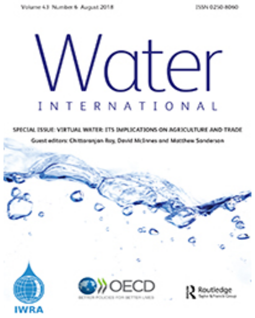

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Can Sub-Saharan Africa feed itself? The role of irrigation development in the region's drylands for food security

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ABSTRACT
This paper assesses the potential role of investments in irrigation in Sub-Saharan Africa in improving food security and self-sufficiency in the region. Focusing on the region's drylands, the study identifies a potential for expanded irrigated area of 6–14 million hectares (ha), depending on technology costs and other factors. Linkage of these results with a global agricultural trade model shows that accelerated irrigation investment can effectively reduce growing food import dependency from 54% under a business-as-usual scenario to a much smaller 17–40%; and can also reduce the population at risk of hunger and child under-nutrition.

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Irrigation; food security; IMPACT model; Sub-Saharan Africa

Introduction

Sub-Saharan Africa has long been beset with food insecurity. Although progress has been made over the past few decades, the region is still faced with great challenges to produce sufficient food (Sasson, 2012; Rosen, Meade, Fuglie, & Rada, 2016). The latest *The State of Food Security and Nutrition* report (FAO, IFAD, UNICEF, WFP & WHO, 2017) finds that 23% of the population suffers from under-nutrition; and that food insecurity worsened, by almost 3 percentage points from 2014 to 2016.

High and growing dependency on imported food is another indicator for the worsening food security situation in the region. Crop yields of major staples in Sub-Saharan Africa lag substantially behind those of other regions of the world (FAOSTAT, 2016). This has resulted in high dependency on net food imports by many countries in the region. Among major countries in Sub-Saharan Africa, only Zambia achieved self-sufficiency of cereal supplies; in several other countries, such as Angola, Mauritania and Namibia, more than 50% of domestic needs for staple cereals are met through imports. Moreover, although there were increases in domestic production, improvements in cereal production were outstripped by population growth and increased demand by those benefiting from economic growth and moving to cities. As a result, the cereal

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import dependency increased from 17% in 2000–02 to 19% in 2011–13 (FAOSTAT, 2016). The lack of self-sufficiency exposes the region to volatile global agricultural markets.

Ameliorating the food security situation in Sub-Saharan Africa requires the deployment of more effective technologies, institutions and policies in the agriculture and related sectors. These have been discussed in many studies (Chen et al., 2011; Devereux, 2016; Garrity et al., 2010; Rosegrant, Cline, Li, Sulser, & Valmonte-Santos, 2005; Rosegrant et al., 2017; Runge, Senauer, Pardey, & Rosegrant, 2003; Van Ittersum et al., 2016; Webber, Gaiser, & Ewert, 2014). A promising option is to expand irrigated agriculture. Food production is intrinsically linked to access to water for productive uses, and irrigated agriculture is overall more productive than rainfed agriculture. Globally, it is estimated that irrigated agriculture accounts for only 20% of cropland, but contributes 40% of total production (FAO, 2016). In Sub-Saharan Africa, crop production is predominantly rainfed; less than 5% of cropland is irrigated (FAO, 2016). Irrigation could well be an important means to help improve agricultural productivity and reduce food insecurity and import dependency in the region.

However, important knowledge gaps remain as to the specific gap that irrigation can and cannot fill in the complex food insecurity picture in the region. For example, irrigation investment is a costly and complex endeavour. The feasibility of irrigation expansion is influenced by many factors, both biophysical and socioeconomic. In two foresight analyses on food security in Sub-Saharan Africa noted above (Rosegrant et al., 2005; Van Ittersum et al., 2016), the expansion rates of irrigated agriculture were largely introduced as exogenous variables into the analyses. Their values were chosen to reflect trends of historical investment rather than irrigation development potential over the region in the future. This paper contributes to closing this gap by using an integrated biophysical and economic modelling approach to assess quantitatively the irrigation development potential in Sub-Saharan Africa and linking this investment with changes in food security and food import dependency.

The study focuses on the dryland zones of Sub-Saharan Africa where hunger and under-nutrition are most severe (Azzarri, Bacou, Cox, Guo, & Koo, 2016). Dryland areas here refer to arid, semi-arid and dry sub-humid zones classified using the aridity index (see Appendix I in the supplemental data online). They cover 43% of total land area (13.9 million km^2), 70% of cropland and 66% of cereal production in Sub-Saharan Africa and are home to about 425 million people, or half the region's population. Given the importance of dryland zones in the region's food production and the higher levels of food insecurity and under-nutrition in these areas, they have received special attention in recent analyses and provide particular promises for irrigation investment (Cervigni & Morris, 2016).

Data and methods

The methodological framework applied is presented schematically in Figure 1. The study consists of two analyses. The first is a strategic planning analysis, in which we estimate irrigation development potential in Sub-Saharan Africa. The strategic planning analysis starts with pre-suitability mapping, which uses multiple environmental suitability criteria to score the suitability of irrigation development potential of land pixels

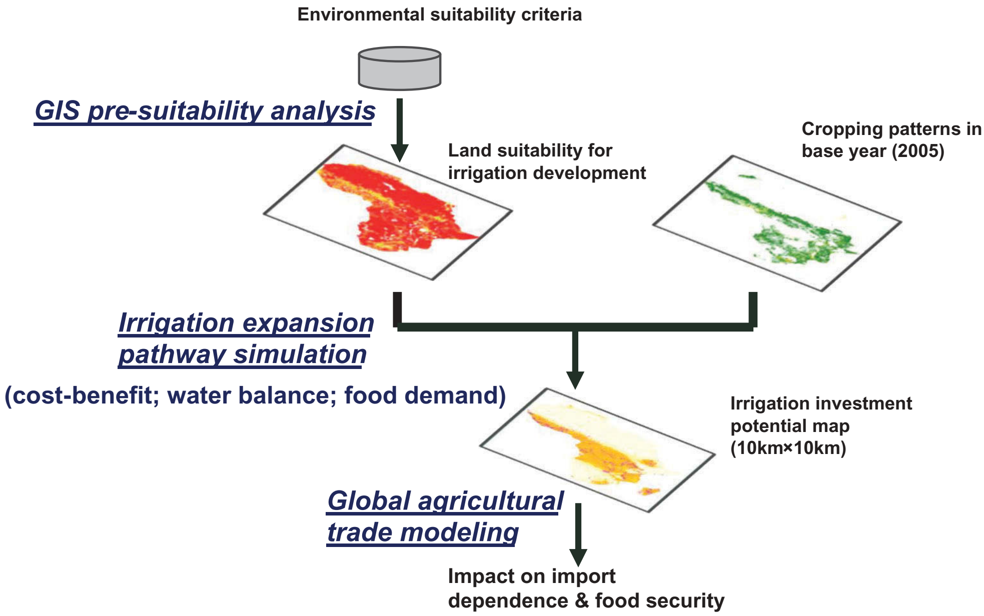

Figure 1. Methodological framework for irrigation development impact assessment.

in Sub-Saharan African countries on a 5 arc-minute grid. The pre-suitability mapping was followed by simulations, using a rule-based algorithm, guided by the calculated land suitability score, to simulate pathways of irrigation development under a series of constraints, including water availability, demand for irrigated crops and cost–benefit analysis of irrigated crop production. The results are identified irrigation development potential.

The second is a simulation analysis that incorporates the estimates of irrigation development potential in dryland zones in the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) (Robinson et al., 2015). IMPACT is a global, partial equilibrium agricultural sector model that has been widely applied to examine global and regional food security issues (Flachsbarth et al., 2015; Ringler, Zhu, Cai, Koo, & Wang, 2010; Rosegrant, Zhu, Msangi, & Sulser, 2008). The linkage between the two modelling systems allows one to examine broader-scale impacts of accelerated irrigation development on food availability, food security and net food trade.

Large-scale irrigation (LSI) and small-scale irrigation (SSI)

In this assessment, we distinguish between LSI and SSI. SSI refers to small irrigation schemes developed to harvest water resources to augment crop production under private ownership of smallholders, which could be fed by groundwater or surface water; LSI is associated with the construction of reservoirs with large storage capacities and is generally publicly financed. The analysis of potential for LSI development requires prior knowledge of locations and storage capacities of those reservoirs. To identify dams, we adapted a dam inventory across Africa provided by the World Bank. The inventory includes 680 dams, of which 373 have a capacity > 50 million m^3. Among the large dams, 253 are operational, while 120 dams are planned or slated for rehabilitation and were included in the study (see Appendix II in the supplemental data online). We assumed that no additional irrigated area can be linked to existing dams, as the area around dams in operation might already be fully exploited. The analysis also did not include barrages or run-of-the-river schemes. Both assumptions led to a lower-bound estimate of irrigation potential in the dryland zones of Sub-Saharan Africa.

Environmental suitability for pre-suitability mapping analysis

The environmental suitability criteria used in the *ex-ante* mapping for SSI and LSI are shown in Table 1. These criteria were determined by expert consultation. The sources of input data are shown in Table 2. The pixel size for the mapping of suitable areas is 0.5 × 0.5 km. A linear weighting scheme was used with all criteria weighted equally. The SSI suitability score of each pixel was calculated as:

$$SSI\ suitability\ score\ (0 \sim 100) = [S_1 + \max(S_2 + S_3) + S_4 + S_5]/4 \quad (1)$$

Table 1. Criteria for *ex-ante* suitability analysis.

Criteria	Range of parameter	Range of score
(a) *Small-scale irrigation (SSI)*		
Slope (S_1)	0–10%	S_1: 100–0
Distance to surface water (S_2)	0–5 km	S_3: 100–0
Groundwater depth (S_3)[a]	0–250 m	S_2: 100–0
Travel time to market (S_4)	0–3 h	S_4: 100–0
Distance to existing irrigation (S_5)	0–10 km	S_5: 100–0
(b) *Large-scale irrigation (LSI)*		
Slope (S_1)	0–10%	S_1: 100–0
Distance to main channel of river downstream of the dam (S_2)	0–5 km	S_2: 100–0
Distance to existing irrigation (S_3)	0–10 km	S_3: 100–0

Note: [a]No groundwater data were available for Madagascar, and so this scoring criterion was dropped for that country.

Table 2. Input data for *ex-ante* suitability analysis.

Criteria	Data set
Topography (slope)	Shuttle Radar Topography Mission (SRTM) elevation data[a]
Groundwater accessibility	British Geological Survey (BGS) quantitative groundwater map for Africa[b]
Distance to perennial surface water	Global Lakes and Wetlands Database[c]; V-Map Perennial Streamlines data set[d]
Proximity to existing irrigation	Food and Agriculture Organization (FAO) Sirte irrigation map "Water for Agriculture and Energy in Africa"[e]
Market access	Nelson's global travel time[f]
Urban extent	Urban Extents Grid, the Global Rural–Urban Mapping Project, version 1 (GRUMPv1)[g]
Protected area	World Database on Protected Areas (WDPA)[h]

Sources: [a]See https://cgiarcsi.community/data/srtm-90m-digital-elevation-database-v4-1/.
[b]Seehttp://www.bgs.ac.uk/research/groundwater/international/africanGroundwater/maps.html/.
[c]Seehttps://www.worldwildlife.org/pages/global-lakes-and-wetlands-database/.
[d]National Imagery and Mapping Agency (1997).
[e]See http://www.fao.org/nr/water.
[f]See http://forobs.jrc.ec.europa.eu/products/gam/.
[g]See http://sedac.ciesin.columbia.edu/data/collection/grump-v1/.
[h]Seehttps://www.iucn.org/theme/protected-areas/our-work/world-database-protected-areas/.

and the LSI suitability score is calculated as:

$$LSI\,suitability\,score(0 \sim 100) = [S_1 + S_2 + S_3]/3 \tag{2}$$

where S_1–S_5 are the scores for each suitability criterion (Table 1). Existing irrigated areas, urban areas and protected areas (Table 2) were removed following the pre-suitability analysis before assessing potential irrigation expansion. Pixels that do not meet slope and travel time ranges were also excluded. Moreover, for LSI, additional topographical analysis was conducted to delineate potential irrigation command areas associated with each dam. Irrigation from these dams was assumed to occur by gravity with command areas up to 200 km downstream of the dam (with the exception of Fomi Dam, which is being planned for multiple purposes, including irrigation up to 600 km downstream); and with water elevation heads of reservoirs of 10–20 m. The suitability criteria in Table 1(b) were applied to the delineated command areas.

For more details on the data and scoring schemes used in this study, see Appendix III in the supplemental data online. The results of the pre-suitability analysis were aggregated into 5 arc-minute areas (approximately 10 × 10 km) by averaging to inform the second step of the simulation analysis.

Simulation of irrigation expansion pathways

The simulation in this step of the analysis involved examining the likelihood of irrigation adoption in each pixel on the 5 arc-minute grid. The Spatial Allocation Model (SPAM) (You, Wood, Wood-Sichra, & Wu, 2014) was used as the base map for simulating irrigation expansion. SPAM 2005 provides spatially disaggregated estimates of cultivated area and yields for 42 crops in 2005 over the world under rainfed and irrigated conditions.

A complete description of the simulation algorithm is provided in Appendix IV in the supplemental data online. The algorithm was applied to each country in Sub-Saharan Africa to determine the irrigation development potential in that country. The design of the simulation algorithm used the following assumptions:

- The adoption of irrigation occurs in a sequence according to the suitability ranking of the pixels in a country. Irrigation first expands to the pixel with the highest suitability score, followed by the pixel with the second highest score etc.
- We first simulated the development of LSI in proximity of planned and to be rehabilitated dams, followed by an assessment of SSI in the remaining areas.
- Given the adverse impacts on forest cover and biodiversity of expanding agricultural land in Sub-Saharan Africa, pixels with existing rainfed croplands were first converted to irrigation, and only when irrigation remains sufficiently profitable were areas not yet cultivated converted.
- Internal rates of return (IRR) were used as a criterion for irrigation investment decisions, that is, irrigation investments will only be made if the IRR of irrigated crop production in the pixel is greater than a predefined level. The IRR calculation is based on the irrigated crop mix of the 5 arc-minute pixel.

The adoption of irrigation can be accompanied by a change in crop mix. We considered this important issue as follows. Irrigation development leads to double cropping with key second-season crops being maize, rice, wheat and vegetables. We allow for a larger set of candidate irrigated crops for the rainy season, including groundnuts, maize, millet, potatoes, sorghum, sugarcane, sweet potatoes, rice, vegetables and wheat. Second, farmers tend to plant high-value crops under irrigation given the higher input costs of irrigated agriculture. We reflect this by assuming that in each season the cultivated area of each crop is proportional to its net profitability (see equations (A-1) and (A-2) in Appendix IV in the supplemental data online), subject to meeting food demand needs in the country (see also below).

The potential for irrigation expansion is also constrained by the availability of renewable water resources and projected demand for irrigated crops. Water availability was evaluated for each reservoir (in the LSI analysis) and at the river basin level (for SSI analysis). Irrigation expansion within the potential command area of a reservoir or in a basin stops when the irrigation water supply capacity of the reservoir is reached or renewable water resources of the basin allocated to irrigation are fully used. The food demand constraint was applied to each individual irrigated crop at the national level. A crop is removed from the list of candidate irrigated crops or remaining simulations when the projected domestic demand for that crop by 2050 is fully met through increased irrigated production.

Irrigation costs and sensitivity analysis

Three levels of irrigation costs (low, medium and high) were considered in the sensitivity analysis, with ranges of US$8000–30,000/ha for LSI and US$3000–6000/ha for SSI (Table 3) based on an expert panel review of irrigation investment costs. The capital cost figures in Table 3 refer to the capital investment cost per investment cycle, and the operation and maintenance (O&M) cost figures are annual. While we do not differentiate between the costs of individual technologies, sensitivity analysis allows one to describe a range of technology cost options that can then be linked to various individual technologies.

We also implemented sensitivity analysis for two alternative IRR, 5% and 12%, which are rates typically considered by multilaterals in irrigation investment decisions, resulting in a total of six sensitivity analyses or alternative irrigation development pathways. To facilitate the discussion, we refer to the scenario with medium irrigation costs and IRR > 5% as the baseline scenario in the discussion, unless otherwise noted.

Table 3. Cost assumptions under three cost scenarios (US$/ha).

	Low		Medium		High	
	Capital[a]	O&M[b]	Capital	O&M	Capital	O&M
LSI	8,000	800	12,000	1,200	30,000	3,000
SSI	3,000	100	4,500	125	6,000	150

Note: LSI, large-scale irrigation; O&M, operation and maintenance; SSI, small-scale irrigation.
[a]costs per investment cycle; [b]costs per annum.

Assessment of impacts of irrigation expansion on food security and agricultural trade

IMPACT incorporates country-specific 'rates of irrigation development' in its 'business-as-usual' (BAU) scenario of agricultural development for 115 countries and regions, including Sub-Saharan Africa. These rates have been determined based on historic trends and expert assessment of likely increases in investment in the future. The strategic planning analysis in this study finds a substantially higher biophysical and socioeconomic potential for irrigation development, particularly through irrigation that is developed by individual farmers themselves than IMPACT BAU suggests. Table 4 compares irrigation development under the IMPACT BAU scenario with the rates of the dryland baseline scenario (medium irrigation costs plus IRR > 5%). We incorporated the faster irrigation expansion rates in the drylands of Sub-Saharan Africa into IMPACT and computed a series of food security indicators to show to what extent accelerated irrigation development in the dryland zones can support food security in the region. The calculated food security indicators include the number of undernourished children, the population at risk of hunger and net trade of major irrigated crops.

Results

Estimated irrigation development potential

The estimated irrigation development potential in Sub-Saharan Africa under the baseline scenario (medium irrigation costs and IRR > 5%) is 18 million ha across all land classes of Sub-Saharan Africa. A map displaying the identified sites with irrigation development potential under this scenario is included in Figure 2. Most of the potential, 14.8 million ha or 84% of the total potential, is for SSI. The potential for LSI, which is largely determined by the number of dams slated for rehabilitation or for construction over the next few decades, is much smaller and estimated at 3.2 million ha. Note that other estimates for irrigation development potential in Sub-Saharan Africa or Africa are available from a few previous studies. Results from different studies may vary substantially due to differences in approaches and data used. While the estimated irrigation development potential in this study is larger than the trends from historical investment reflected in IMPACT BAU, it is at the lower end compared with those estimates established using only a water balance approach (e.g., Altchenko & Villholth, 2015).

Table 4. Irrigated area change rates (%/year), IMPACT 'business as usual' (BAU) scenario and African drylands baseline (medium irrigation costs plus internal rates of return (IRR) > 5%) scenario.

	IMPACT BAU	Dryland baseline
Sub-Saharan Africa	1.66	3.02
Central Africa	2.61	5.30
Eastern Africa	0.10	1.89
Southern Africa	2.82	3.17
Western Africa	2.16	3.86

Note: IMPACT, International Model for Policy Analysis of Agricultural Commodities and Trade.

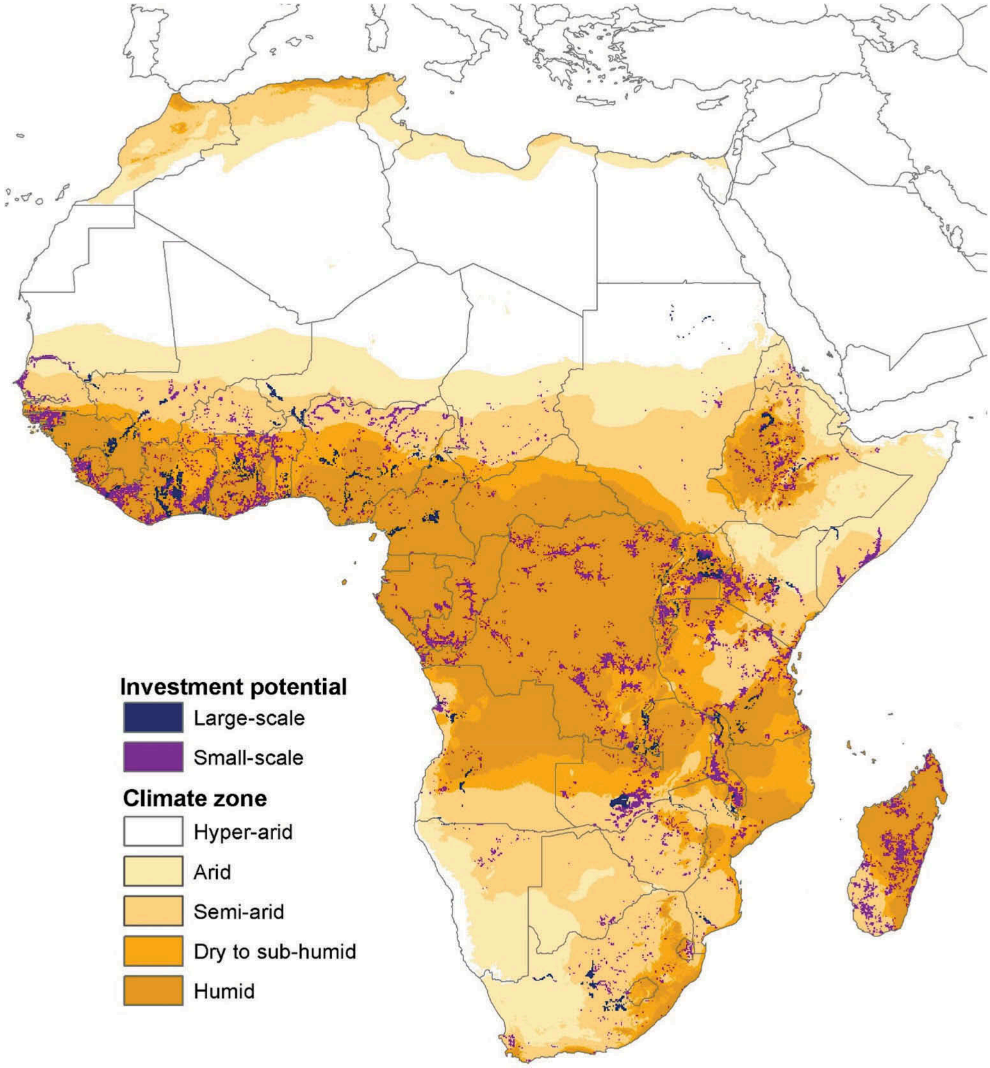

Figure 2. Estimated sites with irrigation development potential in Sub-Saharan Africa.

This is not surprising since we embraced a more integrated approach in our assessment considering cost–benefit analyses as well as the demand for irrigated crop production. The irrigation development potential reported here also serves as an update to the estimate reported by You et al. (2011), which was established in a similar conceptual methodology framework. More recently available input data and a new implementation approach were used in this study.

Table 5 summarizes the irrigation potential by land class. The combined LSI potential across the three dryland zones (arid, semi-arid and dry sub-humid) is 1.6 million ha, or about 50% of the total estimated LSI potential. The share of irrigation potential in dryland zones is larger for SSI: 9 million ha, or 60% of the total SSI potential in Sub-Saharan Africa.

Table 5. Estimated irrigation development potential in Sub-Saharan Africa by land class, medium irrigation cost and >5% internal rates of return (IRR) (ha, thousands).

Class	Large scale	Small scale
Hyper-arid	82	15
Arid	198	403
Semi-arid	686	5,303
Sub-humid	719	3,369
Humid	1,525	5,760
Total	3,210	14,850

Table 6. Distribution of estimated irrigation development potential in Sub-Saharan African drylands by sub-region, under medium irrigation cost and >5% internal rates of return (IRR) (ha, thousands).

Sub-region	Large scale	Small scale
East	326	2,358
Central	87	180
Southern	389	2,159
West	801	4,378
Total	1,603	9,075

Table 6 further summarizes the distribution of estimated area with irrigation potential in dryland zones by sub-region. A total of 10.7 million ha of new irrigation development is feasible, most of which (9 million ha) would be from SSI. Figure 3 ranks the irrigation development potential in dryland zones at country level. Among the four sub-regions in Sub-Saharan Africa, the largest potential for irrigation expansion in dryland zones is in West Africa, where approximately half the total potential is located. The LSI development potential in West Africa's dryland zone amounts to 0.8 million ha, and 4.4 million ha for SSI. The potential for irrigation expansion for East and Southern Africa is lower. The two regions contain 20% and 24% of the LSI development potential (0.3 and 0.4 million ha respectively), and 26% and 24% of the SSI potential (2.4 and 2.2 million ha respectively) in African drylands respectively. The estimated irrigation potential in drylands was lowest in Central Africa, at 0.1 million ha for LSI and 0.2 million ha for SSI, in part because this is the region with the lowest share of drylands in the region.

At the country level, Nigeria in West Africa is the country with the largest estimated potential for irrigation development (LSI plus SSI), accounting for almost half the total estimated irrigation potential in Sub-Saharan African drylands, at 2.5 million ha. Countries ranking second to fourth on the chart are Tanzania, Kenya and Malawi. They boast irrigation potential of more than 0.5 million ha. Other countries with significant irrigation development potential in drylands include Madagascar (0.49 million ha), Ghana (0.46 million ha), Senegal (0.39 million ha), Ethiopia (0.38 million ha), Zambia (0.37 million ha), Somalia (0.36 million ha) and Burkina Faso (0.33 million ha). An additional 12 countries have irrigation potential of between 0.1 and 0.3 million ha.

Both changes in capital cost and IRR affect values of final irrigated area potential. Figure 4(a,b) presents the estimated LSI and SSI potential in the drylands of Sub-Saharan Africa under all scenarios graphically. When the IRR cut-off value is held

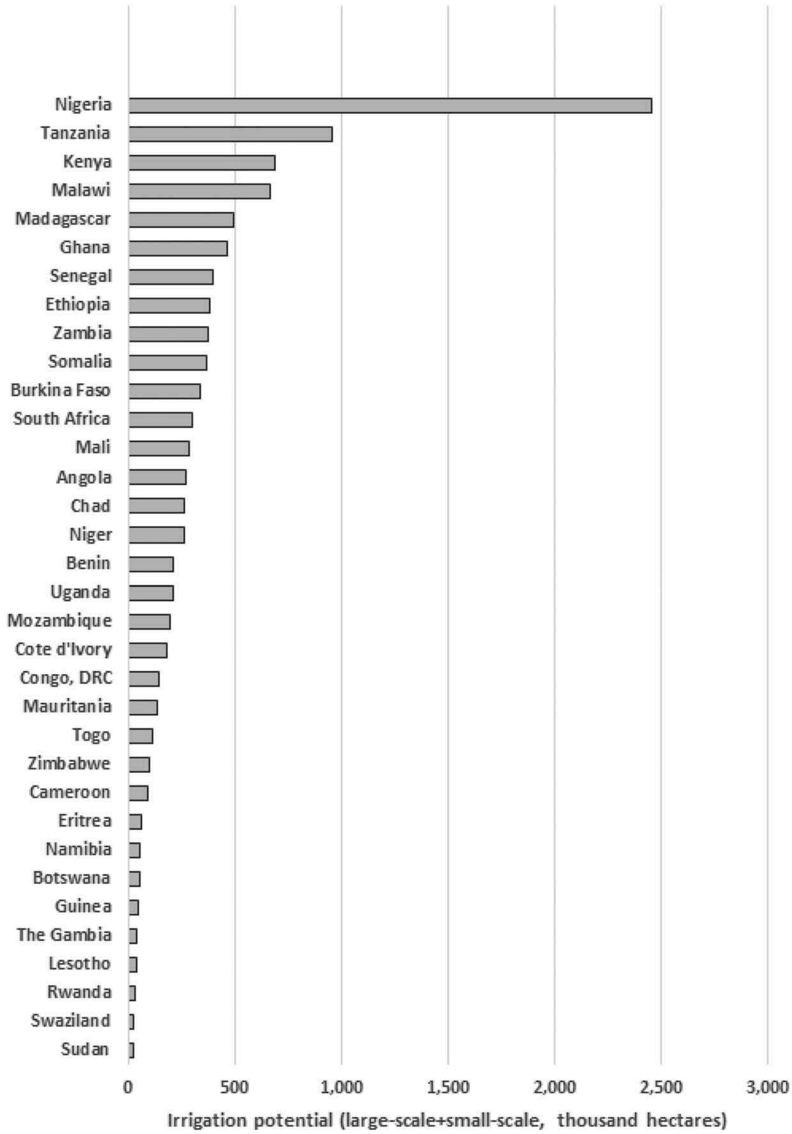

Figure 3. Estimated irrigation development potential in dryland zones by country under the baseline scenarios (medium irrigation costs and internal rates of return (IRR) > 5%) (no irrigation development potential on drylands was identified in Equatorial Guinea, Gabon, Liberia and Sierra Leone; countries with identified irrigation development potential in dryland zones but fewer than 20,000 ha are not shown: Burundi, 7000 ha; Djibouti, 4000 ha; Guinea-Bissau, 2000 ha; and Central African Republic, 2000 ha.

constant, an increase in irrigation costs leads to a reduction in estimated irrigation potential, and vice versa. For instance, with an IRR cut-off of 5%, the potential for LSI and SSI rise from 1.6 and 9.1 million ha to 2.5 and 11.6 million ha respectively, as irrigation costs drop from a medium to the low-cost level. By contrast, if irrigation costs increase, the potential area expansion in dryland areas declines to 1 million ha for LSI and 6.2 million ha for SSI. The potential for area expansion also declines if the IRR cut-

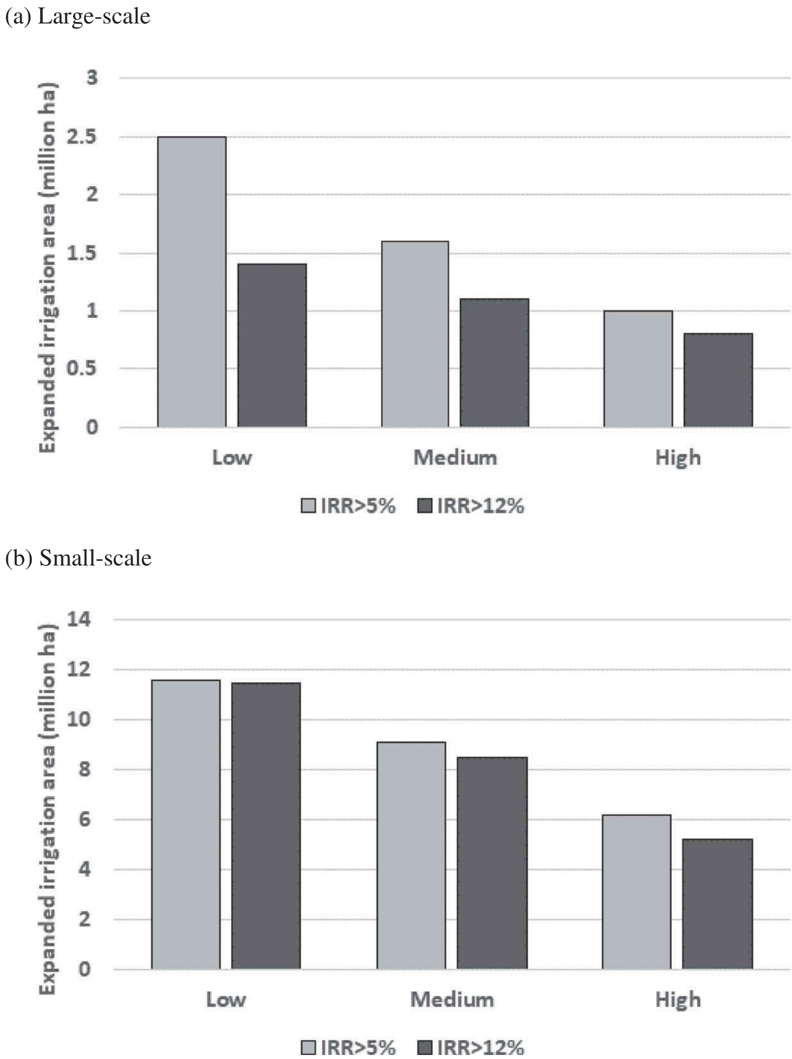

Figure 4. Potential irrigated area on Sub-Saharan Africa drylands under alternative internal rates of return (IRR) and cost assumptions (ha, millions), 2050 results.

off is raised. Under low irrigation cost assumptions, the irrigated area potential for LSI in African drylands declines from 2.5 to 1.4 million ha when the IRR cut-off increases from 5% to 12%, a decline of 43%. The decline is less severe under medium- and high-cost assumptions: under medium-cost assumptions, the area declines from 1.6 to 1.2 million ha when IRR increases from 5% to 12%, a 29% decline; and under high irrigation cost, the area declines from 1.01 to 0.85 million ha, a 16% decline. For SSI, on the other hand, which is generally more profitable, higher IRR are impacting area potential most under the high-cost scenario. At high cost, the potential for SSI in African drylands drops from 6.2 to 5.2 million ha, a 17% decline. Under the combined impacts of irrigation costs and IRR, the largest estimated irrigation development potential on drylands was obtained under the low-cost, low-IRR scenario, which consists of 2.5 million ha for LSI and 11.6 million ha for SSI; and the lowest estimate for irrigation potential was reported under the high-cost, high-IRR scenario, which includes 0.8 million ha for LSI and 5.2 million ha for SSI.

Food security indicators

Tables 7 and 8 and Appendix V in the supplemental data online present the impact of expanded irrigation investment under different IRR and irrigation cost levels on a series of food security indicators. These indicators were estimated using the IMPACT model at country level and aggregated to sub-continental regions in Sub-Saharan Africa.

The impacts of expanded irrigation development on the number of people at risk of hunger are presented in Table 7. The IMPACT BAU scenario suggests that, by 2050, 272 million people will be at risk of hunger in Sub-Saharan Africa. More than one-third of this population is based in Central Africa (92 million people), followed by Eastern Africa (67 million), West Africa (57 million) and Southern Africa (approximately 56 million). Accelerated irrigation development reduces these numbers by up to 14–15 million people under the low-cost scenarios (12% and 5% IRR respectively) and by 6–11 million people under the medium-cost scenarios.

Projected impacts of irrigation expansion are largest in Western Africa both in terms of percentage and number of people – a 9.5%, or 5.4 million, decline in the number of people at risk of hunger under the 5% low-cost scenario. For Southern Africa, the respective figures are 7.5% and 4.2 million; they are 4.9% and 3.3 million for Eastern Africa; and 2.1% and 1.9 million for Central Africa.

We also find that child under-nutrition in Sub-Saharan Africa can be decreased by 0.58–1.71% (0.2–0.7 million children) due to accelerated irrigation development in African drylands on top of baseline irrigation development – with the largest reduction in Southern Africa at 2.4%. Unsurprisingly, the scenario combining a 5% IRR and low irrigation costs (5% low) results in the largest impact, a 1.71% decline, followed by an IRR of 12% combined with low irrigation costs (12% low). The 12% IRR and high-cost scenario (12% high) results in the lowest decline of under-nourished children at 0.58% (for details, see Table A5-1 in the supplemental data online).

For all irrigation area-expansion scenarios in African drylands, net cereal (i.e., wheat, maize and rice) imports to the region decline, with decreases reaching as much as 68%, or 90 million tons (Table 8) from a baseline net import level of 133 million metric tons in 2050. The decline is largest for the 5% IRR low-cost scenario, followed by the 12% IRR low-cost scenario at 62% (82 million tons). At the sub-regional level, both the percentage and absolute decline in net imports is largest in Eastern Africa for the 5% IRR low-cost scenario, at 93% and 32 million tons. As such, accelerated investment in irrigation for both LSI and SSI in African drylands could reduce projected net cereal imports by more than two-thirds.

The cereal import dependency ratio is an important food security indicator. Combined with production data generated in IMPACT modelling, we calculate the cereal import dependency ratio under BAU and the scenarios with various accelerated irrigation investment rates. We find that accelerated irrigation investment could reduce the region's cereal import dependency ratio from 54% under the BAU

Table 7. Impact of expanded irrigation investment on food security–population at risk of hunger, 2050.

	Africa south of the Sahara		Eastern Africa		Central Africa		Southern Africa		Western Africa	
	Population at risk of hunger	Change from baseline	Population at risk of hunger	Change from baseline	Population at risk of hunger	Change from baseline	Population at risk of hunger	Change from baseline	Number of Undernourished Children	Change from baseline
Irrigation investment scenarios	Millions	%	Millions	%	Millions	%	Millions	%	Millions	%
Baseline	271.82	–	67.03	–	92.01	–	55.77	–	57.01	–
5% IRR and low cost	257.03	−5.44	63.73	−4.93	90.13	−2.05	51.60	−7.48	51.58	−9.53
5% IRR and medium cost	261.05	−3.96	65.26	−2.64	90.76	−1.36	52.85	−5.25	52.19	−8.45
5% IRR and high cost	267.19	−1.70	66.16	−1.29	91.18	−0.90	53.73	−3.66	56.12	−1.56
12% IRR and low cost	258.20	−5.01	64.20	−4.22	90.32	−1.83	51.89	−6.96	51.79	−9.15
12% IRR and medium cost	265.50	−2.33	65.67	−2.02	90.92	−1.18	53.18	−4.65	55.72	−2.26
12% IRR and high cost	268.25	−1.31	66.46	−0.85	91.34	−0.73	54.10	−3.01	56.35	−1.15

Note: IRR, internal rates of return.

Table 8. Impact of expanded irrigation investment on net trade, by commodity group, 2050(mt, thousands)[a]

Irrigation investment scenarios	Africa south of the Sahara Net trade	Africa south of the Sahara Change from baseline	Eastern Africa Net trade	Eastern Africa Change from baseline	Central Africa Net trade	Central Africa Change from baseline	Southern Africa Net trade	Southern Africa Change from baseline	Western Africa Net trade	Western Africa Change from baseline
(a) *Cereals (rice, maize, wheat)*										
Baseline	−132,614	–	−34,956	–	−9,019	–	−34,163	–	−54,475	–
5% IRR and low cost	−42,677	89,937	−2,583	32,373	−1,683	7,336	−6,309	27,854	−32,102	22,373
5% IRR and medium cost	−75,549	57,065	−13,132	21,825	−4,327	4,693	−23,103	11,060	−34,987	19,488
5% IRR and high cost	−92,207	40,407	−19,964	14,993	−5,439	3,580	−26,204	7,960	−40,600	13,874
12% IRR and low cost	−50,290	82,324	−5,837	29,119	−2,994	6,025	−8,332	25,832	−33,127	21,348
12% IRR and medium cost	−82,496	50,118	−15,855	19,101	−4,542	4,478	−25,205	8,958	−36,893	17,581
12% IRR and high cost	−99,710	32,904	−21,837	13,119	−5,657	3,363	−28,774	5,389	−43,442	11,033
(b) *Other grains (millet and sorghum)*										
Baseline	−1,714	–	3,945	–	1,605	–	−1,518	–	−5,747	–
5% IRR and low cost	1,182	2,896	3,454	−491	2,075	469	112	1,630	−4,459	1,288
5% IRR and medium cost	−723	991	1,781	−2,164	1,971	366	−444	1,074	−4,031	1,715
5% IRR and high cost	−2,128	−414	1,072	−2,873	1,813	207	−913	605	−4,100	1,647
12% IRR and low cost	498	2,212	2,782	−1,163	2,035	429	12	1,530	−4,330	1,416
12% IRR and medium cost	−1,384	330	1,375	−2,570	1,978	372	−807	710	−3,930	1,816
12% IRR and high cost	−2,516	−802	853	−3,092	1,810	205	−1,024	494	−4,156	1,591
(c) *Groundnuts*										
Baseline	−2,203	–	−990	–	−28	–	−195	–	−990	–
5% IRR and low cost	−574	1,629	−861	129	499	526	47	242	−258	732
5% IRR and medium cost	−1,082	1,121	−919	70	231	259	71	266	−465	526
5% IRR and high cost	−1,519	684	−956	34	56	83	40	235	−659	331
12% IRR and low cost	−810	1,393	−896	94	337	365	75	270	−327	664
12% IRR and medium cost	−1,185	1,018	−929	61	215	243	53	248	−524	466
12% IRR and high cost	−1,682	521	−991	−1	53	80	8	204	−752	238
(d) *Vegetables*										
Baseline	−35,702	–	−10,827	–	−9,129	–	−2,015	–	−13,731	–
5 % IRR and low cost	3,324	39,026	−6,696	4,131	−7,129	2,000	121	2,136	17,027	30,759
5% IRR and medium cost	3,339	39,040	−6,733	4,094	−7,166	1,963	181	2,197	17,055	30,787
5% IRR and high cost	1,612	37,314	−6,966	3,861	−7,157	1,972	94	2,109	15,641	29,373
12% IRR and low cost	2,990	38,692	−6,831	3,995	−7,137	1,992	135	2,150	16,823	30,555
12% IRR and medium cost	2,644	38,346	−6,938	3,888	−7,152	1,977	104	2,119	16,630	30,362
12% IRR and high cost	−142	35,560	−7,888	2,938	−7,240	1,889	−36	1,979	15,022	28,754

(*Continued*)

Table 8. (Continued).

Irrigation investment scenarios	Africa south of the Sahara: Net trade	Africa south of the Sahara: Change from baseline	Eastern Africa: Net trade	Eastern Africa: Change from baseline	Central Africa: Net trade	Central Africa: Change from baseline	Southern Africa: Net trade	Southern Africa: Change from baseline	Western Africa: Net trade	Western Africa: Change from baseline
(e) Root crops (potato and sweet potato)										
Baseline	−16,799	–	−13,925	–	−1,298	–	−9,444	–	7,867	–
5% IRR and low cost	35,226	52,025	874	14,799	−560	738	3,342	12,786	31,569	23,702
5% IRR and medium cost	29,037	45,836	528	14,453	−742	556	3,059	12,503	26,191	18,324
5% IRR and high cost	18,799	35,598	15	13,940	−392	905	2,056	11,499	17,121	9,254
12% IRR and low cost	33,188	49,988	526	14,451	−740	557	3,163	12,607	30,240	22,373
12% IRR and medium cost	25,857	42,657	179	14,103	−566	732	2,428	11,872	23,816	15,949
12% IRR and high cost	14,508	31,307	−176	13,748	−189	1,109	1,347	10,790	13,526	5,659
(f) *Sugar*										
Baseline	−8,908	–	−3,171	–	−695	–	2,401	–	−7,443	–
5% IRR and low cost	9,980	18,888	6,421	9,592	406	1,101	3,564	1,163	−411	7,032
5% IRR and medium cost	8,639	17,547	5,621	8,791	392	1,087	3,592	1,191	−965	6,478
5% IRR and high cost	2,524	11,432	1,665	4,836	317	1,012	3,806	1,405	−3,264	4,179
12% IRR and low cost	9,983	18,891	6,598	9,769	361	1,055	3,561	1,160	−537	6,906
12% IRR and medium cost	6,530	15,437	3,723	6,894	301	996	3,653	1,252	−1,147	6,296
12% IRR and high cost	682	9,590	1,091	4,262	340	1,035	3,651	1,250	−4,400	3,043

[a]Negative values for net trade relate to net imports, and positive values to net exports. A positive change means that 'net importers' are importing less, and 'net exporters' are exporting more. Negative changes represent 'net importers' importing more or 'net exporters' exporting less.

Note: IRR, internal rates of return.

scenario – which itself is a dramatic increase compared with today's dependency ratio – to 31% under the 5% IRR medium-cost scenario, 33% under the 12% IRR medium-cost scenario, 37% under the 5% IRR high-cost scenario, 40% under the 12% IRR high-cost scenario, 17% under the 5% IRR low-cost scenario, and to 20% under the 12% IRR low-cost scenario..

For other grains (millet and sorghum), which are generally not irrigated, the results are mixed – with reversals from net imports to net exports, increases in net imports and declines in net imports, depending on the irrigation scenario and sub-region. For the low-cost scenarios (5% low and 12% low), there are reversals from a small net import to a small net export situation. The highest gains of 2.9 and 2.2 million tons are projected under the two low-cost irrigation expansion scenarios.

For vegetables, the 2050 baseline suggests net imports of 36 million tons. With expanded irrigation development this situation reverses to net exports of as much as 3 million tons for the low IRR and low and medium irrigation-cost scenarios. Vegetables are generally higher value and thus less affected by higher costs or higher IRR. Even under the 12% high scenario, the trade position changes in absolute terms by 36 million tons, although the region remains a small net importer of 0.14 million tons of vegetables. Sub-regionally, Eastern and Central Africa remain net importers, but with large declines in imports – by as much as 38% and 23% respectively. Both Western and Southern Africa become net exporters – with Western Africa exporting up to 17 million tons of vegetables. This strong national production of vegetables under irrigation development likely also provides important nutritional benefits.

Finally, for sugar, Sub-Saharan Africa switches from a net import position in 2050 to a net export position under all accelerated irrigation expansion scenarios – with the highest net export levels – of 10 million tons – under the low-cost scenarios (both 5% and 12% IRR). This is achieved mostly through Eastern Africa's shift from a net-import position (of 3.2 million tons) to a net-export position (of 6.4 and 6.6 million tons), and through a reduction in net imports by Western Africa by as much as 7 million tons.

Discussion and conclusions

This paper assesses the potential role of irrigation investment in the dryland zone of Sub-Saharan Africa in improving food security and self-sufficiency of the region. In a strategic planning analysis, based on a series of assumptions, including environmental criteria for locating potential of LSI and SSI in African drylands, we find large areas for both sustainable and profitable SSI expansion, ranging from 5 to 12 million ha by 2050, with the final values depending on irrigation capital costs (low, medium or high) and acceptable levels of IRR (5% or 12% respectively). We also find substantial potential for increase in LSI of 0.8–2.5 million ha by 2050, all associated with a series of planned reservoirs and several dam rehabilitation projects.

Across dryland regions, the potential for irrigation expansion in this study is largest in West Africa, with approximately 5.2 million ha by 2050 (under the medium-cost, 5% IRR scenario, combining LSI plus SSI), accounting for 49% of all irrigation potential in dryland areas in Sub-Saharan Africa; this is followed by East Africa with 2.7 million ha, or 25% of the total potential, and Central Africa with 2.5 million ha, or 24% of the total potential. The potential for expansion of irrigated area is highly sensitive to capital costs of irrigation infrastructure. When costs of irrigation increase, net profitability of irrigation declines and the potential for irrigating staple crops is reduced, or not feasible/profitable. LSI and SSI area potential declines by more than half between low-cost, low-IRR and high-cost, high-IRR scenarios.

Through a further simulation analysis using the IMPACT model, we evaluated the consequences of accelerated irrigation investment by 2050 in the dryland areas of Sub-Saharan Africa in terms of food security. We conclude that there are important food security implications for the region from irrigation expansion. The most significant impact are changes in food import dependency. Accelerated irrigation expansion following the scheme directly affects the region's net trade position, resulting in a reduction of net cereal imports by as much as 90 million tons, a reduction of net vegetable imports by up to 39 million tons and a switch to a net export position for sugar. Accelerated irrigation investment reduces food import dependency for cereals from a staggering 54% under the baseline to 31% under the medium-cost and > 5% IRR scenario and a much lower 17% under the low-cost and > 5% scenario. Additionally, we found that the population at risk of hunger can and be reduced by 6–15 million people depending on the IRR and cost scenario and child under-nutrition in Sub-Saharan Africa can be decreased by 0.58–1.71% (0.2–0.7 million children).

In addition to those uncertainties and limitations that have been discussed, the study is also subject to additional limitations which merit mentioning below. First, we only reported assessment results under the IMPACT BAU scenario which does not consider climate change. Climate change influences values of various input variables of the planning analysis such as renewable water resources, irrigation water demand and therefore impacts the estimated irrigation development potential. Second, in the strategic planning analysis, we also used fixed crop prices and constant projections on future demands for irrigated crops, rather than deriving prices and demands through iteration with the global agricultural trade model. Finally, irrigation investment decisions are also influenced by local institutions and political favouritism. Extending the assessment to address these limitations is a topic of future research.

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