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Wedge approach to water stress

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Supplementary Methods

Calculation of water stress per basin

Water stress index (*WSI*) is defined by comparing water availability with corresponding water withdrawal for each basin (i) (Falkenmark et al., 1997). Water stress is evaluated per month to consider the seasonal variability and occurs whenever the amount of water withdrawal reaches the threshold of 0.4 in that of water availability in a same sptio-temporal domain (Wada et al., 2011).

$$WSI_i = \frac{W_{w,i}}{A_{w,i} - E_{w,i}}$$

where W_w is the water withdrawal and A_w is the water availability. E_w is the environmental flow requirement. Although environmental flow requirement is best determined by the degree and nature of their dependency on streamflow, such information is rarely observed directly, especially at the scale at which it is modeled in this study. Therefore we calculated E_w to be Q_{90}, i.e. the monthly streamflow that is exceeded 90% of the time, following Smakhtin (2001) and Smakhtin et al. (2004).

Calculation of water wedge options per basin to reduce the global water stressed population

Each water stressed basin (WSI > 0.4) has a finite number of feasible strategies with respect to the present condition. For example, we consider currently existing drivers (irrigated areas, irrigation efficiency, industry/domestic water use, population number, reservoirs, and desalination) as water wedge options for the future to reduce water stressed population for each basin. This potentially prevents new wedge options to appear, but given the historical development it may be reasonable to assume that people would invest existing options more intensively rather than introducing completely new options. Nevertheless, most water wedge options are available for many currently water-stressed basins (see Figure 1). To stabilize the water stressed population by 2050, we randomly pick a water stressed basin and calculate the required volume of water required to get that basin out of water stress. We then divide this amount by available water wedge options for the water stressed basin and assign the amount to each water wedge target. This operation is repeated until the target level in the global water stressed population is achieved.

$$k \times P_G = \sum_{i=1}^{Ns} P_i$$

where k is the corresponding reduction in the global water stressed population, P_G and P_i is the number of water stress population for the globe (G) and for each basin (i), and N_s is the global number of water-stressed basins.

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The global water resources assessment model AQURA

The global water resources assessment model AQURA estimates water stress and the associated number of population under water stress for each grid cell (0.1^o to 0.5^o or ~10 km by ~10km to ~50km by ~50km at the equator) for each time step (day to month) (Wada et al., 2011, 2014; Wada and Bierkens, 2014). The spatial resolution is aggregated into a meaningful unit such as basin so that subbasin water withdrawal and availability does not have to be incorporated. The model is consisted of number of sub-modules that calculate (1) population, (2) livestock water demand, (3) irrigation water demand, (4) industrial and domestic water demand, (5) groundwater pumping, (6) desalinated water use, (7) surface water availability (e.g., runoff, river discharge), (8) groundwater recharge, (9) environmental flow requirement, (10) river routing, and (11) water stress. The sectoral water demand is calibrated against the available water use statistics per sector per country over the historical period (1960-2010). (7) and (8) are prescribed by simulation results from the existing global hydrological model PCR-GLOBWB (Wada et al., 2010; Van Beek et al., 2011). In AQURA, a variety of parameters such as irrigation efficiency, water use intensity, desalination capacity, and pumping rate can be adjusted to evaluate the potential impacts on water demand, water stress, and the number of people living with water stress under past, present and future conditions (1900-2100). The model is currently used in a post-process, and variables (7) and (8) can be supplied from any other existing global hydrological models if available.

Global datasets

To evaluate water wedges, we utilized the latest available global datasets. Future projections of water availability and water demand are based on the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP; http://www.isi-mip.org/) that is a community-driven modelling effort bringing together impact models across sectors and scales to create consistent and comprehensive projections of the impacts of different levels of global warming under SSP2 (Shared Socioeconomic Pathways) that is comparable to a business-as-usual case (Warzawski et al., 2013). The ISI-MIP framework uses five GCMs (Global Climate Models) selected from the newly available CMIP5, primarily due to availability, at project start, of daily transient climate data of the required variables for the RCPs (Representative Concentration Pathways) (Hempel et al., 2013). The selected GCMs cover a broad range of responses of rising global mean temperature and changing precipitation patterns under four RCPs (20 ensemble projections with 5 GCMs by 4 RCPs in total). The data are publicly available to download at http://www.isi-mip.org/. Desalinated water use was taken from available country statistics from two data sources: the FAO AQUASTAT database (http://www.fao.org/nr/aquastat/) and the WRI EarthTrends (http://www.wri.org/project/earthtrends/). Reservoir data were obtained from the newly available and extensive Global Reservoir and Dams Dataset (GRanD) (Lehner et al., 2011) that contains 6,862 reservoirs with a total storage capacity of 6,197 km^3.

References

Falkenmark M, Kijne J W, Taron B, Murdoch G, Sivakumar M V K and Craswell E 1997 Meeting Water Requirements of an Expanding World Population [and Discussion] Phil. Trans. R. Soc. Lond. B. 352 929-936 doi:10.1098/rstb.1997.0072

Hempel S, Frieler K, Warszawski L, Schewe J and Piontek F 2013 A trend-preserving bias correction – the ISI-MIP approach Earth Syst. Dynam. 4 219-236 doi:10.5194/esd-4-219-2013

Lehner B et al. 2011 High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management Fron. Ecol. Environ. 9 494-502 doi:10.1890/100125

Smakhtin V U 2001 Low flow hydrology: a review J. Hydrol. 240 147–186 doi:10.1016/S0022-1694(00)00340-1

Smakhtin V U, Revenga C and Döll P 2004 A pilot global assessment of environmental water requirements and scarcity Wat. Int. 29 307–317

Van Beek L P H, Wada Y and Bierkens M F P 2011 Global monthly water stress: I. Water balance and water availability Water Resour. Res. 47 W07517 doi:10.1029/2010WR009791

Wada Y, van Beek L P H, van Kempen C M, Reckman J W T M, Vasak S and Bierkens M F P 2010 Global depletion of groundwater resources Geophys. Res. Lett. 37 L20402 doi:10.1029/2010GL044571

Wada Y, van Beek L P H and Bierkens M F P 2011 Modelling global water stress of the recent past: on the relative importance of trends in water demand and climate variability Hydrol. Earth Syst. Sci. 15 3785-3808 doi:10.5194/hess-15-3785-2011

Wada Y, Wisser D and Bierkens M F P 2014 Global modeling of withdrawal, allocation and consumptive use of surface water and groundwater resources Earth Syst. Dynam. 5 15-40 doi:10.5194/esd-5-15-2014

Wada,Y and Bierkens M F P 2014 Sustainability of global water use: past reconstruction and future projections, Environ. Res. Lett., resubmitted after revisions.

Warszawski L et al 2013 The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP): Project framework Proc. Natl. Acad. Sci. USA 111(9) 3228-3232 doi:10.1073/pnas.1312330110