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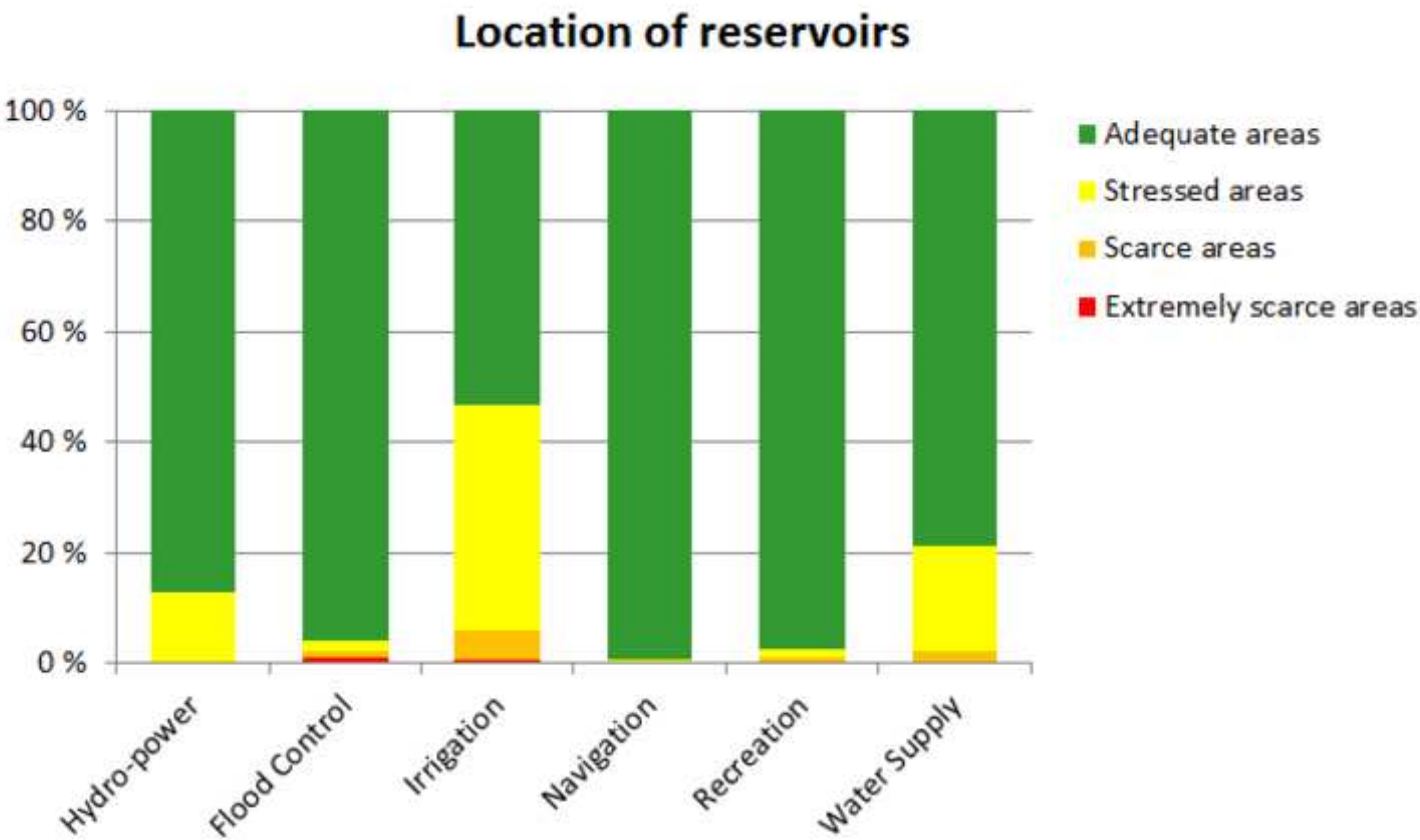

Are reservoirs water consumers or water collectors?

Reflections on the water footprint concept applied on reservoirs

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1 INTRODUCTION

IPCC (2011) presented an extensive review of the potential for renewable energy sources to replace fossil-based fuels and also benchmarked the different renewable technologies. One of the benchmark criteria were the water consumption of electricity production or the water footprint. IPCC (2011) revealed potentially very high water consumption rates from hydropower compared to the other renewables, up to a maximum of 209 m^3/MWh due to evaporative losses from the reservoir surfaces, but it was noted that only a very few studies were available and a number of methodological problems were identified. More recent publications (e.g. Mekonnen and Hoekstra 2012; Demeke et al. 2013; Bakken et al. 2013) present new estimates on water consumption from hydropower projects far beyond those earlier published by IPCC (2011), but do not provide a more consistent picture of the 'true water consumption of hydropower'. In the upper range, Mekonnen and Hoekstra (2012) find that the sum of evaporated water (water footprint) of a sample of 35 evaluated hydropower reservoirs is similar to 10% of the global blue water footprint from crop production and therefore argue that production of hydroelectricity is a large-scale water consumer. Similarly, Gerbens-Leenes et al. (2009) has calculated very high global values for water consumption from hydropower production. Studies within this field of science have, however, also been criticized (e.g. Demeke et al. 2013; Chenoweth et al. 2014; Bakken et al. 2013) due to its weak methodological basis. Given the fact that there is a growing interest in assessing the water footprint of various products, with reference to for instance the on-going development an ISO Water Footprint standard (ISO 14046 2014), we find it reasonable to present our views on the relevance of assessing the water footprint of reservoirs with hydropower production. Before we continue the discussion we would recall the purpose of reservoirs that are to store water from the wet to the dry season[1] in order to supply water of sufficient quantities to those periods of the year where natural runoff cannot meet the society's need of water.

In the following we present and discuss;

1. Facts on reservoirs and their use for hydropower production
2. Fundamental problems with assessing the water footprint of reservoirs, and
3. Problematic aspects of the current methodology as found in the published literature on water consumption from hydropower production.

2 MATERIAL AND METHOD

In order to get an overview of the global picture on the reservoirs, what they are used for and where they are located in terms of available water resources, data from the World Register of Dams (WRD) ('the ICOLD database') was retrieved and analysed (ICOLD 2014). The ICOLD database is considered being the most complete register of reservoirs and dams higher than 15 meters and 39188 dams were registered at the time data was extracted (June 2014). Due to inconsistencies in their descriptions 124 of the dams were removed from the dataset. The dams/reservoirs are classified as single or multipurpose, according to their purposes and the priority of use in the case of multipurpose. The dams' geographical position is given by the country they are located within.

[1] Maybe except the purpose flood control that aims to collect water to reduce the downstream flood risk.

Table 1. Statistics on the purpose of reservoirs derived from the ICOLD-database (ICOLD 2014) (n=39064). Unknown indicates that this information is not properly given in the database. MP stands for multipurpose.

Purpose	Total with this purpose	MP with this purpose	Single with this purpose	No. with this as main purpose	No. with this as second purpose	No. with this as lower than second
Hydropower	9408	3836	5572	1475	1382	979
Flood control	7519	4812	2707	1939	2412	461
Irrigation	19575	5920	13655	4200	1375	345
Navigation	675	575	100	186	213	176
Recreation	4197	2863	1334	380	1500	983
Water supply	7513	4265	3248	1399	1988	878
Unknown	3903	1156	2747	122	517	517

Data from ICOLD was further coupled with the Falkenmark indicator (Falkenmark 1989). The Falkenmark indicator describes the total available freshwater resources to the population of a region (nation) into classes according the severity of the water-scarcity, given as m^3/capita/year. The indicator is well-established, intuitive and easy to use and applied in our study despite it might also mask scarcity information due to its coarse temporal (annual averages) and spatial scale (nation). The spatial resolution is in our analysis probably most problematic for large countries with large internal variation in the status of the water resources, such as China and USA, which might lead to an underestimation of the real number of projects in water-scarce locations. According to Falkenmark (2014) 1000 m^3 per capita per year is given as the threshold value for water scarcity.

3 RESULTS

Table 2. Number of reservoirs with located in areas with different levels of water-scarcity, as defined by Falkenmark (1989). 'S' indicates single-purpose reservoir with this specific purpose, while M stands for main purpose in the case of a multi-purpose reservoir.

	Hydro-power		Flood Control		Irrigation		Navigation		Recreation		Water Supply		Unknown	
Level of scarcity [m^3/capita/year]	S	M	S	M	S	M	S	M	S	M	S	M	S	M
Extremely scarce areas <500	3	2	35	14	53	45	0	0	0	0	13	1	82	0
Scarce areas 500-1000	24	5	4	49	528	429	0	0	5	12	29	68	82	0
Stressed areas 1000-1700	703	162	44	41	6824	451	0	2	29	0	609	268	488	10
Adequate areas >1700	4842	1306	2624	1835	6250	3275	100	184	130	368	2597	1062	2095	112

From Table 2 we can see that very few of the reservoirs in such water-scarce areas are used exclusively for hydropower production (27 among 39064, i.e. only 0.07 %). If we include also those multipurpose reservoirs where hydropower is given as the main purpose, still only 34 out of 39064 reservoirs world-wide are located in water-scarce areas and are used for hydropower production as the single or main purpose (0.09 %). The large majority of the reservoirs in water scarce areas single purpose irrigation reservoirs or have irrigation as their main purpose. From this we can conclude that reservoirs for the single or main purpose hydropower production is to a very little extent located in water-scarce areas, where the elevated water losses due to damming are potentially problematic. The vast majority of the reservoirs developed for hydropower production exclusively or as the main purpose are located in areas without water-scarcity, i.e. in areas with more than 1000 m^3/capita/year water available, thus being located in areas less problematic with respect to water losses from the reservoir surfaces. The 34 reservoirs in water-scarce areas are located in the countries United Arab Emirates, Saudi Arabia, Libya, Yemen, Jordan, Oman, Tunisia, Algeria and Singapore.

Figure 1. The location of the reservoirs with given functions, classified according to level of water scarcity and presented as portion of total number of reservoirs. The reservoirs with single and main purpose are combined.

Figure 1 tells us that 47 % of the reservoirs with irrigation as the single or main purpose are located in areas with less water than 1700 m^3/capita/year than reservoirs with other types of functions, followed by water supply (approx. 21 %). In the other end, there are very few reservoirs with single or main purpose of flood control (4 %), navigation (< 3 %) and recreation (< 1 %) that are located in areas with less water than 1700 m^3/capita/year. One interpretation of this picture might be that food from irrigated land and water supply are both basic services needed to the society, while water is a too scarce resource to be set aside for especially the purposes navigation and recreation.

3 DISCUSSION

3.1 CONSUMER OR COLLECTOR?

The water footprint of a product is defined as the total volume of freshwater that is used directly or indirectly to produce the product. It is estimated by considering water consumption and pollution in all steps of the production chain (Hoekstra et al. 2011). The purpose of a water footprint study is to assess how a certain activity affects the downstream water users in the basin, including the ecosystem. A large water footprint would, as such, affect the downstream water users negatively and should be avoided, and activities with large water footprint would be undesirable in arid regions experiencing water-scarcity. It is then interesting to visit the study of Weichert (2013) that found the highest published water consumption values are typically in the regions with severe water-scarcity, such as the High Aswan Dam in Egypt. At the same time, there are indisputable huge economic benefit of this reservoir to Egypt (e.g. Strzepek et al., 2008), and it appears clear that the awareness of the high water footprint values would never disqualify this project from being built. The benefits of securing adequate water-services to the domestic users, agricultural sector and the power production is higher than the costs of the lost water due to increased evaporation. The importance of reservoirs in arid regions is also supported by Bates et al. (2008). Despite that the value of the evaporated/lost water might be very high in water-scarce regions (Maestre-Valero et al. 2013), we find it reasonable to claim that ‘the higher water-scarcity the more needed are the reservoirs’. The possibly biased picture given by the high water consumption values is that the methodology does not take into account the benefits of the reservoirs in providing water-services.

The downstream activities that are supposed to suffer from high water consumption rates from the reservoir are actually those that can benefit from the regulated flow provided by the reservoir. In the case of the High Aswan Dam in Egypt, the agricultural sector as well as the domestic supply of water from the Dam to the Mediterranean Sea benefit from the reservoir. Those supposed to be ‘the losers’ of the high water footprint are actually ‘winners’ as they are provided more stable flows of water throughout the year.

3.2 SETTING THE RIGHT SPATIAL BOUNDARIES

Global hydrology tells us that the presence of water varies in time and space, but does not disappear nor is created. The definition of water consumption as well as water withdrawal hence involves defining spatial and temporal boundaries of the problem of concern. The outcome of a study will hence depend on how these boundaries are set. As the design of hydropower as well as other infrastructure projects involving water might vary a lot due to its site-specific character, the water might be transferred long distances within and between river basins, the spatial boundaries must be set with great care (Fulton et al. 2014). In the majority of those studies concerning hydropower and water consumption, the spatial boundaries are set to include only the nearby reservoir and the power plant, even though the reservoir might serve as a regulating unit for several downstream hydropower plants ('cascaded development') as well as serving other downstream purposes benefitting from a more even flow pattern. As such, the spatial boundaries defined in the study will affect the outcome of the study a lot. Exemplified, the High Aswan Dam in Egypt serves several purposes, and not only those purposes taking water directly from the reservoirs benefitting from the storage of water, but also irrigated agriculture and domestic drinking water supply located far downstream the reservoir.

3.3 NET ASSESSMENT OF WATER LOSSES AND ALLOCATION

The establishment of a reservoir will change the natural runoff downstream the dam, which is also the purpose of the reservoir. In some cases the reservoirs are established by damming a river creating an artificial lake behind the dam, while in other cases the reservoir are based on a natural lake introducing only small changes to the natural environment. The evaporation from the areas affected by the reservoir might change due to the establishment of the reservoir, but the rate of this change is very specific to the individual case and climatic region. It seems now that there is an agreement in that future assessments of the water footprint shall be carried out based on the 'net'-approach, i.e. subtracting the evaporation prior to the establishment of the reservoir (ref. most updated version of the draft ISO Water Footprint Standard 14046, 2014). It should, however, be mentioned that the majority of the published studies (Bakken et al. 2013), are based on the gross estimation, including those presented in IPCC (2011). Only a few studies have calculated the net effect (Herath et al. 2011, Yesuf

2012; Tremblay et al. 2014), where Tremblay et al. (2014) even found negative numbers for water consumption. It should in relation to this be noted that calculation of the evapotranspiration with reasonable precision is a challenging hydrological task, from both reservoir surfaces as well as natural vegetation. As a large number of reservoirs are multi-purpose, allocation of the water losses between the various functions should be done, but a methodology to do this appears to be non-existing in published literature.

3.4 HANDLING THE IMPACT

Current methodological framework for the calculation of water footprint/consumption from reservoirs takes to a limited extent into account the positive effect of increased water availability from the reservoir (e.g. IPCC 2011; Bakken et al. 2013; ISO 14046 2014). The dominating approach simply calculates the water consumption dividing the evaporated water of on annual power production, while the latest version of ISO 14046 (2014) uses a different methodology acknowledging the increased availability. In ISO 14046 the impact is corrected based on a local/regional water scarcity-factor, which appears as a reasonable approach in order to assess the possible negative effect by the water footprint, but the positive effects of the regulation (increased water availability) might be higher the more water-scarce area the reservoir is in located in.

3.5 THE RISK OF GENERALISATION

We would like to draw the attention to the very site-specific character of hydropower projects compared to other energy technologies. This can for instance be seen in the water consumption values presented by IPCC (2011, Figure 9.6), confirmed by e.g. Olsson (2012) and Bakken et al. (2013), and a similar much higher variance for hydropower than the other technologies can be observed on emission on green-house gases (GHGs) in IPCC (2014, Figure 7.6). The site-specific character of hydropower can be explained by the fact that the location and design of the projects to a large extent is determined by local topography and climatic conditions. It is important to keep this in mind when comparative studies across energy technologies are carried out. There is a risk of presenting a very biased picture when average values for hydropower are developed or even worse, when these values are applied to a new case without case-specific data, as the average values might be far out of range for the individual plants.

4 CONCLUDING REMARKS

We have in this study presented some basic statistics on the world's reservoirs and found that only very few reservoirs located in water-scarce areas are used exclusively for hydropower production or have power production as the main purpose (fewer than 0.1 %). As the purpose of the majority of the reservoirs located in water-scarce areas are to collect water in the wet season to secure adequate supply of water for irrigation and domestic water supply in the dry season (and flood control in the wet season), we find it fundamentally problematic to assign a water footprint to such an infrastructure, even though these reservoirs might also be used for power production. Rather opposite – the fact that reservoirs increase the availability of water in the dry season make reservoirs needed. The evaporative water losses is something we must accept in order to increase other and more important benefits of the reservoirs. If so, we would conclude that assigning water footprint/consumption values of reservoirs will convey the wrong message to decision-makers unless the reservoirs' effect on the availability of local water resources is fully accounted for.

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