SIEBERT, S. & P. DÖLL (2007): Irrigation water use – A global perspective. In: LOZÁN, J.L., H. GRAßL, P. HUPFER, L. MENZEL & C-D. SCHÖNWIESE (eds.): *Global Change: Enough Water for all?* Universität Hamburg / GEO, 104-107.

References cited in the article:

ALCAMO, J., P. DÖLL, T. HENRICHS, F. KASPAR, B. LEHNER, T. RÖSCH & S. SIEBERT (2003): Development and testing of the WaterGAP 2 global model of water use and availability. Hydrological Sciences Journal 48(3), 317-338.

BRUINSMA, J. (ed.) (2003): World agriculture towards 2015/2030 – an FAO perspective. FAO, Rome, Italy, 444 pp.

CHAPAGAIN, A.K., A.Y. HOEKSTRA & H.H.G. SAVENIJE (2005): Saving water through global trade. UNESCO-IHE, Value of Water Research Report Series No. 17, Delft, The Netherlands.

DÖLL, P. & S. SIEBERT (2002): Global modeling of irrigation water requirements. Water Resources Research 38(4), 8.1-8.10, DOI 10.1029/2001WR000355.

DÖLL, P. (2002): Impact of climate change and variability on irrigation requirements: a global perspective. Climatic Change 54(3), 269-293.

GLEICK, P.H. (2003): Water use. Annu. Rev. Environ. Resour. 28, 275-314.

MITCHELL, T.D. & P.D. JONES (2005): An improved method of constructing a database of monthly climate observations and associated high-resolution grids. International Journal of Climatology 25, 693-712.

SHIKLOMANOV, I.A. (2000): Appraisal and assessment of world water resources. Water International 25(1), 11-32.

SECKLER, D., U. AMARASINGHE, D. MOLDEN, R. DE SILVA & R. BARKER (2000): World water demand and supply 1990 to 2025: scenarios and issues. IWMI Research Report 19, IWMI, Colombo, Sri Lanka, 40 pp.

SIEBERT, S. , P. DÖLL, J. HOOGEVEEN, J.-M. FAURES, K. FRENKEN, S. FEICK (2005): Development and validation of the global map of irrigation areas. Hydrology and Earth System Sciences 9, 535-547.

2.4 Irrigation water use – A global perspective

Stefan Siebert & Petra Döll

SUMMARY: *Quantitative, spatially resolved estimates of historical, present-day and future irrigation are an important basis for sustainable agriculture and water management. Here we present estimates of the extent of irrigated areas and of irrigation water use that are based on statistical data, modelling and scenario assumptions. The global figures are supplemented by data on a regional level, by statistics for the extent of irrigated areas and by two maps showing the actual extent of irrigated areas and irrigation water use at a resolution of 0.5 degree by 0.5 degree. Results of a global irrigation model indicate that climate change may lead to moderate increases of the irrigation water use at the global scale but to larger changes at the local and regional scale.*

Introduction and definition of terms

While Chmielewski (Chapter 2.3) provides an introduction to water use by irrigation, we focus here on the spatial distribution of irrigation on the globe as well as on quantitative estimates of historic and possible future developments of both irrigated areas and irrigation water use. Knowledge about where on Earth irrigation occurs and how much water is used for it is an important basis for understanding, for example, the role of water for food security or the relevance of agriculture for sustainable water management. Please note that at global and national scales, the extent of irrigation as well as the related water use cannot be measured precisely. Therefore all figures are estimates that are derived by various methodologies (mainly processing of census data, modelling and remote sensing).

To fully understand data on irrigation, it is important to distinguish a number of terms. »Area equipped for irrigation« (AEI) is the area equipped with irrigation infrastructure (infrastructure to irrigate the crops and infrastructure that supplies irrigation water), while the »area actually irrigated« (AAI), also called »net area irrigated«, refers to the area that has been irrigated at least once in a year. AAI is usually smaller than AEI because of damage of infrastructure, shortage of water or no need for irrigation because of humid climate conditions in the reference period. In addition, in a crop rotation system only some crops may be irrigated while the others are rainfed. The »irrigated area harvested« (IAH), also called »gross area irrigated«, refers to the area of irrigated crops harvested in a reference period. Thus, the cropping area in an irrigated double-cropping system is counted twice if the reference period is one year.

Similarly, there are many terms in the literature representing different meanings of water uses. First, »withdrawal water use« needs to be distinguished from »consumptive water use«. While the former refers to withdrawals of water from its source (e.g. from a groundwater well or a reservoir), the latter refers to the part of the withdrawn water that cannot be reused within the river basin (Gleick 2003). By far the largest fraction of the »irrigation consumptive water use« (ICWU) is the evapotranspiration of the irrigation water in the fields. »Irrigation withdrawal water use« (IWWU) is always larger than ICWU as some part of the applied water will run off at the soil surface or leach below the root zone. This return flow can potentially be reused downstream. Many studies at the global scale do not provide statistics for IWWU or ICWU but for »agricultural withdrawal water use« (AWWU) and »agricultural consumptive water use« (ACWU), respectively. Agricultural water uses are the sum of water uses for irrigation, livestock and in some cases also inland fisheries.

Spatial extent of irrigation areas

Depending on the source of information the various available estimates of the historical and present extent of irrigated land differ by more than 25%, but actual uncertainty is assumed to be higher.

Historical development

Irrigation has been practised for millennia. Large irrigation systems were located in the basins of Euphrates-Tigris (Mesopotamia), and the Nile as well as in parts of China. Additionally it is well known that ancient irrigation systems have been used in particular for oasis agriculture. It was estimated that around 1800 the global extent of irrigated land was about 8 Mio ha, and 47 Mio ha around 1900 (Shiklomanov, 2000). During the last century the extent of AEI doubled until 1945, and doubled again until 1980 (*Fig. 2.4-1*). During the last decade the increase of AEI slowed down because of several reasons. The large-scale irrigation schemes in many parts of Eastern Europe and the former Soviet Union went out of operation because the technical infrastructure was not flexible enough to meet the requirements of the new private farms operating market orientated at a smaller scale. Because of missing drainage infrastructure parts of the global irrigation areas faced water-logging and salinity and needed rehabilitation.

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Finally, limited water resources and increasing competition by other water use sectors avoided an increase of irrigated land in many arid regions.

Present situation

Based on a global data base of sub-national irrigation statistics it was estimated that about 274 Mio ha were equipped for irrigation around the year 2000 (SIEBERT et al. 2005, *Table 2.4-1*). More than 50% of the global irrigation area was located in India, China and in the United States (*Fig. 2.4-2*). AAI was estimated to be in the range of 213–242 Mio ha for the same period, while IAH was about 315 Mio ha (PORTMANN, University of Frankfurt, unpublished). The main irrigated crops at the global scale are rice (IAH of 103 Mio ha), wheat (IAH of 67 Mio ha), maize (IAH of 29 Mio ha) and cotton (IAH of 16 Mio ha). Remote sensing based global estimates of AAI and IAH are higher; in a recent inventory compiled by IWMI (http://www.iwm igmia.org), for example, AAI was estimated to be 318 Mio ha, while IAH was 637 Mio ha. The main sources of uncertainty of the existing remote sensing based inventories might be the low resolution of the used input data (usually 1 km^2) and the missing consideration of information related to soil properties and cropping practises. However, there are also uncertainties of the census-based estimates of AEI presented here (e.g. in *Table 2.4-1*). Census surveys may for example underestimate small scale informal irrigation (e.g. peri-urban irrigation in some African countries) or overestimate irrigated areas by considering also unused and damaged infrastructure (e.g. in Eastern Europe).

Table 2.4-1: Area equipped for irrigation (AEI), area actually irrigated (AAI) and irrigated area harvested (IAH) per world region around the year 2000 (in Mio ha). The spatial extent of each world region shown in *Fig. 2.4-2*.

Region	*AEI*	*AAI**	*IAH*
North America	28.7	20.5	21.0
Central America	7.9	6.4 – 7.2	7.4
South America	10.1	7.6 – 8.2	8.2
Northern Africa	5.8	5.6 – 5.8	8.9
Western Africa	1.0	0.5 – 0.6	0.8
Eastern Africa	3.5	2.0 – 2.3	3.1
Southern Africa	1.9	1.7	2.3
Western Europe	2.1	0.9	1.0
Eastern Europe	7.6	3.7 – 3.9	4.2
Southern Europe	10.0	8.8 – 9.0	9.8
Russian Federation	4.9	4.1	4.1
Near East	18.8	12.7 – 16.5	17.2
Central Asia	14.8	10.2 – 11.8	11.8
East Asia	59.9	52.4 – 58.0	90.6
South Asia	77.2	58.8 – 74.9	97.7
South-East Asia	16.8	14.4 – 14.5	24.0
Oceania	2.6	2.4	2.7
World	**273.7**	**212.6 – 242.2**	**314.9**

* Range reflects missing information on specific crop rotations

Scenarios of the future extent of irrigated areas

Most of the international organisations expect in their baseline scenarios that AEI will continue to increase in the next decades. The projection of FAO for the developing countries assumes an increase of AEI from 202 Mio ha (1997–1999) to 242 Mio ha in 2030 which is a 20% increase (BRUINSMA, 2003). The baseline scenario of IWMI assumes an increase of AEI of 22% in the period 1995–2025 (SECKLER et al. 2000). However, there are many other scenarios which encompass completely different developments of irrigated areas for this period, ranging from decreases of the global irrigation area to much stronger increases. It is highly uncertain how the increasing global trade will affect the spatial pattern of irrigation areas. To fulfil the growing food demand, semi-arid and arid countries can import food instead of extending irrigation, i.e. import so-called »virtual water« and thus save their own water resources (CHAPAGAIN et al. 2005).

Spatial pattern of irrigation water use

The spatial pattern of irrigation water use is determined by the density of irrigation areas (compare *Figs. 2.4-2* and *2.4-3*), the type of crop and the climate conditions during the growing season. Census-based statistics collected from water suppliers or water user associations usually refer to IWWU, while estimates of ICWU are usually model outputs. However, the accuracy of both census statistics and model outputs are flawed by many sources of uncertainty such that published estimates of irrigation water use vary considerably.

Development of agricultural water uses during the last century

An assessment of AWWU and ACWU at the global scale covers the period 1900 to 1995 (SHIKLOMANOV 2000).

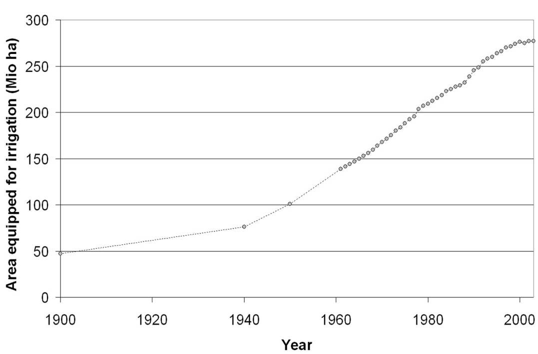

Fig. 2.4-1: Global extent of area equipped for irrigation in the period 1900–2003 (data sources: SHIKLOMANOV 2000; FAOSTAT).

According to these estimates global AWWU increased from 513 km³/year in 1900 to 1080 km³/year in 1950 and 2504 km³/year in 1995. This development is related to the increase of irrigated areas. The assessment assumed a very efficient water use in irrigation, which results in very high estimates of ACWU. ACWU was reported to have increased from 321 km³/year in 1900 to 722 km³/year in 1950 and 1753 km³/year in 1995. AWWU as a fraction total water withdrawals was reduced from about 89% in 1900 to 66% in 1995. At the same time, ACWU as a fraction of total consumptive water use was reduced from 97 to 85%, which was mainly an effect of water consumption by evaporation from an increased number of open reservoirs. If open reservoir evaporation is not considered a consumptive water use, ACWU as a fraction of total consumptive water use decreased from 97% in 1900 to 93% in 1995.

Present situation

AWWU data collected at the national scale and provided by the FAO AQUASTAT gateway (http://www.fao.org/ag/agl/aglw/aquastat/dbase/index.stm) sum up to about 2662 km³/year. However, not for all countries are data available in the AQUASTAT data base, and, depending on the specific country, the latest available data may date back to 1978.

The figures presented below were derived by applying the global water model WaterGAP (Döll & Siebert 2002; Alcamo et al. 2003). According to the model, average annual global IWWU was 2942 km³ (78% of total withdrawal water use) and ICWU was 1287 km³/year (91% of total consumptive water use), respectively (*Fig. 2.4-3*). These values represent the water requirements which lead to optimal crop growth on the areas equipped for irrigation

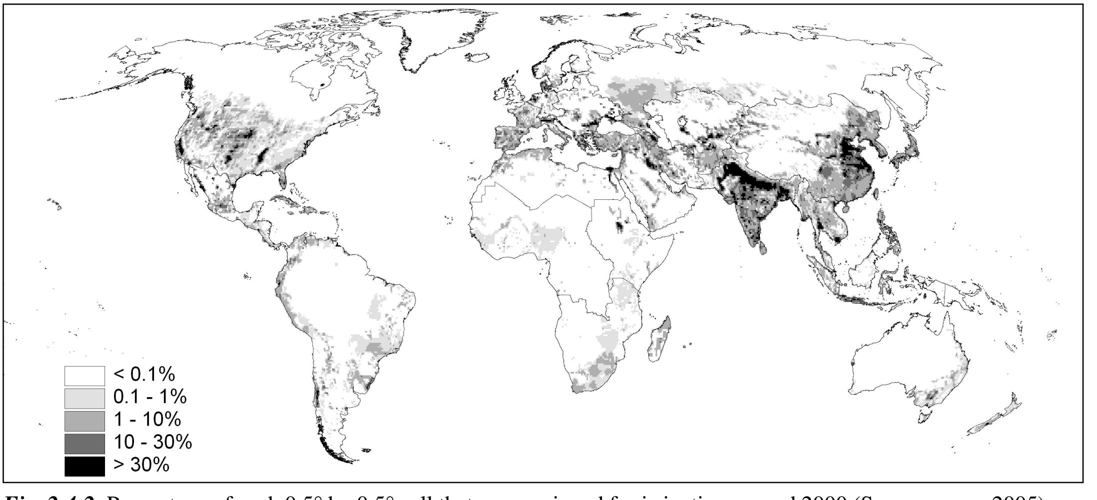

Fig. 2.4-2: Percentage of each 0.5° by 0.5° cell that was equipped for irrigation around 2000 (Siebert et al. 2005).

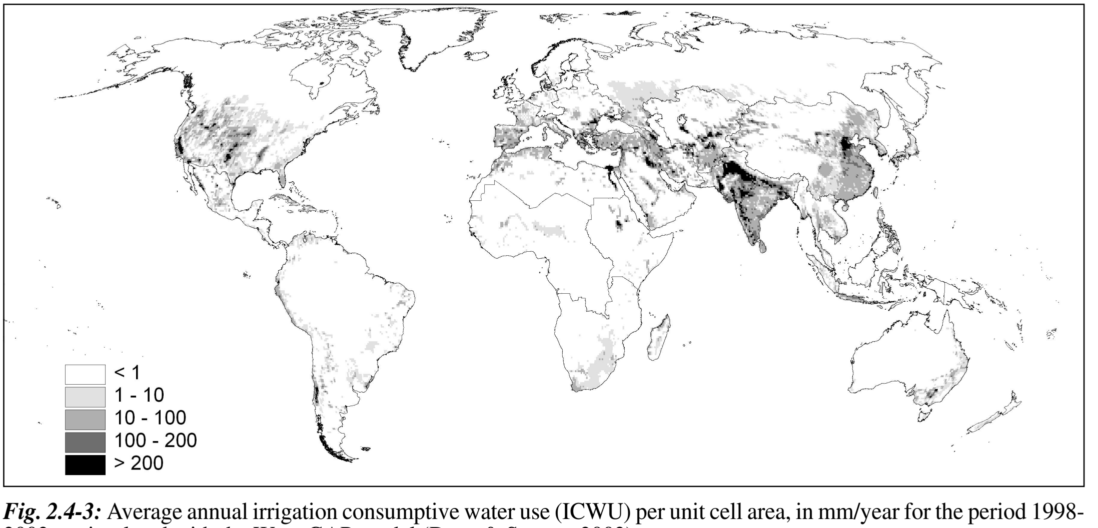

Fig. 2.4-3: Average annual irrigation consumptive water use (ICWU) per unit cell area, in mm/year for the period 1998-2002 as simulated with the WaterGAP model (Döll & Siebert 2002).

Table 2.4-2: Impact of climate change vs. impact of interannual climate variability on irrigation consumptive water use (ICWU) for two climate change scenarios (DÖLL 2002, modified). The percentage of the global area equipped for irrigation that is affected by increasing or decreasing ICWU is listed.

	Percent of global area equipped for irrigation affected			
	2020s		*2070s*	
	ECHAM4	*HadCM3*	*ECHAM4*	*HadCM3*
Increase of ICWU due to climate change but weaker than impact of climate variability	46	50	28	25
Increase of ICWU due to climate change and stronger than impact of climate variability	20	19	34	39
Decrease of ICWU due to climate change but weaker than impact of climate variability	16	18	13	14
Decrease of ICWU due to climate change and stronger than impact of climate variability	18	13	25	22
Total	100	100	100	100

around 2000 under climate conditions reported for the period 1998–2002 (MITCHELL & JONES 2005). Thus, these values should overestimate actual irrigation water use. Livestock water use for the same period is computed as 27 km^3/year. The annual ICWU per ha of irrigated area is highest in arid regions with a high cropping intensity, for example along the rivers Nile and Indus. The interannual variation of irrigation water use is low in arid regions and high in more humid regions. This is because irrigation in more humid regions is supplementary, with the largest part of crop water use coming from precipitation. For example, assuming a constant irrigation area during the period 1901–2002, ICWU of Egypt is 45.3 km^3 in a 1-in-10 wet year and 47.4 km^3 in a 1-in-10 dry year which is an increase of about 5%. In contrast ICWU of the United Kingdom more than triples in a 1-in-10 dry year (with 0.22 km^3) as compared to a 1-in-10 wet year (with 0.06 km^3).

Irrigation water use under the impact of global change

Future irrigation water use will be influenced by changing location and extent of irrigation areas and by the changing climate. Additionally, IWWU will be affected by changing irrigation water use efficiencies. The future development of all these influence factors is highly uncertain. The specific impact of climate change on irrigation water use was assessed with the WaterGAP model (DÖLL 2002). Irrigated areas were kept constant, and results of two global climate models (HadCM3 and ECHAM4) for the same emissions scenario (IS92a) were applied. It was found that global ICWU would increase by 3% (ECHAM4) or 5% (HadCM3) until the 2020s and by 5% (ECHAM4) or 8% (HadCM3) until the 2070s (as compared to the climate normal 1961–1990). At the regional level, large climate driven increases of ICWU were computed for Canada (38% for the 2070s using ECHAM4 and 21% using HadCM3), South Asia (12% for the 2070s using ECHAM4 and 15% using HadCM3) and South-east Asia (78% for the 2070s using ECHAM4 and 67% using HadCM3). A large climate driven decrease of ICWU was computed for Northern Africa (-16% for the 2070s using ECHAM4 and -13% using HadCM3).

In order to assess the severity of climate change impacts, it is useful to compare the changes of ICWU due to climate change to the interannual variability of ICWU, as the irrigation sector is adapted to this variability. Therefore the computed climate driven change of ICWU was also compared to the present variability of ICWU represented by the difference between ICWU in a 1-in-10 dry (or 1-in-10 wet year) to the ICWU under average climate conditions (*Tab. 2.4-2*). For the 2020s, increase of ICWU due to climate change will be larger than present variability on 20% of the irrigated land (AEI), while for the 2070s, this will be true for more than 30% of the irrigated land.

Conclusion

At the global scale irrigation is by far the largest water use sector, accounting for more than 90% of the total consumptive water use. Irrigation water use per unit of surface area is largest in arid regions with high cropping intensity while interannual variations of irrigation water use are largest in humid regions. Climate change may lead to moderate increases of the irrigation water use at the global scale but to larger changes at the local and regional scale. The reported figures on the past and present irrigation water use are still rather uncertain, and more interdisciplinary research is needed to quantify the impact of global change on irrigation water use♦