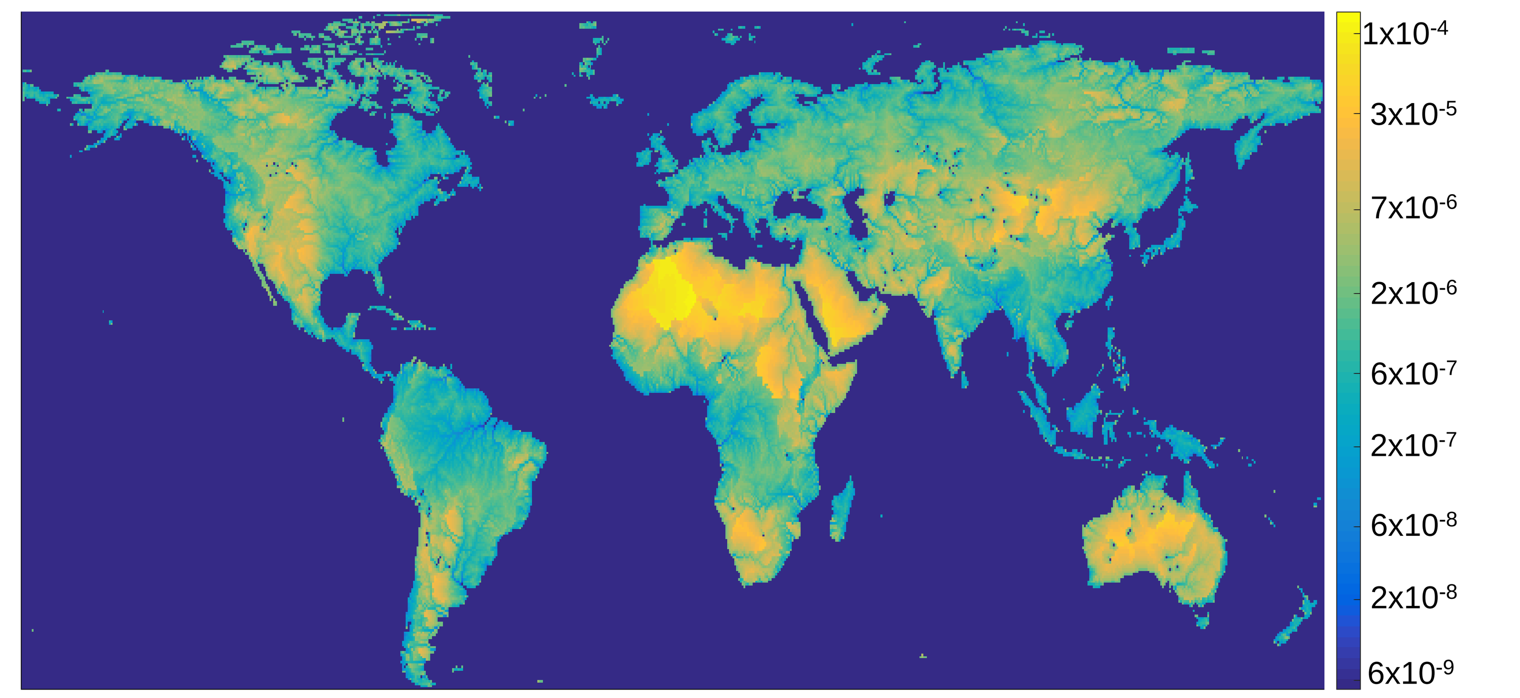
3. The environmental cost of a reference surface water withdrawal

The index is applied at a global scale with a **0.5° spatial resolution** and using yearly average data of river discharge which have been obtained using the flow direction grid and the runoff data of the UNH/GRDC Composite Runoff V1.0 database [*Fekete et al., 2002*]. The **reference water withdrawal** has been fixed at 1 m³ s⁻¹. The results in this poster are assessed with *α=0.5* and normalized by I_{world}.

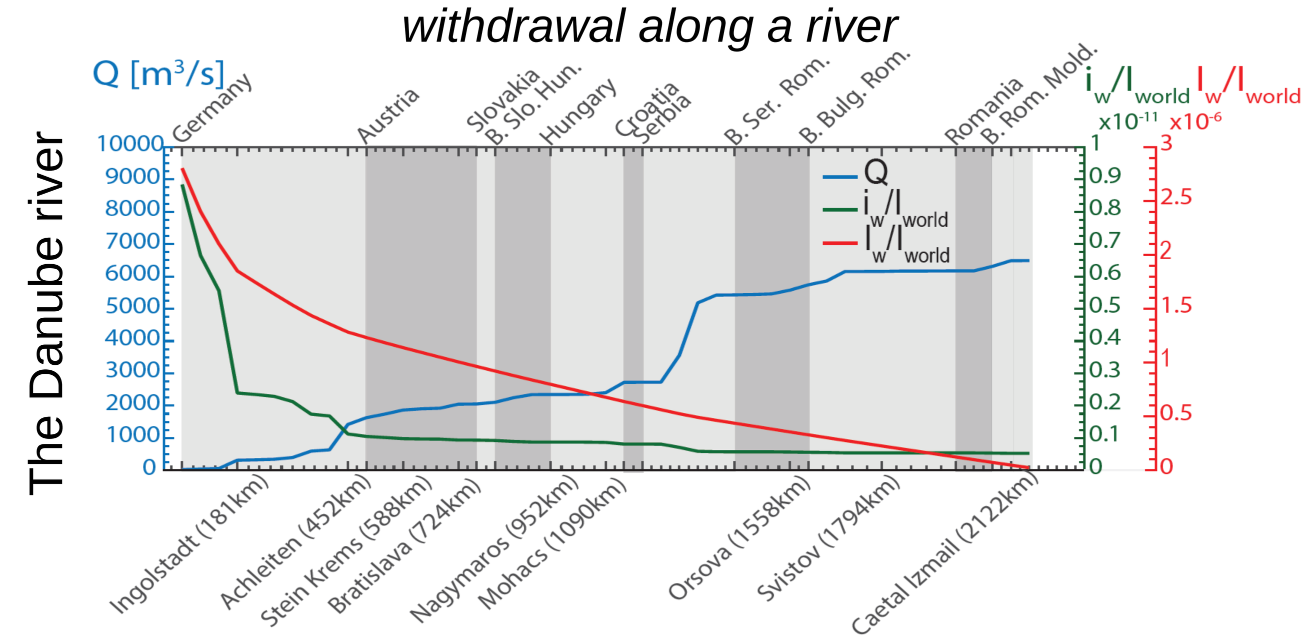
The impact per unit length



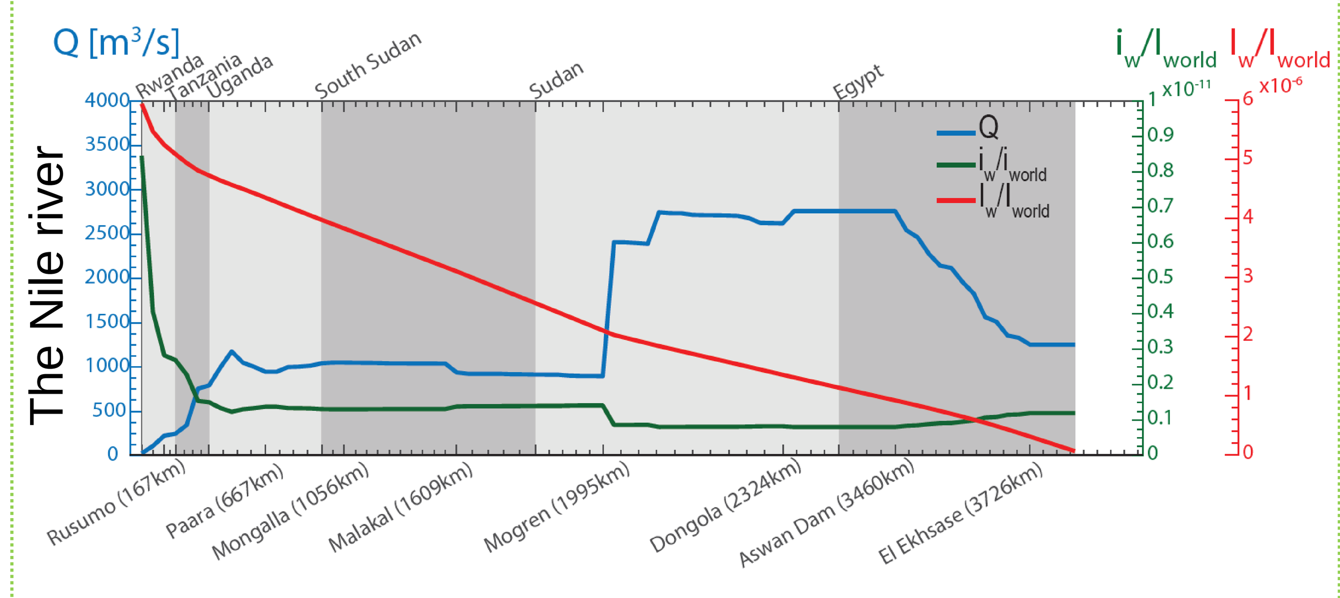
The environmental cost of a reference surface water withdrawal



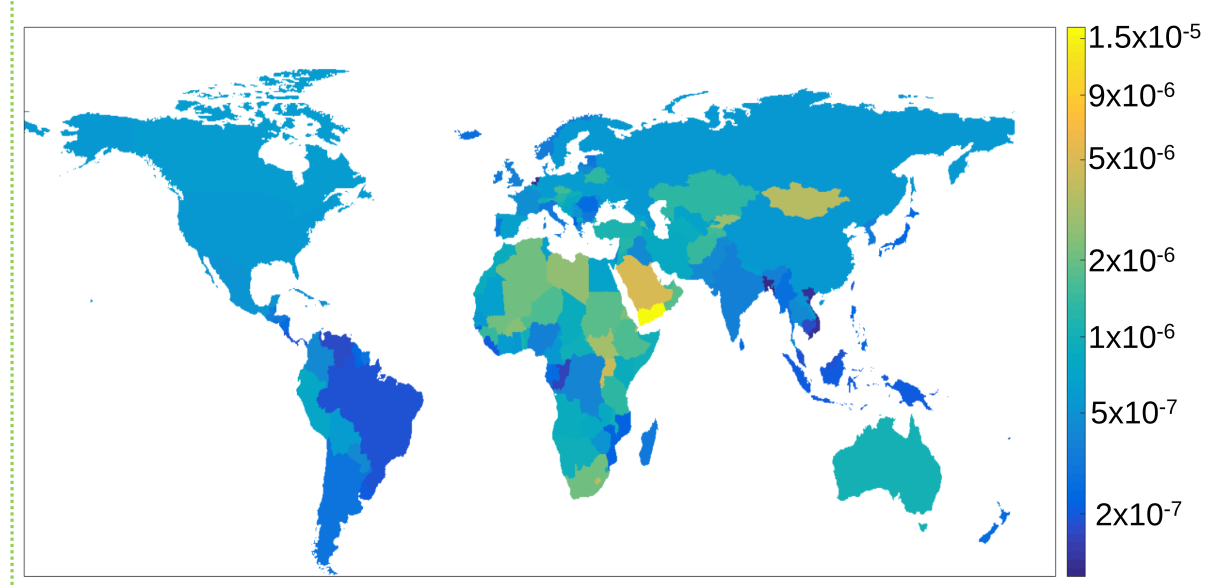
The environmental cost of a reference surface water withdrawal along a river



In the same river a fixed water withdrawal has a higher environmental cost if this occurs in the upper part of the river (see the red line in figures). This occurs for two reasons: (i) usually river discharge gradually increases from the spring to the river mouth and the same amount of W, thus, represents a very different share of the available water; (ii) a water withdrawal impacts all the downstream sections.

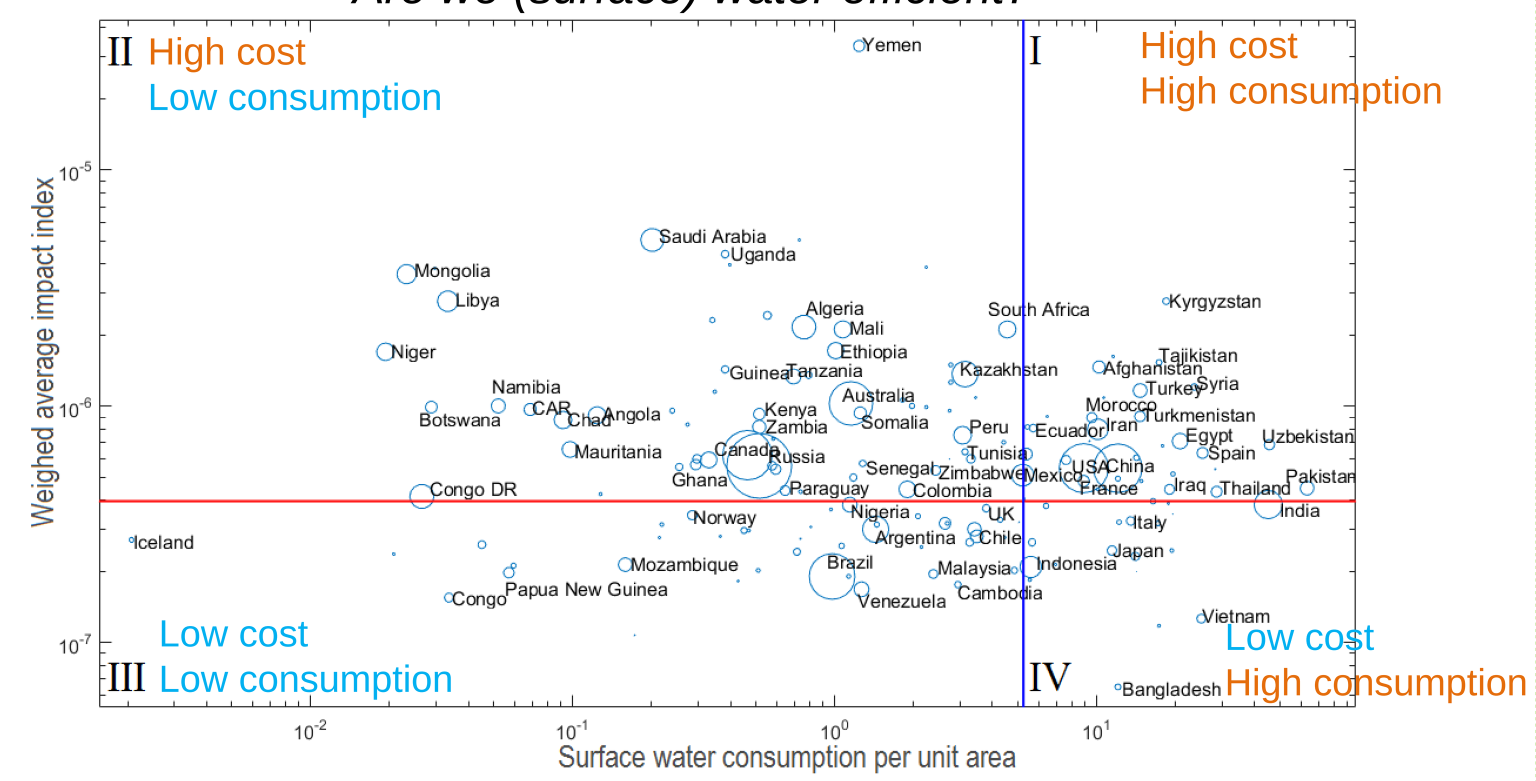


The weighted average environmental cost at the country scale



In order to consider the fact that water is usually withdrawn where it is more abundant, the environmental cost at the country scale can be assessed as a weighted average, using the river discharge as the weight.

Are we (surface) water efficient?



Scatter plot of the yearly national surface water consumption [*Mekonnen and Hoekstra, 2011*] per unit area and the weighted average environmental cost at the country scale. The red line is the world weighted average of I_w, and the blue line is the world average surface water consumption per unit area.

4. Conclusions

The index highlights regions and countries more **environmentally vulnerable to surface water exploitation**. Since the index systematically assesses the environmental cost by accounting for the downstream propagation effect of a water withdrawal on the fluvial ecosystem, it aims to support decision-making in **transboundary river** basins as well, with the challenge to support water management strategies overcoming administrative borders. Moreover, the index is a possible novel tool to analyse the **food trade network** with an impact-oriented approach.

References

Fekete, B. M., C. J. Vörösmarty, and W. Grabs (2002), High-resolution fields of global runoff combining observed river discharge and simulated water balances, Global Biogeochemical Cycles.

Mekonnen, M. M., and A. Y. Hoekstra (2011), National water footprint accounts: the green, blue and grey water footprint of production and consumption, UNESCO-IHE.

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