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3.1.9 Assessment of global scale water stress indicators

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SUMMARY: *A global water model is used to identify hot spot regions of future water stress and to determine the number of people living with severe water stress. The impacts of climate change and socio-economic driving forces derived from the A2 and B2 IPCC scenarios are analysed. Climate change impacts are considered using future climate data on temperature and precipitation generated by two different climate models, ECHAM4/OPYC3 and HadCM3. Depending on the scenario, climate model, and indicator, the number of people living in river basins with severe water stress increases by a factor of 2.5 to 3.5 between current conditions and 2075.*

Indicators are used to clarify the meaning of complex results, for example those obtained with global models. Global water assessments usually employ only one indicator to describe water stress (ALCAMO et al. 2000, ALCAMO et al. 2003b, ARNELL, 2004, VÖRÖSMARTY et al. 2000). However, considering the uncertainty of using aggregated indicators, it is advisable to compare the results of at least two different indicators. In this article we present two indicators of water stress that are based on water availability, water withdrawals, water consumption, and 90% reliable monthly discharge. All these values have been computed with the global water model WaterGAP (Water – Global Assessment and Prognosis), which has been described in ALCAMO et al. (2003a, b) and DÖLL et al. (2003).

To identify future hot spot regions of water stress and to determine the number of people living in river basins with severe water stress, two of the latest emission scenarios of the Intergovernmental Panel on Climate Change (IPCC 2000) – A2 and B2 – are analysed. Both scenarios assume a future regionalised world, with the A2 scenario focusing on economic values, and the B2 on environmental issues.

The A2 scenario assumes a relatively high population growth (close to, but below the UN »high« projection) and a low to moderate growth in the economy. The trend in greenhouse gas emissions is among the highest considered by the IPCC scenarios and therefore the intensity of climate change in terms of temperature and precipitation changes are also among the strongest.

In comparison to the A2 scenario, the B2 scenario shows a lower population development (following the UN »medium« projection) with higher economic growth. However, the B2 scenario also has a stronger accent on environmental policies as compared to A2 which results in significantly lower use of fossil fuels, and hence lower greenhouse gas emissions (greenhouse gas emissions in B2 are 55% lower than in A2). The lower level of greenhouse gas emissions in B2 also leads to smaller changes in temperature and precipitation as compared to the A2 scenario.

Methodology

To compute the impact of climate change and socio-economic drivers on future water resources we use the WaterGAP model (ALCAMO et al. 2000, 2003a, DÖLL et al. 2003). WaterGAP computes both water availability and water uses on a 0.5° by 0.5° (longitude and latitude) global grid. WaterGAP consists of two main components: a Global Hydrology Model to simulate the terrestrial water cycle and a Global Water Use Model to estimate water withdrawals and water consumption (*Fig. 3.1.9-1*). The estimation of the current and future water stress has been carried out on a river basin scale basis.

The aim of the Global Hydrology Model is to simulate the characteristic macro-scale behaviour of the terrestrial water cycle in order to estimate water availability. Herein, water availability is defined as the total river discharge, which is the sum of surface runoff and groundwater recharge. The model covers most of the terrestrial surface of the Earth with a geographic grid containing 66896 grid cells with a size of 0.5° by 0.5° except Antarctica. For each grid cell, information on the fraction of land and freshwater areas (lakes, reservoirs, and wetlands) is available. Land cover is assumed to be homogeneous within each grid cell. The upstream/downstream relationship among the grid cells is defined by a global drainage direction map (DDM30) which indicates the drainage direction of surface water (DÖLL & LEHNER 2002). Thus, each individual grid cell is assigned to a drainage basin. In a standard model run, river discharges in approximately 11050 river basins are simulated.

River discharge is affected by water withdrawals and return flows. In WaterGAP, natural cell discharge is therefore reduced by the consumptive water use in a grid cell as calculated by the Global Water Use Model of WaterGAP. This model consists of several modules that calculate both the water withdrawals and water consumption in the household, industry, irrigation, and livestock sectors. In this context, water withdrawals depict the total amount of water used in each sector while the consumptive water use indicates the part of withdrawn water that is

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consumed by industrial processes or human needs or lost by evapotranspiration. For most water use sectors – except irrigation – only a small amount of water is consumed, whereas most of the water withdrawn is returned, probably with reduced quality, to the environment for subsequent use. WaterGAP simulates water use for the agricultural sector on a 0.5° grid scale, but for domestic and industry sectors on a country scale. These country-scale estimates are downscaled to the grid size within the respective countries using demographic data (ALCAMO et al. 2003a). Grid cell outputs are then summed up to the river basin scale.

In order to take into account the uncertainties of climate models we analysed climate scenarios generated from two different General Circulation Models (GCMs) – the ECHAM4/OPYC3 model of the Max Planck Institute of Meteorology in Germany and the German Climate Computing Center (ROECKNER et al. 1996, CUBASCH et al. 2001) (the ECHAM4 model) and the HadCM3 model of the Hadley Center in Great Britain (GORDON et al. 2000, POPE et al. 2000). For our analyses, mean monthly precipitation and temperature data from both GCMs for the 2070s are used to scale the present-day 30-year time series 1961–1990 (NEW et al. 2000).

Water stress

A widely used concept to describe and analyse water stress is the usage of indicators that illustrate the pressure put on water resources by external drivers. One of the most common used indicators is the ratio of annual water withdrawals to annual water availability (w.t.a.) (ALCAMO et al. 2000, VÖRÖSMARTY et al. 2000). Here, the annual water withdrawals are the total volume of water abstracted from surface or groundwater sources within a river basin for the four main water use sectors and water availability is the total river discharge defined above. A drainage basin is assumed to be under low water stress if w.t.a. ≤ 0.2; under medium water stress if $0.2 <$ w.t.a. ≤ 0.4 and under severe water stress if w.t.a. > 0.4. This classification was used by the World Water Commission (COSGROVE & RIJSBERMAN 2000), UN Comprehensive Assessment of Freshwaters (WMO 1997), ALCAMO et al. (2000, 2003b), and VÖRÖSMARTY et al. (2000).

The second indicator included in this article is the consumption-to-90% reliable monthly discharge ratio (C/Q_{90}). Here the total annual water consumption is divided by the long-term average 90% reliable monthly discharge on the drainage basin level. The 90% reliable monthly discharge Q_{90} is the discharge that is exceeded in 9 out of 10 months for the period under consideration, and is used as a typical design flow for surface water supply. The C/Q_{90} indicator considers not only the variability of the discharge but also the reduction of natural discharge by upstream consumptive use. With this indicator, we assume that a drainage basin suffers from severe water stress if $C/Q_{90} > 1$ or, in other words, if consumption exceeds the 90% reliable monthly discharge. For $0.5 < C/Q_{90} \leq 1$ the basin is under medium stress and for values below 0.5, the basin has low stress. It should be kept in mind that both indicators, as calculated here, do not factor in the storage of surface water from year-to-year.

For our analysis we compare baseline conditions with scenarios of the 2070s. Because of the availability of data, baseline conditions for water use are based on 1995 estimates. By convention, baseline conditions for water availability are computed for the »climate-normal« period from 1961 to 1990.

*Fig. 3.1.9-2*A shows the w.t.a. indicator for the 2070s under the assumptions of the A2 scenario, using the ECHAM4 climate. Regions with severe water stress are

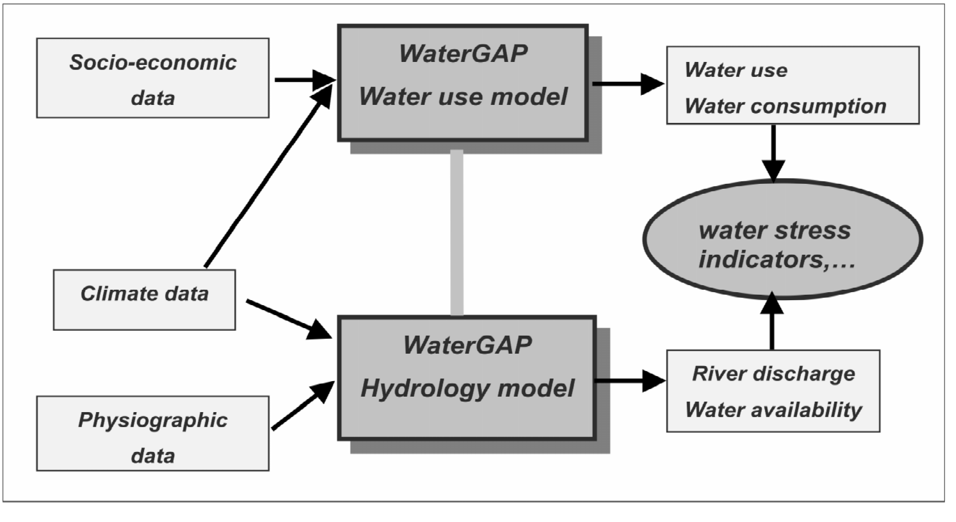


Fig. 3.1.9-1: Overview of the WaterGAP model.

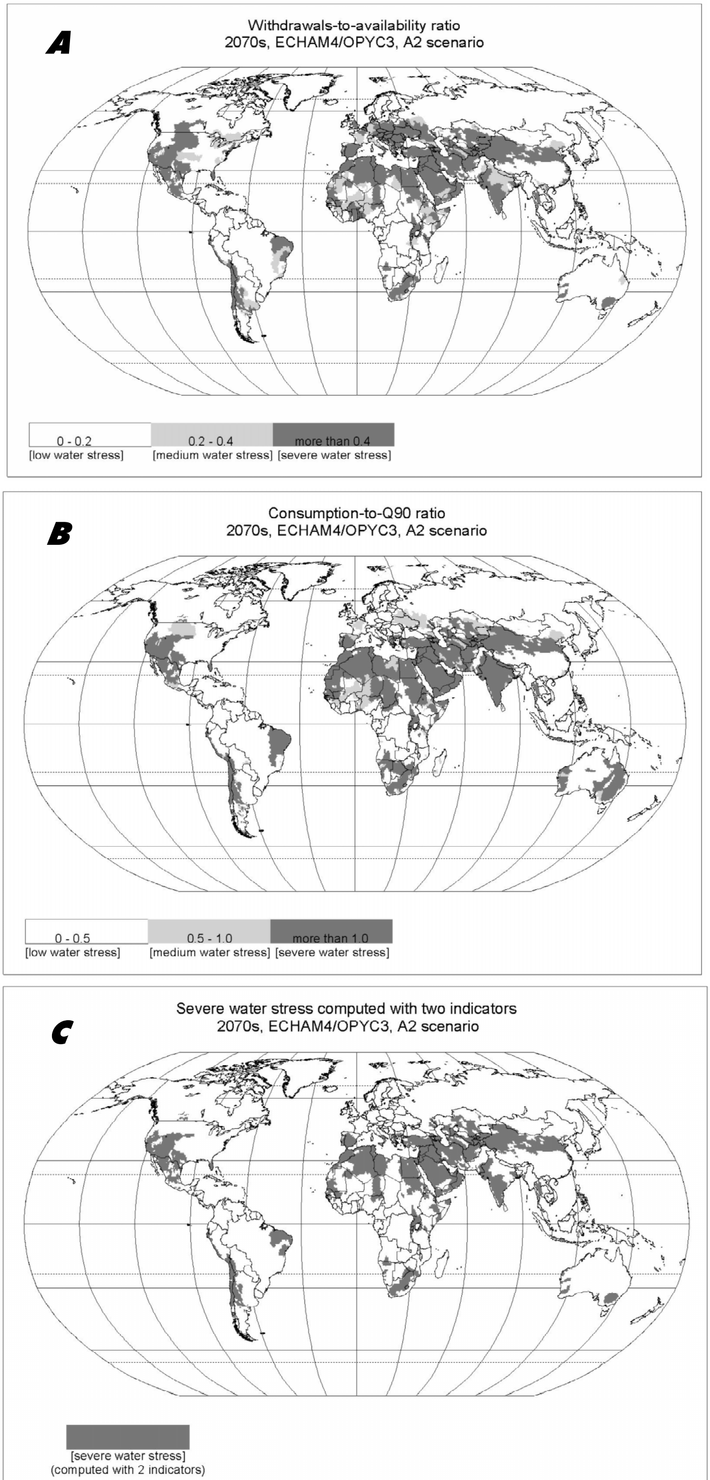
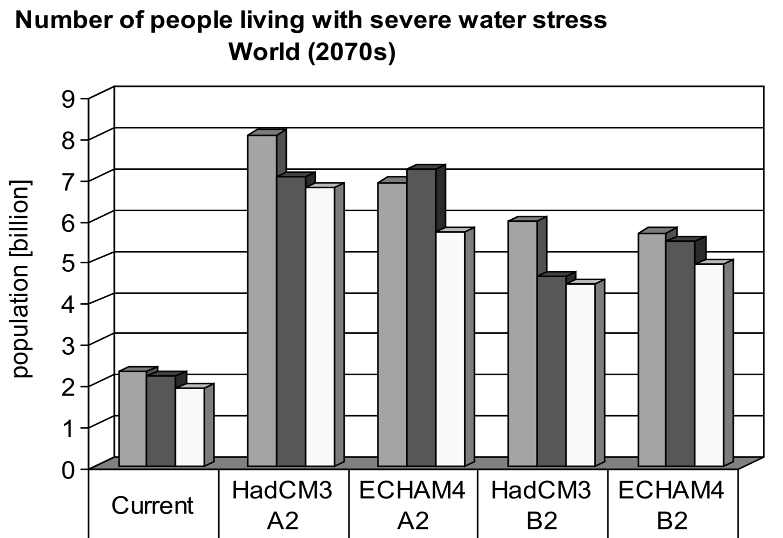


Fig. 3.1.9-2: Water stress in 2070s for the A2 scenario based on ***A:*** withdrawals-to-availability ratio (w.t.a.), ***B:*** consumption-to-Q90 ratio, and ***C:*** an overlay of both indicators.

south-eastern Europe, large parts of Africa and Asia, the Middle East, the western United States, and the west coast and north-east of Latin America. *Fig. 3.1.9-2B* depicts the consumption-to-Q90 ratio for the same scenario and time period. The areas with severe water stress are larger in Africa and Australia, but almost all of Europe drops out of this category. The consumption-to-Q90 indicator leads to a global area with severe water stress that is 10% larger than the estimated area of the w.t.a. ratio. The comparison of *Fig. 3.1.9-2A* and *B* shows that the indicators both agree and disagree in many areas of the world; the total estimation of river basin area with severe water stress varies between 36.4 and 40.9 million km² for the two different water stress indicators under the A2 scenario. This disagreement is due to the different definitions and thresholds of the indicators. *Fig. 3.1.9-2C* shows the overlap area of severe water stress as computed with the two indicators. The overlap area covers 29.5 million km² and includes south-western United States, Mexico, north-east Brazil, west coast of Latin America, large parts of northern and southern Africa, the Middle East, Central Asia, and northern China.

In a similar way we calculated the same indicators for the B2 scenario. *Table 3.1.9-1* gives an overview of the river basin area with severe water stress according to the two water stress indicators for the A2 and B2 scenarios and different GCMs. Water stress area is time dependent because socio-economic drivers produce different patterns of water withdrawals and climate change different patterns of water availability.

Next to the area with severe water stress, we calculate the number of people living in river basins under severe water stress. Using the w.t.a. ratio as the first indicator of water stress, around 2.28 billion people live today with severe water stress. This number increases to 5.65 to 8.03 billion people



	Current	HadCM3 A2	ECHAM4 A2	HadCM3 B2	ECHAM4 B2
wta > 0.4	2.279	8.030	6.879	5.916	5.650
C/Q90 > 1.0	2.187	7.013	7.190	4.609	5.454
overlapping area	1.875	6.738	5.671	4.422	4.905

scenario

Fig. 3.1.9-3: Number of people living in river basins with severe water stress.

in the 2070s depending on the scenario and climate model (*Fig. 3.1.9-3*). Taking into account the second indicator, the consumption-to-Q90 ratio, the number of people varies between 4.61 and 7.19 billion. For the overlap area of both indicators, 4.42 to 6.74 billion people are estimated to live in river basins with severe water stress between today and the 2070s.

Table 3.1.9-1: Percentage of global river basin area with severe water stress according to two different water stress indicators, scenarios, and climate input data.

Scenario	***Withdrawals-to-availability ratio > 0.4***	***Consumption-to-Q90 ratio >1***	***Overlap area***
current	21.6	26.9	19.8
A2, ECHAM4	27.4	30.1	22.8
A2, HadCM3	29.2	30.8	24.9
B2, ECHAM4	26.4	30.9	23.2
B2, HadCM3	27.7	29.6	24.0

Conclusions and recommendations

In this study we have used the WaterGAP model to identify future hot spots of water stress and to estimate the number of people living in river basins with severe water stress. In this context we analysed the impacts of climate change and changing socio-economic drivers under the IPCC A2 and B2 scenarios on future global water stress. In the 2070s, the global river basin area with severe water stress will increase by 27 to 42% depending on the scenario and climate model considered.

The water stress results obtained using the two different indicators withdrawal-to-availability ratio and consumption-to-90% reliable monthly discharge ratio point out that there is no best indicator. It is shown that both indicators are complementary and illustrate different aspects of water stress. Each of them has its own advantages and disadvantages related to its significance and uncertainty. We found a large overlap in the areas accounted by both indicators in the severe water stress category. On the other hand we found that the two indicators also disagree in many world areas. This uncertainty shows that further research is needed for a well-defined classification and definition of water stress♦