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Improving irrigation efficiency will be insufficient to meet future water demand in the Nile Basin

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ABSTRACT

The Nile River Basin covers an area of approximately 3.2 million km^2 and is shared by 11 countries. Rapid population growth is expected in the region. The irrigation requirements of Nile riparian countries of existing (6.4 million ha) and additional planned (3.8 million ha, 2050) irrigation schemes were calculated, and the likely water savings through improved irrigation efficiency were evaluated. We applied SPARE:WATER to calculate irrigation demands on the basis of the well-known FAO56 Crop Irrigation Guidelines. Egypt (67 $km^3\,yr^{-1}$) and Sudan (19 $km^3\,yr^{-1}$) consume the highest share of the 84 $km^3\,yr^{-1}$ total (2011). Assuming today's poor irrigation infrastructure, the total consumption was predicted to increase to 123 $km^3\,yr^{-1}$ (2050), an amount far exceeding the total annual yield of the Nile Basin. Therefore, a key challenge for water resources management in the Nile Basin is balancing the increasing irrigation water demand basin-wide with the available water supply. We found that water savings from improved irrigation technology will not be able to meet the additional needs of planned areas. Under a theoretical scenario of maximum possible efficiency, the deficit would still be 5 $km^3\,yr^{-1}$. For more likely efficiency improvement scenarios, the deficit ranged between 23 and 29 $km^3\,yr^{-1}$. Our results suggest that that improving irrigation efficiency may substantially contribute to decreasing water stress on the Nile system but would not completely meet the demand.

Study Region: The Nile River Basin covers an area of approximately 3.2 million km^2 and is shared by 11 countries. Rapid population growth is expected in the region.

Study Focus: Record population growth is expected for the study region. Therefore, the irrigation requirements of Nile riparian countries of existing (6.4 million ha) and additional planned (3.8 million ha, 2050) irrigation schemes were calculated, and likely water savings through improved irrigation efficiency were evaluated. We applied a spatial decision support system (SPARE:WATER) to calculate the irrigation demands on the basis of the well-known FAO56 Crop Irrigation Guidelines.

New Hydrological Insights for the Region: Egypt (67 km^3yr^{-1}) and Sudan (19 km^3yr^{-1}) consume the highest share of 84 km^3yr^{-1} (2011). Assuming today's poor irrigation infrastructure, the total demand were predicted to increase to 123 km^3yr^{-1} (2050), an amount far exceeding the total annual yield of the Nile Basin. Therefore, a key challenge for water resources management in the Nile Basin is balancing the increasing irrigation water demand and available water supply.

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1. Introduction

1.1. Irrigation efficiency

Water consumption is globally driven by agricultural demand to grow food and feed for people and animals (Rost et al., 2008; Siebert and Döll, 2010; FAO, 2016). Strategies for decreasing water consumption by agriculture include better management of rainfall (Rockström et al., 2009) and irrigation (Pereira et al., 2002). In particular, the latter is important because unsustainable irrigation is globally a major driver of water resource depletion, e.g., of river flows (Döll et al., 2009) and groundwater aquifers (Wada et al., 2012). As a consequence, surface and groundwater resources are under severe pressure worldwide (Gleeson et al., 2012; Hoekstra et al., 2012). Nevertheless, irrigation is indispensable for feeding people (Siebert and Döll, 2010). Hence, the management of irrigated areas was addressed in this study for one of the world's largest river basins, where irrigation has shaped agriculture for thousands of years: the Nile River Basin. In particular, we investigated the likely effects of improved irrigation efficiency for the future, i.e., the ratio between the water made available for plant water uptake and the water taken from the source (surface and groundwater).

Irrigation efficiency has been discussed in great detail (Howell, 2003; Jensen, 2007; Lankford, 2012), and general instructions for the estimation of irrigation efficiency have been provided by the FAO Irrigation and Drainage guidelines (Brouwer et al., 1989). The efficiency of an irrigation scheme is derived from two components. The conveyance efficiency (off-farm, e_c) is calculated according to water losses that occur when water is delivered to farms (e.g., through leakage and evaporation from canals and cracks in canal bunds). The application efficiency (on-farm, e_a) is calculated according to losses on fields, e.g., evaporation from the soil surface and open waters and interception and deep percolation into the groundwater. The scheme efficiency (e) is derived by multiplying both components ($e = e_c \times e_a/100$).

Water savings through improved irrigation efficiency has been discussed for Saudi Arabia, where arid climate and irrigation with fossil groundwater resources are dominant, and the agriculture sector consumes most of the scarce water resources (Multsch et al., 2016b). Multsch et al. (2016b) have shown that national water consumption could potentially be reduced by 32% if no salt sensitive crops are grown and modern irrigation technology is adopted. Hence, irrigation efficiency plays a major role, as shown in a global study (Jägermeyr et al., 2015) highlighting the likely water savings gained by decreasing non-beneficial consumptive use, i.e., by limiting losses through evaporation and interception and decreasing non-recoverable return flow (e.g., water flows to salinized water bodies).

1.2. Objective and approach

We evaluated the water consumption of irrigated agriculture in the riparian countries of the entire Nile River Basin, because a substantial expansion of irrigation schemes is expected in the coming decades (BCEOM, 1999; WREM, 2006; Awulachew et al., 2012). Previous studies have highlighted that the accompanying agriculture water demand cannot be met in the future (Awulachew et al., 2012). This situation is likely to worsen because many dams are being constructed, which will alter river flows, most probably decreasing water resources for downstream users (McCartney et al., 2012). Collaboration between riparian countries is important to solve the current and future water resources demands in the Nile River Basin (Abdelhady et al., 2015). Furthermore, technical approaches, such as improving irrigation efficiency, may be a measure to partly counteract future water scarcity (McCartney et al., 2012), but it is currently unknown to what degree this is feasible.

Three objectives were focused on in this study. First, the water consumption of today's irrigated agriculture (existing areas) was estimated on the basis of current irrigation technology. National plans show considerable increases in the extent of irrigation schemes during the coming decades up to 2050. Therefore, in a second step, we estimated the water consumption for additional planned irrigated areas up to 2050, assuming that the irrigation efficiency remains at today's level. When summing up existing and planned irrigated areas, a prediction of the future water demand in the Nile River Basin can be done.Third, scenarios were assessed that assumed stepwise improvements in irrigation efficiencies as well as a theoretical best technology scenario leading to maximum efficiency. Our key question addressed the problem of whether the quantity of likely water savings through improved irrigation technology might be sufficient to provide for the total water consumption of planned irrigation schemes in the future.

The study relied on existing data obtained primarily from the Nile Basin Initiative (NBI) (such as the Nile Basin Decision Support System (NB DSS), Multi-Sector Investment Studies for the Eastern Nile and the Nile Equatorial Lakes region) and from public data sources. The field level water demand model SPARE:WATER (Multsch et al., 2013), which was integrated into a geographic information system, was set up with site-specific crop parameters and high resolution gridded climate data to assess the water requirements for growing field crops and to evaluate the water savings from improved irrigation efficiency.