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Determining the Dynamics of Agricultural Water Use: Cases from Asia and Africa

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Abstract

Across Africa and Asia, water resources are being affected by a complex mixture of social, economic, and environmental factors. These include climate change and population growth, food prices, oil prices, financial disruptions, and political fluctuations. The need to produce more food will have one of the largest impacts on water and will continue to reshape the patterns of agricultural water use in major food-growing regions. With this increasing demand on water for agriculture, from large-scale irrigation to intensification of rainfed systems, it is becoming increasingly important to ensure that water resources decision-making has access to information that captures the spectrum of water uses, across seasons, and over time. Furthermore, the major sectors that place demands on water and otherwise affect the resource need water-related information to inform their decisions. In this paper we consider two cases where the range of agricultural water management uses have been examined. We examine the methodologies and approaches used, the utility of this information to decision-making in the water and agricultural sectors, and the limitations of the information gathered.

Keywords: agriculture, water, data

Agriculture is the largest consumer of water in Africa and Asia and plays an essential role in economic development and poverty reduction in these regions. Growth in the agricultural sector is critical to achieving the Millennium Development Goals related to poverty and hunger eradication. While these, in their present form, aim to reduce the proportion of people who suffer from hunger by 50% between 1990 and 2015, the proportion of people in the developing world who went hungry from 2005 to 2007 remained stable at 16% despite significant reductions in extreme poverty (MDG Report 2011). Projections show that feeding a world population of 9.1 billion people in 2050 will require raising 2007 levels of food production by around 70%; production in sub-Saharan Africa and parts of South and East Asia would need to double (Rockström et al. 2010). In order to achieve this, new strategies aimed at sustainably increasing agricultural production and ensuring the effective use of land and water resources are necessary. Future increases in food production will need to occur largely on existing agricultural land; 80% of the growth in crop production in developing countries is expected to come from higher yields and increased cropping intensity, with the remainder coming from land expansion (FAO 2009). Allowing for relatively ambitious reductions in inefficiencies will necessitate large increases in water use. It is estimated that annual agricultural water use will need to increase from approximately 7,100 km^3 globally to between 8,500 and 11,000 km^3 in order to meet food requirements in 2050 (de Fraiture et al. 2010).

As water scarcity is increasing in many regions, along with salinization and pollution of rivers and water bodies and degradation of water-related ecosystems, mobilizing the water resources needed to increase food production will require informed decisions within the water sector and in related sectors in order to balance water use and requirements among sectors (FAO 2011). Climate change is likely to complicate these efforts; the Intergovernmental Panel on Climate Change has highlighted the increased vulnerability of freshwater resources under climate change scenarios that result in greater climatic and hydrological variability (Field et al. 2012). Effective management of water across sectors requires information on how much water is available and how much is being used and depleted for various purposes, as well as an understanding of how this will change under future scenarios. As a result, achieving water security for regions, nations, and individuals is increasingly identified as one of the greatest development challenges confronting the world today (USAID 2013).

To showcase lessons learned in providing the information needed for effective water decision-making, we consider two cases, the Greater Mekong Subregion and the Nile Basin, where the range of agricultural water management uses have been studied at the regional scale as an input to planning and policy formulation (Fig. 1). The overall objective of this paper is to demonstrate the potential tools and methods that can be used to assess agricultural water use at the national to regional scale. The two case studies have been selected because agriculture is the biggest consumer of water in each and is critical to poverty reduction. Informed decisions are essential in each location in order to balance water use requirements among sectors as well as to ensure effective management of the resource under climate-change scenarios and future increases in food production. Analysis of these two regions allows us to examine the methodologies and approaches used to assess agricultural water use, the utility of this information to decision-making in the water and agricultural sectors, and the limitations of the information gathered.

	Greater Mekong Subregion	Nile Basin
Population	275 million	238 million
Area	2.6 million km^2	3.1 million km^2
Countries	Cambodia, Vietnam, Lao P.D.R., Thailand, Mynamar, China	Tanzania, Kenya, Rwanda, Burundi, Uganada, Democratic Republic of Congo, Ethiopia, Sudan, South Sudan, Eritrea, Egypt
Major Crops	Rice, maize, cassava	Cassava, maize, wheat
Annual Rainfall	700-5000 mm/yr	0-2060 mm/yr

Figure 1. Overview of the study locations (Source: Johnston et al. 2010; Nile Basin Initiative 2012).

The Greater Mekong Subregion

Rapid economic growth and increasing populations in the Greater Mekong Subregion (GMS) are resulting in increasing demand for food. To keep pace with growing populations and dietary changes, food production in the GMS will need to increase by an estimated 25% over the next 15 years. In order to achieve this, decisions need to be made regarding the management of water resources in the region that balance the requirements of different sectors. The three major interlinked water-related sectors in the GMS are hydropower, agriculture, and fisheries. Management responses need to take into account the interactions and trade-offs between these sectors in order to offset potential conflicts and to capitalize on synergies (Johnston et al. 2010).

Agriculture is currently the greatest consumer of water in all GMS countries, accounting for 68% of all withdrawals in the People's Republic of China and in Vietnam, to more than 90% in Cambodia, Lao P.D.R., Myanmar, and Thailand (Johnston et al. 2010). As the availability of renewable freshwater is high in most countries, rainfed systems dominate and the proportion of irrigated land is low in comparison to other regions. Upgrading these systems has the potential to increase resilience to future increases in climatic variability, and promises large social, economic, and environmental paybacks in terms of reducing poverty and boosting economic development. A study, commissioned by the Swedish International Development Cooperation Agency (Sida) and undertaken by the International Water Management Institute, investigated opportunities for improving production in rainfed agriculture in the GMS through small-scale water management interventions (Johnston et al. 2012). The study analyzed the agro-ecosystems and current patterns of production in the GMS, the impacts of climate on production (using current and projected future climate data), the suitability of crops under different conditions, and the current versus potential yield. Suitable agricultural water management interventions for different contexts were also assessed, as was the current and potential use of groundwater in agriculture in the region.

Data Availability and Constraints

Data for the agro-climate analysis were derived from the global Climate Research Unit (CRU) of the University of East Anglia, which provided gridded, monthly rainfall and potential evapotranspiration data at 0.50 for the period 1901 to 2009 (Mitchell and Jones 2005). In addition, detailed analysis of variability in key climate parameters relating to crop growth were analyzed for two locations (Ubon Ratchathani in Thailand and Luang Prabang in Lao P.D.R.) using pan evaporation data measured from 1962 to 2004 and rainfall time series recorded at the two stations from 1953 to 2004. Potential climate change in the GMS was characterized using daily rainfall and temperature time series produced by the regional climate model, Providing Regional Climates for Impacts Studies (PRECIS), and forced by the global climate model, European Centre Hamburg Model, version 4 (ECHAM4), under the SRES scenarios A2 and B2 over the period 1960 to 2049.

As this was a regional analysis, agricultural statistics were compiled at national to provincial level. National crop production and yield trend data were derived from published national statistics compiled by FAO available through the FAOSTAT database (faostat .fao.org), which includes data from 1960 to the present. To examine spatial patterns of production, crop statistics at provincial level were compiled from data published by national statistical agencies and FAO Regional Data Exchange System (FAORAP) (www.faorap-apcas.org). Availability of data varied between countries; reliable time series data at provincial level could be sourced at the time of the study only for Cambodia (MAFF 2009) and Vietnam (VN GSO 2011).

Bioclimatic suitability of crops was assessed using data from the FAO EcoCrop database (ecocrop.fao.org). Because of the constraints of the basin-scale study, suitability was assessed based only on bioclimatic variables without considering factors such as soil requirements, pests and diseases, or the specific requirements of different varieties.

Information on current agricultural water management practices, and particularly irrigation, was derived from a range of sources, including official estimates of irrigation coverage reported in FAO's AQUASTAT database, national and global land cover mapping (e.g., European Space Agency (ESA) GlobCover), crop production statistics reported by season, and published studies. Estimates of irrigated area are inconsistent and generally unreliable for all GMS countries. This is because of a number of factors. The region's dominant crop is paddy rice, which is grown under varying degrees of water management that range from fully rainfed to fully irrigated, depending on location and season. The distinction between irrigated and rainfed cropping in lowland systems is blurred. Growing paddy rice requires water management to maintain inundated conditions even if the water used comes mainly from rainfall or from the recession of seasonal floods. On average, more than half of crop water requirements for irrigated crops in GMS come from rainfall (Johnston et al. 2012). Crop production statistics do not distinguish whether the crop is irrigated and dry season figures include a large component of rainfed production. For example, more than half of Cambodia's reported dry-season rice crop is actually recession rice watered primarily from receding floodwaters (Nesbitt 2003), while in the Mekong Delta, cultivation of two irrigated dry-season crops per year has progressively replaced traditional wet-season rice, but both crops receive a significant amount of rainfall. Statistics on the area equipped for irrigation do not accurately reflect the actual extent of irrigation, since, in many areas, only a small proportion of the land equipped for irrigation receives water during the dry season. Even in the wet season, poor maintenance and design mean that many systems are not fully functional (see for example Thuon and Bastakoti 2010; McCartney et al. 2013). Areas of informal, farmer-managed pump irrigation are rarely recorded in official statistics, though evidence suggests that they are an increasingly important component of irrigated production.

Our study focused on compiling comprehensive and consistent data across the GMS, which was available only at province to national level. Government agricultural statistics are compiled at finer resolution, but are usually aggregated to district or province level before publication. The FAORAP website (http://www.faorap-apcas.org/) provides details of the systems for reporting subnational agricultural statistics in each country. Data on crop statistics and water resources at district to village level are sometimes available through government departments in internal reports, usually in local languages, but coverage is patchy and often restricted to specific research studies. Data are used mostly within government agencies for statistical reporting and planning, and analysis and verification vary significantly between countries. There are initiatives in several countries to make data on development-related issues more available in the public domain—see for example Open Development Cambodia (http://www.opendevelopmentcambodia.net/) and Myanmar Information Management Unit (www.themimu.info).

Discussion

The quality and availability of data significantly limited analysis of the effectiveness of and constraints to rainfed agriculture in the GMS. The first issue is the poor quality of information on irrigation. To determine the extent to which access to water is limiting productivity, better information is needed on two different aspects: on the location and extent of irrigation infrastructure (including small-scale, farmer-managed infrastructure, and groundwater systems); and the degree to which irrigation is actually used in different seasons. The first is a relatively simple, though evolving, inventory; the second is more difficult, since it varies both seasonally and spatially. Crop statistics, as currently reported, are not adequate to define irrigation use. Approaches using multitemporal satellite measurements of greening and evapotranspiration are increasingly being used to map and monitor irrigation (see for example Conrad et al. 2007; Gumma et al. 2010).

Secondly, we found that crop statistics reported at national or even province levels are not sufficiently spatially disaggregated to reflect the impacts of weather extremes, which tend to be highly localized. For example, the severe regional drought of 1998 was not reflected by a national-level drop in yield or total production (except in Myanmar); neither was the drought of 2004 in Thailand, despite estimates that it affected 2 Mha of crops (Bank of Thailand 2005). Collation of crop production data at district to village level would provide a more robust basis for assessing yield patterns and trends.

Because of the paucity of data on farming practices (such as use of fertilizers, improved varieties, mechanization, etc.), it is not possible to disaggregate the impacts of water management on yield from those of other management factors. These data tend to be collected only sporadically and for specific studies. The Cambodian Commune Database (available at http://db.ncdd.gov.kh/cdbonline) provides an interesting example of what could be done in this area. This database compiles information collected at village level for a wide range of socioeconomic and agricultural indicators, including areas irrigated from different sources, use of chemical fertilizers and pesticides, and ownership of pumps and tractors. This is potentially a very valuable resource for understanding trends in agricultural practices. In practice, however, data are not regularly collected for all fields, and there are inconsistencies in data between years, making trend analysis impossible at this stage.

The Nile Basin

Poverty, food insecurity, and water scarcity are widespread across the Nile Basin, which covers approximately 10% of the African continent and is home to about 20% of the population. Rapidly increasing populations coupled with existing high levels of food insecurity mean that increasing agricultural production is an urgent imperative for the region (Johnston 2012). The poorer countries in the basin have a greater dependence on agriculture, with contribution to Gross Domestic Product ranging from 17% in Egypt to 55% in Ethiopia (World Bank 2008). In contrast to Asia, where agricultural expenditure as a percentage of agricultural Gross Domestic Product ranges from 8.5% to 11% over the past ten years, in Africa this figure is only 5% (Fan et al. 2008). While the importance of increasing government spending for agriculture has been recognized by African leaders, it is critical to identify the high potential investments that can contribute to increased production and achievement of target growth rates in agricultural Gross Domestic Product.

The identification of suitable water management interventions that will improve access to water, particularly for the poor, and yet sustain the resource, requires an understanding of water availability and use in the basin. A study commissioned by the Challenge Program on Water and Food was undertaken by the International Water Management Institute in the Nile Basin to identify high-potential investments that could reduce poverty yet also reverse trends in land and water degradation (Molden et al. 2009). A key component of this study focused on the assessment of water availability across the region, and the water productivity of existing agricultural systems, in order to determine how much water is being used and where there are opportunities to increase agricultural productivity. An initial assessment of the availability of water for agriculture in the basin was carried out using traditional data sources such as hydrological records, climate data, and agricultural statistics (Johnston 2012). A water accounting framework based on remotely sensed data was also applied to understand water use patterns and the benefits derived from these uses in the basin (Karimi et al. 2013). Crop water productivity was assessed for the agricultural systems based on the ratio of benefits (i.e., yield) to the amount of water required to produce them, which provides an understanding of the spatial distribution of the effectiveness of water use (Karimi et al. 2012a).

Data availability and constraints

Climate data used in the study were derived from the Climate Research Unit (CRU) (Mitchell and Jones 2005). As in the GMS, these were supplemented by observational data compiled and analyzed in this case by Sutcliffe and Parks (1999). Hydrological data were drawn from two sources: a major compilation of data for the Nile by Sutcliffe and Parks (1999), updated by Sutcliffe (2009), and a water account for 23 sub-basins of the Nile developed by Kirby et al. (2010) using the ds552.1 dataset of Dai and Trenberth (2003).

The extent, type, and location of agricultural production was assessed using a combination of national agricultural statistics and land cover maps derived from remote sensing data (European Space Agency Globcover 2009) and an earlier dataset based on AVHRR imagery from 1992–93 (International Water Management Institute 2006). Crop statistics are available for all Nile countries at the national level in FAOSTAT, but disaggregated statistics at the state or province level are patchy, available only for certain crops and for some years. Ethiopia and Sudan publish annual statistics for major crops at subnational levels based on field surveys. Such data are not available or accessible, however, for other countries of the basin. The International Water Management Institute's analysis was based on a combination of published national statistics, unpublished statistics compiled by FAO (2010), and a study by Bastiaanssen and Perry (2009) for the Nile Basin Initiative. As in the GMS, and despite a very different setting, estimates of irrigated area in the Nile Basin vary widely, ranging from 4.9 to 6.4 million ha, due at least in part to confusion in reporting areas of single versus double cropping. Estimates of areas of rainfed agriculture are even more variable since much of the rainfed agriculture is small-scale subsistence production in mixed crop-livestock systems.

A water accounting framework was developed by Karimi et al. (2013) to understand how water is used in the Nile Basin and to identify opportunities for improvement (Fig. 2). The water accounting analysis was exclusively based on remote-sensing data. Core input datasets included precipitation derived from 10-day RFE product at 1 km spatial resolution, land cover (European Space Agency GlobCover 2009), and actual evapotranspiration (split into E and T) also at a spatial resolution of 1 km, calculated using ETLook (Bastiaansen et al. 2012). All datasets are publicly available except for the maps of evapotranspiration, which are a propriety dataset produced by the company WaterWatch (www.waterwatch.nl) and were available only for a single year because of cost restrictions. The accounting method was used to estimate overall water stocks of the basin, water consumption by different land-use classes including rainfed and irrigated agriculture, and the basin outflow as well as water and land productivity. The framework separates green water and blue water (Falkenmark and Rockström 2006) and also divides overall water consumption to managed and unmanaged processes. Managed processes refer to water consumptions that are caused by human interventions such as agriculture, domestic and industrial use, and evaporation from manmade reservoirs. Unmanaged processes refer to water consumption through evapotranspiration of natural vegetation and evaporation from lakes and natural water bodies. Such information can play a key role in understanding water flows in a basin. For example, results of the study suggest that in the Nile Basin only 4% of total rainfall ends up in the blue-water system (which includes water in rivers, lakes, and aquifers) with the remainder (96%) consumed through green processes (i.e., evaporation and transpiration from retained rainfall in soil profiles).

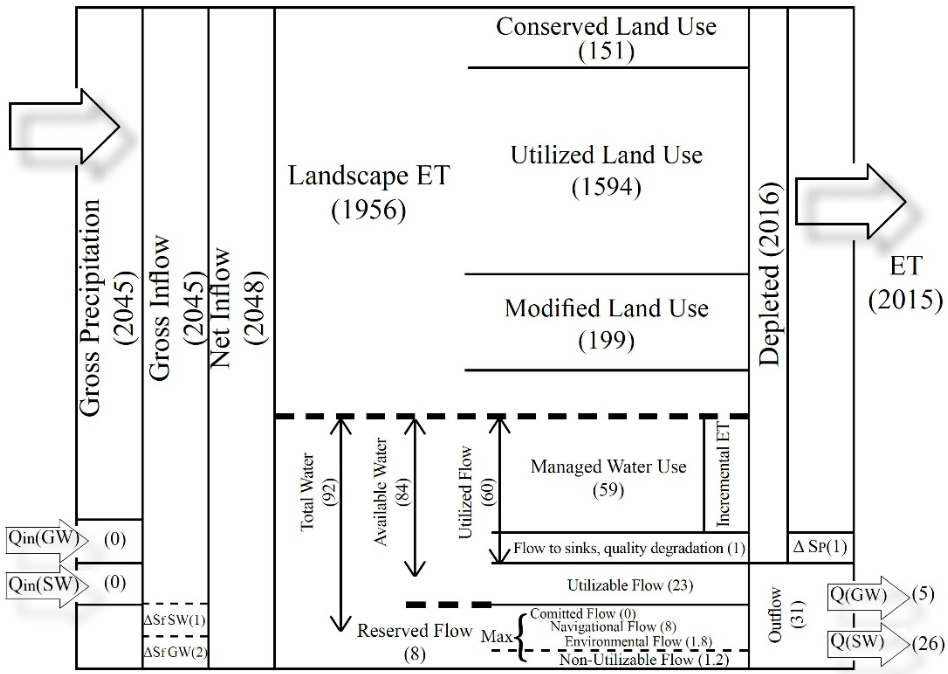

Figure 2. Water account for the Nile Basin, based on remotely sensed data (based on Karimi et al. 2013).

Maps of actual evapotranspiration derived from remotely sensed data were used to assess consumptive water use across the basin. This was combined with the Standardized Gross Value of Production (SGVP), derived from national production statistics, in order to estimate crop water productivity across the basin (Fig. 3). Using a standardized index such as the SGVP overcomes data constraints that typically occur when working at the transboundary level. Different pricing systems and local market fluctuations can complicate efforts to estimate the total value of agricultural goods and services in large transboundary basins such as the Nile (Karimi et al. 2012b). For this study, wheat was chosen as the base crop, with prices of other crops pegged to the international standard wheat price allowing for comparison of the economic value of the different crops regardless of the country or location (Molden et al. 1998).

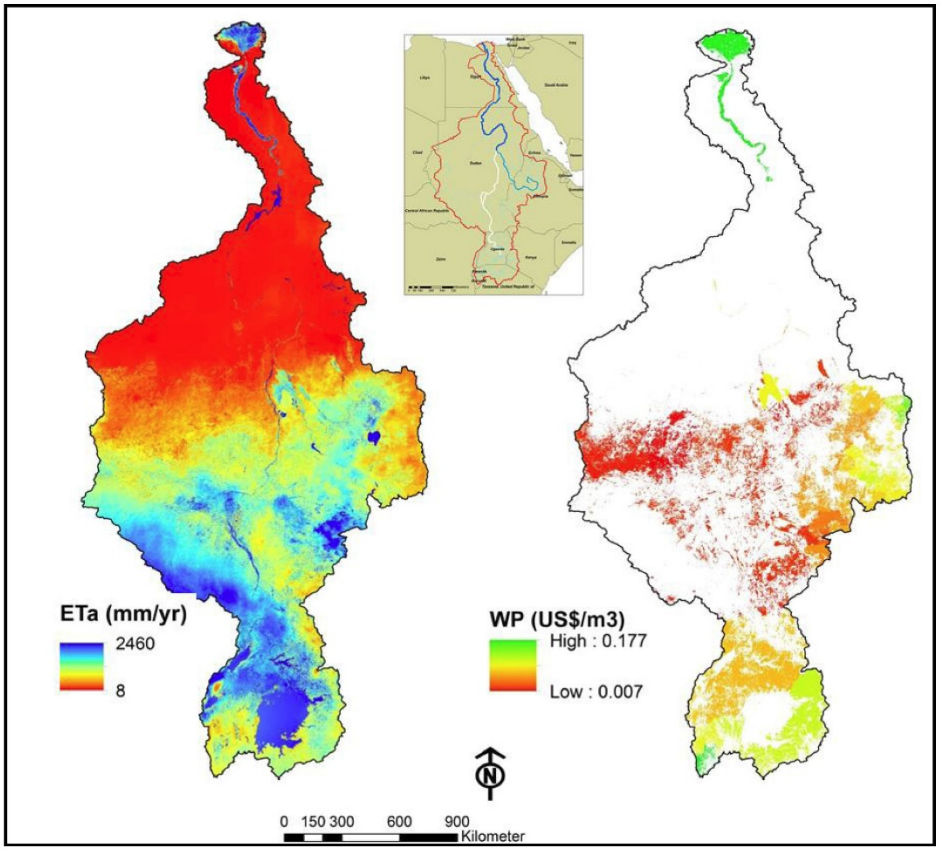

Figure 3. Actual evapotranspiration and derived crop water productivity for the Nile Basin (from Karimi et al. 2012b).

Discussion

Since the Nile is effectively a closed basin with less than 2% of total annual precipitation reaching the sea, accurate accounting of water availability and use is an important priority. However, it is surprisingly difficult to get a clear picture of the volume and distribution of flows in the basin. For example, estimates for flow entering the sea through the Delta vary between 4 and 28 km^3 (see Johnston 2012). This is in part because of extreme spatial and temporal variability in flows but is exacerbated by lack of data, despite a relatively well-developed and long-established hydrological monitoring network. Availability of flow monitoring data has declined rather than increased since the 1960s, and data for major stations in Egypt have not been released into the public domain since the 1990s.

Estimates of water use are similarly constrained. Irrigation accounts for the largest fraction of water use in all Nile Basin countries, but estimates of irrigated area and irrigation water use vary widely, which compromises planning for water allocation. For example, recent studies put demand within Egypt between 42 and 66 km^3 annually (Awulachew et al. 2012 and FAO 2010, respectively). In planning terms, the difference is highly significant. Given that Egypt's nominal total allocation (for all uses including irrigation) under the Nile

Agreement is 55.5 bcm, the lower estimate indicates that Egypt has room to increase current levels of irrigation. The higher estimates suggest that Egypt is already overusing its allocation by 10 bcm (20%) and is dependent on "excess" flows to Aswan that may not be guaranteed in the longer term, resulting in vulnerability to any increase in upstream withdrawals (Johnston 2012). Karimi et al. (2012a) used satellite estimates of ET and land use in combination with census data on crop production and market prices of crops to map crop water productivity in the Nile basin. They were able to distinguish significant differences in water productivity across the basin by comparing crop yield and other production statistics with water use (mapped as evapotranspiration). The method provides useful information on spatial variation of productivity of water use in agriculture. Nonetheless, the spatial resolution of the resulting map depends on the scale at which production statistics are reported and collected. In the Nile Basin, production statistics are available at province and state level at best. Hence, the results are too coarse for any decision on focused interventions. The effectiveness and accuracy of these analyses would be considerably increased if agricultural statistics could be disaggregated to a finer level, particularly in Sudan and Ethiopia, where conditions for rainfed agriculture vary significantly within a single state. In the absence of detailed information on crop types, all the agricultural crops were aggregated. As a result, the effect of crop choice on overall water productivity could not be assessed. Information on climate and land use is very sparse in many areas of the Nile Basin and, as a result, many studies rely on remotely sensed data. Multi-temporal evapotranspiration datasets, such as those produced from MODIS (modis.gsfc.nasa.gov), enable consistent estimates of crop water use and (within the constraints of low spatial resolution) can be used to map irrigated areas. Products from sensors such as MODIS are publicly available, and those derived from combinations of different datasets are becoming more accessible to nonspecialist users through initiatives such as the Famine Early Warning Systems Network (www.fews.net). Importantly, these databases are acquired through replicable methods and are politically neutral, a significant fact in the highly political transboundary context of the Nile. Validation of these data (and model outputs derived from them) against actual field conditions is, however, an ongoing and important challenge.

In the light of Egypt's dependence on the Nile, and the prospect of conflict between basin countries over water, perhaps the most pressing question facing planners in the basin is the extent to which upstream development will impinge on supplies to Egypt. The International Water Management Institute's study concluded that uncertainties in current estimates of both irrigation demand and available flows are so high that it is not possible to determine the stage at which demand will outstrip supply in Egypt. That such a critical question cannot be resolved underlines the urgent need to improve water-related information for the basin, and, equally importantly, sharing of that information among countries. The Nile Basin Initiative (www.nbi.org) is attempting to address these deficiencies by promoting open exchange of information through institutional dialogues and a shared information system (http://nileis.nilebasin.org/). Progress is limited by the lack of available data in some countries but also by the difficult politics of transboundary water management in the Nile Basin (see Abawari 2011; Paisley and Henshaw 2013).

Conclusions

Two cases have been presented in this paper through which a range of agricultural water management uses has been examined. The methodologies and approaches used have been discussed, and the availability and constraints of available data determined. In the GMS, the quality and availability of data significantly limited analysis of the effectiveness of, and constraints to, rainfed agriculture. In particular, the poor quality of information on irrigation and the lack of detailed or spatially disaggregated crop statistics proved a major hindrance. In the Nile, the integrity of the hydrological monitoring network and the availability of reliable records of river flows were a major constraint, along with the lack of accurate data on irrigation extent and water use. Crop statistics were also required at a higher level of disaggregation.

As in the Nile and GMS, agriculture is the largest consumer of water in many countries across Africa and Asia. Future increases in food production to meet the needs of expanding populations in these regions will necessitate large increases in water use. Mobilizing the water resources needed and identifying appropriate management decisions will require an understanding of how much water is available. Detailed, reliable, and regular water accounts in agricultural basins are needed to ensure proper monitoring and management of water resources. In both of the case studies presented here, the quality and availability of data has limited the analysis and hindered the identification of appropriate interventions to increase the productivity of the agricultural systems.

Access to hydrological data is still a challenge in many parts of the world. Investing in data collection is critical at the national level, and the UN has emphasized that the decline of hydrological networks needs to be stopped and reversed so that decision-making can be based on solid empirical evidence (UN Water 2013). With the increasing demand on water for agriculture to meet global food needs, it is becoming increasingly important to ensure that water resources decision-making has access to information that captures the spectrum of water uses across seasons and over time. The lack of such information will directly affect the identification of successful and sustainable investments and limit the formulation of informed policies that are viable in the long term as well as the immediate future.

In recent years, the increasing availability of Earth observation data has resulted in a move away from conventional, ground-based measures, and ways of augmenting data availability with approaches developed that increasingly rely on the use of remote sensing data. Remotely sensed data are an attractive alternative to in situ methods. Satellites provide spatial information with a high temporal frequency over wide areas and are publicly (although not always freely) available. Hence, they provide the opportunity for building time series databases on various hydrological parameters such as precipitation, evapotranspiration, snow cover, and soil moisture at different spatial and temporal scales. The replicable, publicly available nature of the data is particularly important in regions where there is potential for conflict over water resources. In addition, significant progress has been made over the past few years in data assimilation capabilities allowing for the integration of remote sensing data products along with ground-based observations into land surface and hydrological models, metrics, and accounting frameworks.

The water accounting framework described by Karimi et al. (2013) offers an alternative approach to assessing water use in a basin where almost all of the input data can typically be derived from satellite measurements. The framework provides a link between water consumption and land use. Hence, it allows evaluation of the impact of future interventions, which involve land use change, on water flows in river basins. The WA+ separates blue and green water flows. This has an important implication for water allocations and also for identifying effective water-saving strategies. The example described by Karimi et al. (2012b) is based on analysis for a single year, but the real benefits of such accounting practices will come with multiple-year analysis. Multiple-year analysis would allow planners to define the baseline status of water resources in the basin, assess performance of the current basin water management regime in an average year, identify future issues and opportunities for water resources development, and evaluate the impact of proposed large-scale interventions in water and land management, such as increasing areas under irrigation. Flow measurements data, if they exist, can be used to verify the results of water accounting analysis at both basin and sub-basin levels. Ideally water accounting should be done at sub-basin level and with a monthly temporal scale. This would allow the users to better understand local conditions, and spatial and temporal variations of water availability and water use patterns.

In addition to the above, it is important to stress the need for better information other than that on water, especially from the agricultural sector. Effective management of water requires information on how much is available, how this is being used, the impact of other sectors on water, and an understanding of how this will change under future scenarios. Informed decision making in the water and related sectors, especially agriculture, requires access to relevant information that captures this. Other than the information that could be drawn from remotely sensed sources, the studies reviewed here relied on global data sets that are usually aggregated from national reports, especially for data related to agricultural production. The rigor and completeness of such information varies considerably. Furthermore, the availability of relevant comprehensive data sets that are disaggregated at the subnational levels was generally quite limited in the countries in both of these important basins.

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