AGWATER SOLUTIONS

Improved livelihoods for smallholder farmers

REGIONAL ANALYSIS OF INLAND VALLEY IRRIGATION

Potential for expansion in Sub-Saharan Africa

JULY 2012

Introduction

Sub-Saharan Africa (SSA) faces great challenges in development, including the highest poverty rate in the world, food insecurity, and malnutrition. Given that agriculture is the single most important source of rural livelihood in Africa, an agricultural growth strategy will go a long way to reducing hunger and poverty on the subcontinent. Among the numerous challenges to enhancing agricultural production in SSA is the large spatial and temporal variability and availability of water resources. Currently, agriculture in SSA is predominantly rainfed. The limited access to water in arid areas or during dry seasons and drought spells often presents restrictions to farming and to improving agricultural productivity. Therefore, agricultural water management has been regarded as a promising solution to boost levels of agricultural productivity in SSA.

Inland valley irrigation is a traditional agricultural water management method that could potentially be improved and expanded throughout the region. This irrigation scheme utilizes the favorable conditions of water availability at the inland valley bottom, and is primarily used for cultivation of rice and, sometimes, vegetables. Both irrigation and drainage infrastructure are equally important for the successful development of inland valley irrigation.

Methodology

This brief is based on a study that uses an integrated modeling system that combines geographic (GIS) data analysis, biophysical and economic predictive modeling, and crop mix optimization tools to assess the regional potential for smallholder agricultural water management in SSA and South Asia (SA). It focuses on the potential for the expansion of inland valley irrigation throughout SSA.

The assessment process includes two components: ex-ante GIS and predictive modeling analyses. The ex-ante analysis uses a set of suitability criteria to identify areas where the technology could potentially be applied, pixel by pixel, across the region. The formulation of assessment criteria and the scoring scheme were developed through expert consultations and validation and reflect the best available expert knowledge. For inland valley irrigation, the environmental suitability criteria for ex-ante GIS analysis are shown in Table 1.

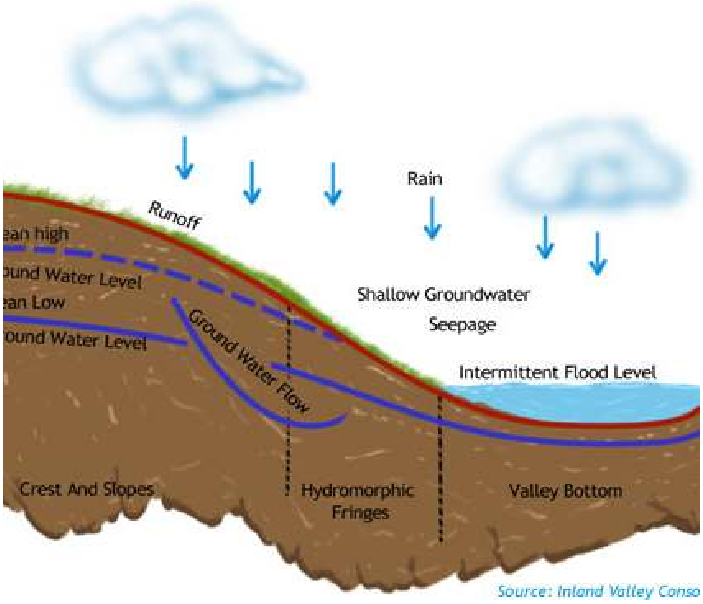

Diagram to illustrate the structure of an inland valley.

A pixel with a score greater than 57 is considered to have irrigation potential. The application areas derived from the suitability analysis were also compared with the labor-constrained application areas obtained from rural population analysis at the basin level; the minimum of the two application areas in a river basin was selected as the final ex-ante estimates for the areas with irrigation potential in the river basin.

The results derived from ex-ante GIS analysis are further refined in an analysis that involves the application of two biophysical and economic predictive modeling tools: the Soil and Water Assessment Tool (SWAT) and the model of Dynamic Research Evaluation for Management (DREAM). Currently, agriculture in SSA is predominantly rainfed and farming activities concentrate in the rainy seasons.

This analysis assumes that inland valley irrigation would enable producers to extend crop production into the dry season, when the irrigation demand is highest. Under this assumption, the SWAT and DREAM models were run to simulate the hydrology, estimate crop water demand and agricultural productivity in the added dry growing season, and forecast price shifts in agricultural commodities as a result of increased supply.

Table 1. Ex-ante GIS analysis criteria for inland valley irrigation

Criteria for inland valley irrigation	Scoring scheme
Topography	Jenness TPI Landform Classification, Valley = 34, Other = Excluded
Runoff	2 - 25 mm/m = 0, 25 - 45 mm/m = 8, 45 - 75 mm/m = 17, 75 - 110 mm/m = 25, > 110 mm/m = 33
Distance to surface water	< 1km = 33, >1km = Excluded

Note: mm/m=millimeters per month.

The results produced from the SWAT–DREAM predictive analysis allow for quantitative water balance and cost–benefit analysis of irrigation activities. This further constrains the potential for irrigation expansion compared to the ex-ante analysis, based on physical scarcity and economic viability.

Other key assumptions in the predictive modeling assessment include the following:

- *Water Availability*. In the assessment, it is assumed that small reservoirs start to operate two months prior to the irrigation (dry) season and can only collect a fraction of annual runoff. Moreover, 20 percent of runoff is reserved for environmental flows.

- *Cultivation of Particular Crops*. The assessment assumes that inland valley irrigation is used for the cultivation of a series of crops based on evidence from field studies including: rice, tomatoes, onions, peppers, cabbages, and beans.

- *Fertilizer Input*. Agricultural production in SSA is characterized by the wide presence of low-input farming systems. However, because there exists strong synergy between water and nutrient management—that is, farmers need to provide an appropriate amount of nutrients to the soil, especially nitrogen, to ensure irrigation is effective in improving crop yields—medium rates of nitrogen fertilizer applications were assumed in the crop simulation. The assumed amount of nitrogen fertilizer applied to each crop type is shown in Table 2. The estimated yields of selected crops cultivated under irrigation and assumed nitrogen fertilizer applications (as opposed to the estimated yields in low-input farming systems in SSA) are shown in Table 3.

- *Production and Irrigation Costs*. Assumed costs of production for the selected crops are shown in Table 2. A cost for irrigation of US$753 per hectare per year was also assumed, with average amortized capital investment costs of $503/ha-yr, maintenance costs of $50/ha-yr, labor and operating costs of $200/ha-yr, and a reinvestment timeframe of 30 years. The cost–benefit results are very sensitive to these cost assumptions. A sensitivity analysis in which irrigation costs were increased or decreased by 50 percent was, therefore, conducted.

It is expected that irrigation will boost agricultural productivity and increase the supply of agricultural commodities, while also lowering their prices. To account for the effect of price changes on the economic profitability of irrigation development, the DREAM model is used to forecast price shifts. Baseline data for the model were obtained from FAOSTAT Food Balance sheets, FAO PriceSTAT, and the IFPRI IMPACT model.

Table 2. Nitrogen fertilizer application rates and nonirrigation production costs assumed in the crop simulation and crop mix optimization

Crops	N fertilizer (KG/ha)	Costs (US$/ha-yr)
Rice (paddy)	80	1,000
Onions	100	3,500
Cabbage	100	4,000
Tomatoes	100	3,500
Peppers	100	3,000
Beans	0	1,000

Source: IFPRI Team based on project inputs and secondary sources

It was found that the estimated irrigation potential is also sensitive to changes in initial crop prices. A 30 percent increase and a 30 percent decrease in initial crop prices were implemented as additional sensitivity analyses.

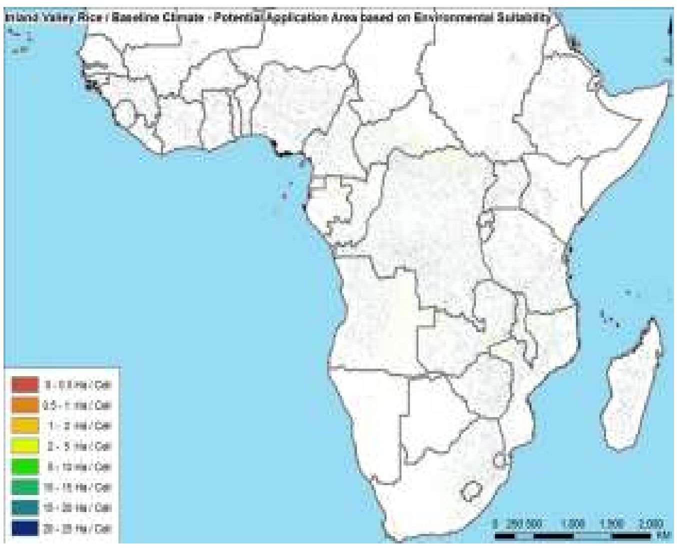

Figure 1: Suitable area for expansion of inland valley irrigation, ex-ante results
Source: IFPRI Team

Table 3. Yield improvement of estimated high-input (HI) yields of selected crops cultivated under irrigation and assumed nitrogen fertilizer applications compared to low-input (LI) rainfed yields

Country	Green bean		Paddy rice	
	LI	HI	LI	HI
	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)
Central Africa				
Angola	0.2	385	-	-
Cameroon	0.5	-62	1.0	327
Central African Republic	-	-	1.2	218
Republic of Congo	0.5	-55	0.7	348
Democratic Republic of Congo	0.4	59	0.7	441
Equatorial Guinea	-	-	-	-
Gabon	-	-	1.0	223
Eastern and Indian Ocean countries				
Burundi	0.4	102	-	-
Ethiopia	0.6	40	-	-
Kenya	0.5	88	-	-
Madagascar	0.5	63	1.0	496
Rwanda	0.4	138	1.3	277
Tanzania	0.5	66	1.8	184
Uganda	0.5	15	1.4	263
Gulf of Guinea				
Benin	0.4	-81	1.3	200
Côte d'Ivoire	-	-	1.6	159
Ghana	-	-	1.5	163
Guinea	-	-	1.3	220
Guinea-Bissau	-	-	1.2	177
Liberia	-	-	1.2	243
Nigeria	-	-	1.4	191
Sierra Leone	-	-	1.1	282
Togo	0.3	-72	1.1	240
Southern Africa				
Botswana	0.01	1,466	-	-
Lesotho	0.4	291	-	-
Malawi	0.3	148	1.2	309
Mozambique	0.2	98	0.3	1,384
Namibia	0.2	329	-	-
South Africa	1.4	-23	-	-
Swaziland	0.2	405	3.4	61

Country	Green beans		Paddy rice	
	LI	HI	LI	HI
	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)
Zambia	-	-	0.9	448
Zimbabwe	0.4	49	2.2	129
Sudano-Sahelian region				
Burkina Faso	-	-	1.4	179
Chad	0.3	-68	0.8	326
Eritrea	0.3	20	-	-
Gambia	-	-	1.4	126
Mali	-	-	0.8	396
Mauritania	0.9	-94	-	-
Niger	0.4	-42	1.8	147
Senegal	-	-	0.7	394
Somalia	0.3	-77	-	-
Sudan	1.9	-86	1.6	124

Source: IFPRI Team
Note: LI rainfed yields are derived from the Spatial Production Allocation Model (SPAM).

Table 4. Ex-ante potential for the expansion of inland valley irrigation in SSA, assuming 100 percent

Country Name	Potential application area (1000 ha)	Rural population reached (thousand people)
Central	11,410	64,351
Eastern and Indian Ocean Countries	7,154	40,130
Gulf of Guinea	6,463	36,006
Southern Africa	7,007	35,020
Sudano-Sahelian	2,275	15,763
All SSA	34,308	191,269

Source: IFPRI team

Table 5. Predictive modeling results for the potential expansion of inland valley irrigation, baseline scenario results

Country	Application area (thousand ha)	Net revenue (US$ billion/yr)	Rural population reached (thousand people)	Water consumption (billion m³/yr)	Water consumption Increase %
Angola	763	0.41	4,321	4.35	553.3
Cameroon	67	0.02	373	0.16	17.2
Central African Republic	272	0.05	1,332	0.84	716.2
Congo	0.1	0.0003	0.3	0.0001	0.02
Congo, DRC	1,300	0.43	7,510	4.82	1,385.6
Equatorial Guinea	6	0.001	53	0.01	6.8
Gabon	26	0.01	137	0.04	67.8
Central Africa	**2,434**	**0.92**	**13,727**	**10.21**	**363.1**
Burundi	58	0.07	329	0.22	60.6
Ethiopia	827	1.32	4,777	3.36	188.9
Kenya	329	0.42	1,680	0.87	52.0
Madagascar	56	0.002	297	0.19	6.0
Rwanda	71	0.10	356	0.20	157.9
Tanzania	717	0.62	4,144	2.92	166.1
Uganda	463	0.26	2,622	0.90	134.8
Eastern and Indian Ocean Countries	**2,520**	**2.78**	**14,205**	**8.67**	**91.7**
Benin	23	0.01	136	0.08	36.3
Côte d'Ivoire	352	0.05	2,230	1.03	193.4
Ghana	680	0.35	3,023	2.06	724.0
Guinea	132	0.04	877	0.39	86.6
Guinea-Bissau	27	0.03	190	0.10	124.1
Liberia	175	0.05	1,106	0.40	1,838.0
Nigeria	227	0.10	1,163	0.91	7.1
Sierra Leone	187	0.04	1,244	0.66	72.2
Togo	23	0.01	143	0.06	57.1
Gulf of Guinea	**1,826**	**0.68**	**10,111**	**5.70**	**36.7**
Botswana	3	0.002	12	0.01	9.2
Lesotho	14	0.02	64	0.04	96.4
Malawi	470	1.39	2,456	2.21	373.8
Mozambique	123	0.23	614	0.53	53.9
Namibia	1	0.0001	3	0.003	2.0
South Africa	518	0.58	2,304	1.48	24.4
Swaziland	16	0.01	94	0.05	7.7
Zambia	1,245	0.52	6,638	7.18	643.3

Table 5. Predictive modeling results for the potential expansion of inland valley irrigation, baseline scenario results (cont'd)

Country	Application area (thousand ha)	Net revenue (US$ billion/yr)	Rural population reached (thousand people)	Water consumption (billion m³/yr)	Water consumption Increase %
Zimbabwe	96	0.05	491	0.54	36.4
Southern Africa	**2,485**	**2.81**	**12,676**	**12.05**	**106.7**
Burkina Faso	223	0.05	1,662	0.78	63.9
Chad	17	0.001	103	0.07	9.5
Eritrea	0.3	0.001	2	0.002	2.3
Mali	1	0.0001	4	0.002	0.03
Mauritania	0.3	0.00001	2	0.001	0.1
Niger	7	0.003	45	0.02	1.0
Senegal	5	0.004	55	0.02	1.3
Somalia	1	0.001	7	0.004	0.1
Sudan	125	0.23	859	0.42	3.0
The Gambia	0.01	0.00003	0.2	0.00001	0.02
Sudano-Sahelian region	**379**	**0.28**	**2,739**	**1.32**	**4.5**
All SSA	**9,644**	**7.47**	**53,457**	**37.95**	**55.7**

Source: IFPRI Team

Inland valleys offer water availability and could potentially be improved and expanded throughout the region.

Potential for expansion of inland valley irrigation in SSA

The ex-ante assessment shows that inland valley irrigation could be expanded to 34 million ha, potentially reaching a rural population of 191 million (Table 4). The potential for expansion of inland valley irrigation is highest in the Central region, with potential expansion of over 11 million ha reaching 64 million people.

The Eastern, Gulf of Guinea, and Southern regions also show considerable potential for expansion of the technology, with 7, 6, and 7 million ha potential application areas in these regions, respectively.

Taking river basin hydrology, environmental constraints, yield improvements, costs of the investment, and price impacts of expanding crop production into account results in considerably lower potential for adoption of inland valley irrigation in the region compared to the ex-ante assessment (Figure 2).

The results of the SWAT–DREAM assessment for inland valley irrigations are summarized in Table 5 (next page) for the baseline scenario. The results indicate a potential area expansion of 10 million ha, reaching 53 million people, with the greatest potential found in the Central, Eastern, and Southern regions. This represents less than one third of the area potential shown in the ex-ante analysis, suggesting that there are considerable environmental and economic constraints to the expansion of inland valley irrigation schemes throughout the region.

Total net revenues as a result of the expansion of inland valley irrigation throughout the region would be $7 billion per year, with revenues highest in the Eastern and Southern regions. The total increase in water consumption as a result of the expansion of inland irrigation in SSA is estimated at 38 billion m^3/yr, an overall increase of 56 percent, with the largest increases found in the Central and Southern regions.

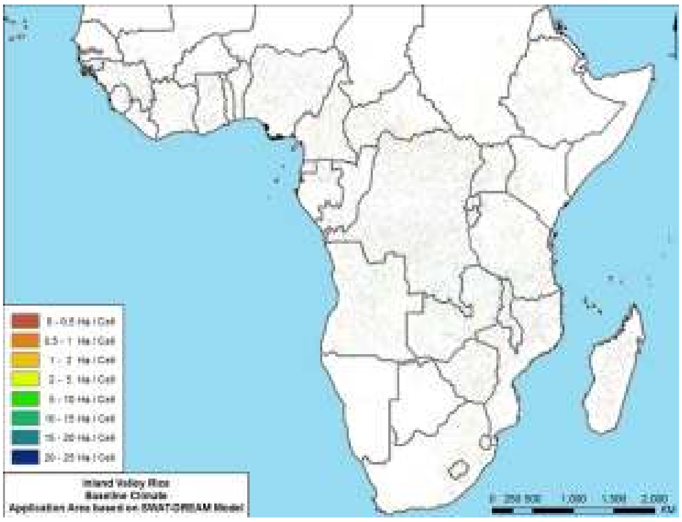

Figure 2: Suitable Area for expansion of inland valley irrigation, SWAT-DREAM results
Source: IFPRI Team.

The results of the sensitivity analysis (Table 6) show that the estimated application areas, net revenues, and rural population reached increase with decreasing irrigation costs and higher food prices, and vice versa. With a 50 percent reduction in the cost of irrigation, the application area would increase by 3 million ha, net revenues would increase by $4 billion per year, and rural population reached would increase by 19 million. Conversely, the application area decreases by 4 million ha, net revenues decline by $3 billion, and the number of people reached decreases by 21 million when irrigation costs increase by 50 percent.

Under the different crop price scenarios, a 30 percent increase in initial crop price results in an additional potential application area of 4 million ha, an increase in net revenues of $8 billion, and an additional 22 million people reached; while a decrease in the initial crop price results in a lower application area (by 7 million ha), a reduction in net revenues (by $5 billion), and fewer people reached (by 37 million), compared to the baseline.

Table 6. Predictive modeling results for the potential expansion of inland valley irrigation, scenario results

	Baseline	-50% irrigation cost	+ 50% irrigation costs	-30% initial crop price	+ 30% initial crop price
Area (thousand ha.)	9,644	13,082	6,070	3,097	13,680
Rural population reached (thousand people)	53,457	72,610	32,921	16,763	75,868
Net revenue (US$ billion)	7.47	11.59	4.67	2.05	15.86
Water consumption (billion m^3/yr)	37.95	49.54	24.87	12.74	51.48
Irrigation water consumption increase (%)	55.68	72.69	36.49	18.69	75.53

Source: IFPRI Team

Note: Results shown are for all of SSA

In terms of water use, water consumption increases significantly under the various inland valley expansion scenarios. A 50 percent decrease in irrigation costs or a 30 percent increase in initial crop price would increase water use by an additional 12 billion or 13 billion m^3/yr, respectively, compared to the baseline.

The impact of climate change on the application potential of inland valley irrigation across SSA was also estimated under two climate scenarios projected by the CSIRO-Mk3.0 model (Csia) and the CNRM-CM3 model (Cnra) (Table 7). In a preliminary analysis, the two scenarios were identified as the "driest" and "wettest" scenarios, respectively, among 12 future climate change scenarios projected by general circulation models for SSA. Both scenarios use the SRES A2 emissions scenario, which is considered moderate.

The results in Table 7 show that changes in the estimated application area due to the climate change range from -15 percent to -4 percent. This result shows that even the wettest climate change scenario for SSA has negative implications for the expansion potential of inland valley irrigation.

Conclusions

The ex-ante analysis reveals large expansion potential for inland valley irrigation in SSA in terms of application area and rural population reached. However, when additional constraints are introduced, the potential is significantly reduced. The two main constraints to the expansion of inland valley irrigation revealed in this study are the limited availability of runoff and large development costs. Climate change also threatens the potential expansion of inland valley irrigation.

An inland valley can provide the space and conditions for smallholder agriculture.

Table 7. Ex-ante and predictive modeling results for the potential expansion of communal river diversions under climate change

	Ex-Ante			SWAT+DREAM		
	Baseline	Csia	Cnra	Baseline	Csia	Cnra
Area (thousand ha)	34,308	33,8277	34,073	9,644	8,217	9,231
Rural population reached (thousand people)	191,269	188,281	189,696	53,457	45,303	50,431
Net revenue (billion dollars)	-	-	-	7.47	6.37	6.57
Water consumption (billion m^3/year)	-	-	-	37.95	35.58	40.99
Irrigation water consumption increase (%)	-	-	-	55,68	52.20	60.14

Source IFPRI Team.
Note: Results shown are for all of SSA.