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Supplementary material to

"Modelling global water stress of the recent past: on the relative importance of trends in water demand and climate variability"

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1 Desalination

Desalination is realised mostly by using distillation and membrane technology. Large amounts of desalinated water are being consumed in the Middle East and North Africa (the MENA region), where over 70% of the global desalination capacity is installed (World Water Assessment Programme, 2003) and people receive only 1% of the global runoff (Vörösmarty et al., 2005). Although energy and economic costs to process sea water to produce purified water is still much higher than conventional water supply measures such as irrigation supply and groundwater pumping (The 2030 Water Resources Group, 2009), the amount of desalinated water use has been rising since the 1990s and reached 4.41 $km^3\,yr^{-1}$ in 2000. Table S2 gives past desalinated water use from 1960 to 2000.

The amount of desalinated water use is generally small (see Table S2) compared to total water demand in most of countries in the world but has a large impact on WSI in some countries in the Middle East. Figure S1 shows simulated WSI with and without inclusion of desalinated water use for Kuwait, Qatar, Saudi Arabia and United Arab Emirates. In Kuwait, the amount of desalinated water use has been increasing since 1960 and it satisfies nearly half of total water demand for 2000. In Qatar and United Arab Emirates, desalinated water meets one-third and quarter of total water demand, respectively. Although Saudi Arabia uses the largest amount of desalinated water in the Middle East, the impact on simulated WSI is less compared to the other countries due to the much larger demand.

2 Groundwater abstraction

Table S3 shows data and model based estimates of the global groundwater abstraction. The data based estimates are mainly based on country statistics and have a fairly good agreement, falling into a range of 600 to 800 $km^3\,yr^{-1}$. On the other hand, the model based estimates vary significantly among the studies. Wisser et al. (2010) estimate total groundwater abstraction to be 1708 $km^3\,yr^{-1}$ which is twice as large as the data based estimates. Döll (2009) estimates that to be 1100 $km^3\,yr^{-1}$ based on a fraction of groundwater to total water withdrawals per country multiplied with grid cell estimates of total water withdrawals computed by WaterGAP (Alcamo et al., 2003). Vörösmarty et al. (2005), Rost et al. (2008), Wisser et al. (2010), Hanasaki et al. (2010) and Pokhrel et al. (2011) implicitly quantified the amount of non-renewable groundwater abstraction based on the amount of water demand exceeding locally accessible supplies of blue water. As a result, their estimates are sensitive to estimated water demand (1206-3557 $km^3\,yr^{-1}$) and simulated blue water availability (36,921-41,820 $km^3\,yr^{-1}$) and the uncertainties are large.

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Table S1: Previous global studies to estimate irrigation water demand.

Previous studies	Climate input	Reference evapotranspiration	Irrigated area	Crop	Crop calendar	Additional components	Gross/Net demand (km^3 yr^{-1})	Year	Spatial resolution
Döll and Siebert (2002)	CRU TS 1.0 (New et al., 2000)	Priestley and Taylor	Döll and Siebert (2000)	Paddy Non-paddy	Optimal growth	Irrigation efficiency Cropping intensity	2452/1091.5	Avg. 1961-1990	0.5°
Hanasaki et al. (2006)	ISLSCP (Meeson et al., 1995)	FAO Penman-Monteith	Döll and Siebert (2000)	Paddy Non-paddy	Optimal growth	Irrigation efficiency	2254/1127	Avg. 1987-1988	0.5°
Rost et al. (2008)	CRU TS 2.1 (Mitchell and Jones, 2005)	Gerten et al. (2007): Priestley and Taylor	Siebert et al. (2007) Evans (1997)	11 crops pasture	Simulate vegetation/crop growth by LPJmL (Bondeau et al., 2007)	IPOT and ILIM Green water use Irrigation efficiency	2555/1364$^{\mathrm{IPOT}}$ 1161/636$^{\mathrm{ILIM}}$	Avg. 1971-2000	0.5°
Wisser et al. (2008)	CRU TS 2.1$^{\mathrm{CRU}}$ NCEP/NCAR$^{\mathrm{NCEP}}$ Kalnay et al. (1996)	FAO Penman-Monteith	Siebert et al. (2005, 2007)$^{\mathrm{FAO}}$ Thenkabail et al. (2006)$^{\mathrm{IWMI}}$	Monfreda et al. (2008)	Optimal growth	Irrigation efficiency Flooding applied to paddy irrigation	3000-3400$^{\mathrm{CRU_FAO}}$ 3700-4100$^{\mathrm{CRU_IWMI}}$ 2000-2400$^{\mathrm{NCEP_FAO}}$ 2500-3000$^{\mathrm{NCEP_IWMI}}$	Avg. 1963-2002	0.5°
Siebert and Döll (2010)	CRU TS 2.1	FAO Penman-Monteith$^{\mathrm{PM}}$ Priestley and Taylor$^{\mathrm{PT}}$	Portmann et al. (2008)	26 crops	Portmann et al. (2008)	Green water use	2099/1180$^{\mathrm{PM}}$ 2404/1448$^{\mathrm{PT}}$	Avg. 1998-2002	0.5°
Hanasaki et al. (2010)	NCC-NCEP/NCAR reanalysis CRU corr. (Ngo-Duc et al., 2005)	Bulk formula (Robock et al., 1995)	Siebert et al. (2005)	Monfreda et al. (2008)	Simulate a cropping calendar by H08 (Hanasaki et al., 2008b)	Irrigation efficiency Virtual water flow	2380/1530	Avg. 1985-1999	0.5°
Sulser et al. (2010)	CRU TS 2.1	Priestley and Taylor	Siebert et al. (2007)	20 crops (You et al., 2006)	FAO CROPWAT with some adjustments	Future scenarios (TechnoGarden, SRES B2 HadCM3 climate)	3128/1423^{2000} 4060/1603^{2025} 4396/1785^{2050}	2000 2025 2050	281 Food Producting Units
Wada et al. (2011)	CRU TS 2.1	FAO Penman-Monteith	Portmann et al. (2008)	26 crops	Portmann et al. (2008) Siebert and Döll (2008)	Green water use Irrigation efficiency	2057/1176	Avg. 1958-2001	0.5°
Pokhrel et al. (2011)	JRA-25 Reanalysis (Kim et al., 2009; Onogi et al., 2007)	FAO Penman-Monteith	Siebert et al. (2007) and Freydank and Siebert (2008)	18 crops Leff et al. (2004)	SWIM model (Krysanova et al., 1998)	Energy balance Soil moisture deficit Preplanting irrigation	2158(±134)/906(±62)$^{\mathrm{a}}$ 2462(±130)/1021(±55)$^{\mathrm{b}}$	Avg. 1983-2007$^{\mathrm{a}}$ 2000$^{\mathrm{b}}$	1.0°

Table S2: Past desalinated water use with the largest user (%) from 1960 to 2000 based on the FAO AQUASTAT data base.

1960	1970	1980	1990	2000
Globe ($km^3\ yr^{-1}$)				
0.26	0.42	0.94	2.74	4.41
Largest user				
Saudi Arabia (62%)	Saudi Arabia (55%)	Saudi Arabia (40%)	Saudi Arabia (25%)	Kazakhstan (31%)

Table S3: Global estimates of groundwater abstraction.

$km^3\ yr^{-1}$	Total/Non-renewable	Year	Gross/Net	Runoff/Recharge	Sources
			Data based estiamtes		
Postel (1999)	NA/around 200	NA	–	–	Based on various literature and statistics
IGRAC-GGIS	734/NA	2000	–	–	Based on various literature and country statistics
Shah et al. (2000)	750-800/NA	Contemporary conditions	–	–	FAO AQUASTAT, Llamas et al. (1992), Takeuchi and Murthy (1994)
Zektser and Everett (2004)	600-700/NA	Contemporary conditions	–	–	Based on various country statistics
			Model based estiamtes		
Vörösmarty et al. (2005)	NA/389$^{\mathrm{Irr.}}$-830$^{\mathrm{Total}}$	Average of 1995-2000	3557$^{\mathrm{Total}}$/1206$^{\mathrm{Irr.}}$	39,294/NA	Implicitly simulated by WBM (0.5°) (Vörösmarty et al., 2000, 2005; Fekete et al., 2002)
Rost et al. (2008)	NA/730	Average of 1971-2000	2534-2566 /1353-1375	36,921/NA	Implicitly simulated by LPJmL (0.5°) with four different precipitation inputs
Döll (2009)	1100/NA	2000	4020/1300	38,800/NA	Implicitly calculated based on water withdrawals and a fraction of groundwater to water withdrawals
Wisser et al. (2010)	1708/1199	Contemporary conditions	2997/NA	37,401/NA	Implicitly simulated by WBMplus (0.5°)
Hanasaki et al. (2010)	NA/703	Average of 1985-1999	NA/1690	41,820/NA	Implicitly simulated by H08 (1.0°) (Hanasaki et al., 2008a,b)
Siebert et al. (2010)	545/NA	2000	NA/1277	39,549/12,600	Based on statistics of 15,038 national or sub-national administrative units for irrigation purpose only
Wada et al. (2010)	734(±82)/283(±40)	2000	NA/NA	36,200/15,200	Explicitly calculated based on IGRAC-GGIS data and simulated groundwater recharge (0.5°)
Pokhrel et al. (2011)	NA/455(±42)	2000	2462(±130)/ 1021(±55)	NA/NA	Unsustainable water use simulated by MATSIRO (1.0°) with five different precipitation inputs

Table S4: Correlation between computed gross water demand and reported water withdrawal from the FAO AQUASTAT data base and between computed gross and net water demand and estimated water withdrawal and water consumption of Shiklomanov (2000a,b) per country. R^2 and α denote the coefficient-of-determination and the slope of regression line, respectively.

FAO AQUASTAT								
Sector		1970	1975	1980	1985	1990	1995	2000
Agriculture	R^2	0.98	0.98	0.96	0.97	0.97	0.99	0.98
	α	0.88	0.90	1.00	1.05	0.99	1.10	0.98
Industry	R^2	0.98	0.99	0.98	0.97	0.97	0.92	0.98
	α	0.96	0.94	0.80	0.99	0.99	0.80	0.90
Domestic	R^2	0.97	0.98	0.95	0.97	0.98	0.96	0.95
	α	1.15	0.98	1.01	0.90	1.10	0.90	1.06
Total	R^2	0.96	0.98	0.99	0.96	0.96	0.98	0.96
	α	1.12	0.90	1.10	1.02	0.99	1.08	0.99

Shiklomanov (2000a,b)							
Sector		1960	1970	1980	1990	1995	2000
Total (gross)	R^2	0.92	0.91	0.94	0.97	0.95	0.95
	α	1.11	1.10	1.08	0.99	0.94	0.94
Total (net)	R^2	0.96	0.97	0.96	0.97	0.95	0.94
	α	1.16	1.15	1.10	1.12	1.05	0.99

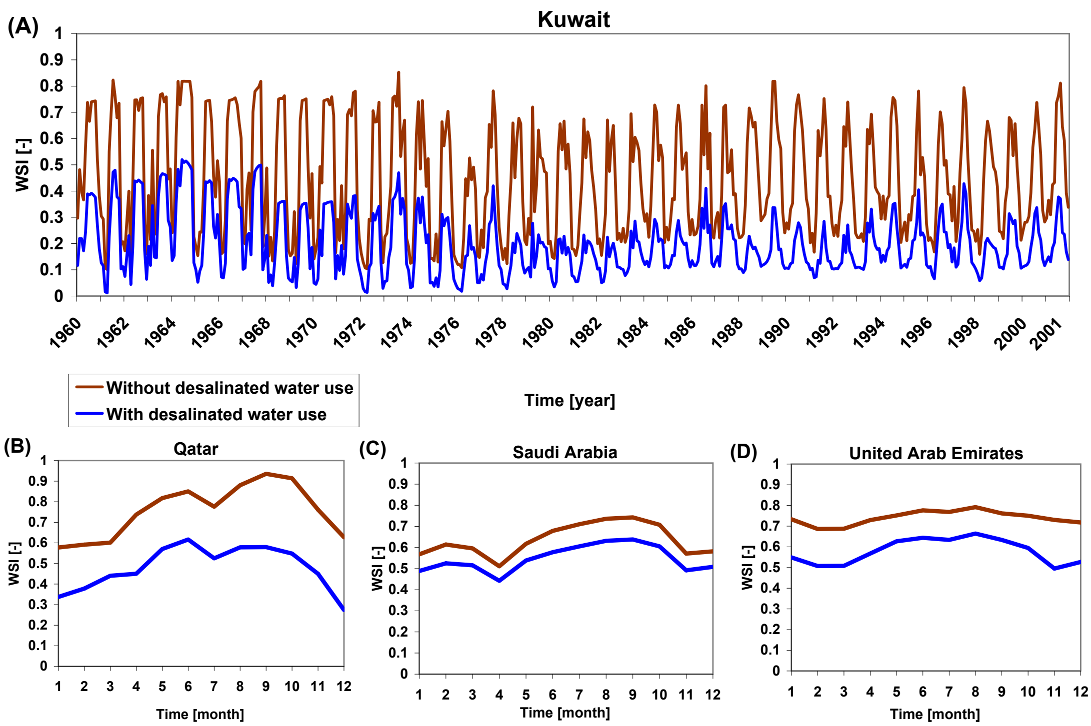

Fig. S1: Comparisons of simulated country-averaged monthly water scarcity index (WSI; y-coordinate; dimensionless) between that with the inclusion of desalinated water use and that without desalinated water use for a) Kuwait (1960-2001), b) Qatar (2000), c) Saudi Arabia (2000) and d) United Arab Emirates (2000).

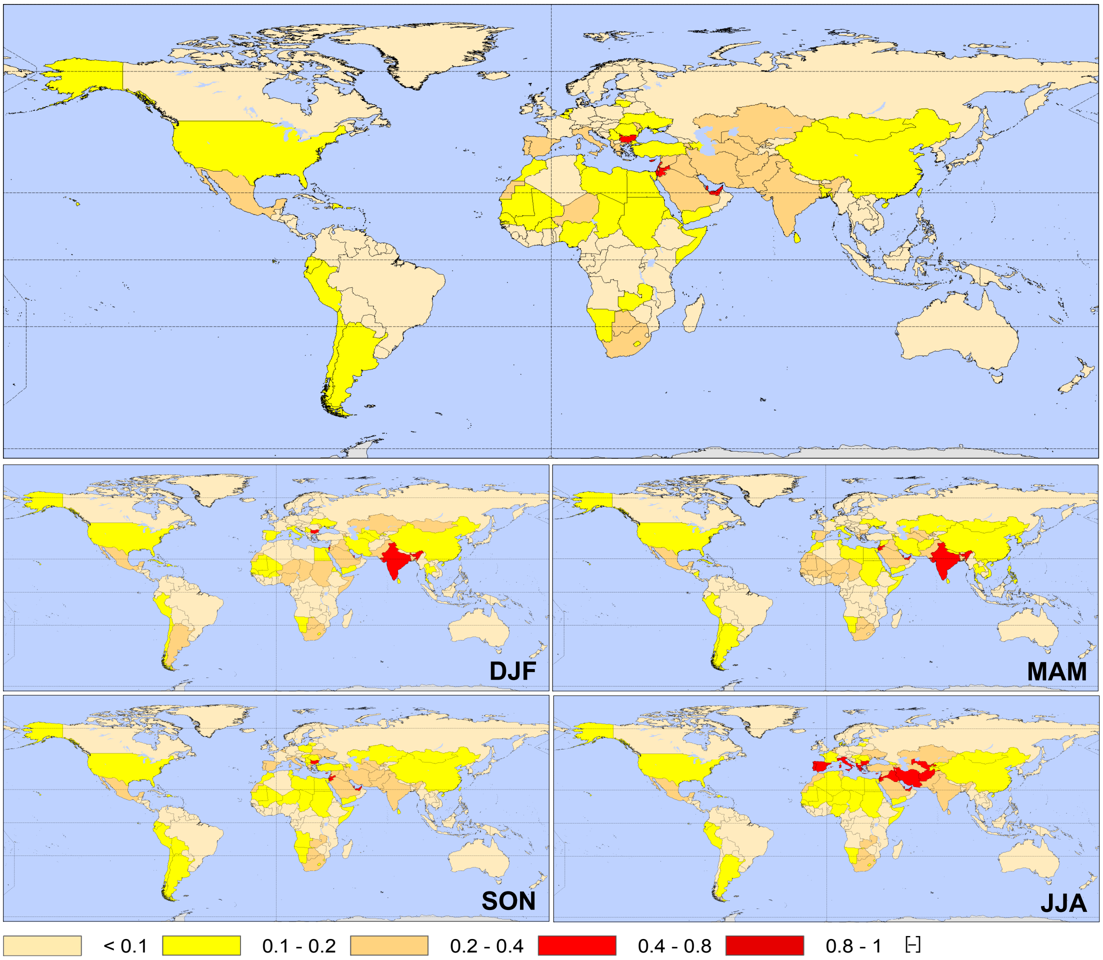

Fig. S2: Long-term mean (1960-2001) of annual country averaged water scarcity index (dimensionless) and that for each season (clockwise from top-left; DJF: December-January-February, MAM: March-April-May, JJA: June-July-August, SON: September-October-November)