AGWATER SOLUTIONS
Improved livelihoods for smallholder farmers

REGIONAL ANALYSIS OF SMALL RESERVOIRS

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, enhanced agricultural water management has been regarded as a promising solution to boost levels of agricultural productivity in SSA.

Small reservoirs are important for small-scale irrigation expansion across SSA. In most of the region, small reservoirs are earthen or cement dams that are less than 7.5 meters deep. They can store up to 1 million cubic meters (m^3) of water; irrigation area varies and can be as low as 50 hectares or less. Capital investment is generally externally driven, and community management remains the norm. Small reservoirs provide significant opportunities for soil and water conservation, for drought proofing, and for developing small-scale, community-based irrigation schemes. A well-designed reservoir can support multiple water uses, including livestock watering, fisheries, domestic and small-business water use, and handicraft activities. Small reservoirs are assets in which significant investments have been made by governments, donors, nongovernmental organizations (NGOs), and communities. They are high in demand among local communities, fit in with national strategies and policies, and continue to attract funding from international development partners. However, a critical look at their current performance shows that small reservoirs perform well below expectations when it comes to irrigation. By contrast, they provide multiple benefits that are often unaccounted for to multiple users, including women.

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 small reservoirs 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 small reservoirs, the environmental suitability criteria for ex-ante GIS analysis are shown in Table 1.

A pixel with a score greater than 64 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 small reservoirs 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. 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.

Table 1. Ex-ante GIS analysis criteria for small reservoirs

Criteria for small reservoirs	Scoring scheme
Topography	0-4% = 25; 4-20% = 0; >20% = 0
Runoff	2 - 25 mm/m = 0; 25 - 45 mm/m = 6; 45 - 75 mm/m = 13; 75 - 110 mm/m = 19; > 110 mm/m = 25
Market access	5 km = 10 minutes = 25; 10 km = 20 minutes = 17; 20 km = 40 minutes = 8; 30 km = 60 minutes = 06; 0 km = 120 minutes = 0
Distance to surface water	< 5 km = 25.0; >5 km = excluded

Note: mm/m=millimeters per month

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

- *Limited Storage Capacity*. 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 small reservoirs are used for the cultivation of a series of crops based on evidence from field studies including: tomatoes, onions, peppers, cabbages, beans, peas, potatoes, sweet potatoes, sugarcane, groundnuts, maize, wheat, and rice.

- *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.

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

Crops	N fertilizer (KG/ha)	Costs (US$/ha-yr)
Tomatoes	100	3,500
Onions	100	3,500
Peppers	100	3,000
Cabbage	100	4,000
Beans	0	1,000
Peas	0	500
Potatoes	80	3,000
Sweet potatoes	60	2,500
Groundnuts	0	1,000
Sugarcane	80	1,500
Wheat	50	700
Maize	60	600
Rice (paddy)	80	1,000

Source: IFPRI Team based on project inputs and secondary sources

- *Production and Irrigation Costs*. Assumed costs of production for the selected crops are shown in Table 2. A labor and operating cost for irrigation of US$200 per hectare per year was also assumed. For this intervention, the initial capital investment cost ($21,500 per ha over 30 years) is assumed to be financed by governments or donors, not the smallholders themselves. 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. An additional scenario considers the potential of small reservoirs when small farmers assume all capital investment costs.

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.

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.

Potential for expansion of small reservoirs in SSA

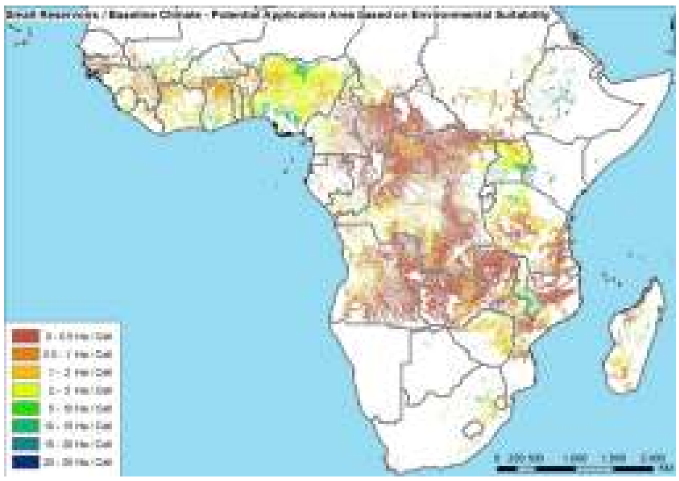

Figure 1: Suitable area for expansion of communal river diversions, ex-ante results
Source: IFPRI Team

The ex-ante assessment shows that the potential for the expansion of small reservoirs is 27 million ha, potentially reaching a rural population of 455 million people in the region. The potential for small reservoir expansion is highest in the Gulf of Guinea region, with potential expansion of over 8.5 million ha reaching a rural population of 136 million, driven largely by the large potential in Nigeria. The Eastern, Central, and Sudano–Sahelian regions also show considerable potential for expansion of the technology, with 126, 86, and 61 million people potentially reached in these

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	Sweet potato		Green bean		Maize		Paddy rice		Groundnut	
	LI	HI	LI	HI	LI	HI	LI	HI	LI	HI
	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)
Central Africa										
Angola	2.2	547	0.2	385	0.3	1,195	-	-	0.1	2,432
Cameroon	8.1	68	0.5	-62	1.3	215	1.0	327	0.3	647
Central African Republic	6.8	36	-	-	1.1	274	1.2	218	0.8	155
Republic of Congo	-	-	0.5	-55	0.8	378	0.7	348	0.4	410
Democratic Republic of Congo	-	-	0.4	59	0.9	349	0.7	441	0.8	153
Equatorial Guinea	2.6	309	-	-	-	-	-	-	0.8	137
Gabon	6.8	58	-	-	0.9	329	1.0	223	0.7	142
Eastern and Indian Ocean countries										
Burundi	6.4	157	0.4	102	1.0	349	-	-	0.7	289
Ethiopia	-	-	0.6	40	1.1	262	-	-	0.5	446
Kenya	6.8	155	0.5	88	1.0	352	-	-	1.4	72
Madagascar	6.0	171	0.5	63	1.1	298	1.0	496	-	-
Rwanda	5.9	202	0.4	138	0.7	615	1.3	277	1.1	151
Tanzania	1.5	990	0.5	66	1.8	140	1.8	184	0.6	308
Uganda	4.5	215	0.5	15	1.8	128	1.4	263	0.7	288
Gulf of Guinea										
Benin	7.3	56	0.4	-81	1.2	226	1.3	200	0.6	202
Côte d'Ivoire	4.9	153	-	-	1.0	302	1.6	159	0.7	195
Ghana	6.5	73	-	-	1.1	268	1.5	163	0.7	185
Guinea	7.6	49	-	-	1.1	254	1.3	220	0.7	173
Guinea-Bissau	-	-	-	-	1.0	284	1.2	177	1.2	47
Liberia	-	-	-	-	-	-	1.2	243	0.6	271
Nigeria	14.2	-15	-	-	1.5	167	1.4	191	1.7	30
Sierra Leone	2.8	327	-	-	1.1	270	1.1	282	0.7	186
Togo	6.1	81	0.3	-72	1.2	246	1.1	240	0.5	275
Southern Africa										
Botswana	-	-	0.01	1,466	0.1	4,322	-	-	1.0	163
Lesotho	-	-	0.4	291	1.8	148	-	-	-	-
Malawi	11.8	23	0.3	148	1.5	183	1.2	309	0.7	326
Mozambique	30.9	-57	0.2	98	1.1	277	0.3	1,384	0.4	524
Namibia	-	-	0.2	329	0.8	429	-	-	0.4	529
South Africa	9.1	88	1.4	-23	1.7	176	-	-	1.1	189
Swaziland	1.8	956	0.2	405	0.9	410	3.4	61	-	-
Zambia	8.1	76	-	-	1.1	301	0.9	448	0.4	602

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 (cont'd)

Country	Sweet potato		Green beans		Maize		Paddy rice		Groundnut	
	LI	HI	LI	HI	LI	HI	LI	HI	LI	HI
	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)	Rainfed yield (t/ha)	Irrigated yield (% increase)
Zimbabwe	2.2	546	0.4	49	1.6	163	2.2	129	0.7	270
Sudano-Sahelian region										
Burkina Faso	9.8	9	-	-	1.3	221	1.4	179	0.5	292
Chad	6.2	57	0.3	-68	0.8	434	0.8	326	0.6	272
Eritrea	-	-	0.3	20	0.7	507	-	-	-	-
Gambia	-	-	-	-	1.2	246	1.4	126	0.7	140
Mali	14.3	-21	-	-	0.8	433	0.8	396	0.7	213
Mauritania	1.9	284	0.9	-94	0.9	396	-	-	0.6	225
Niger	13.9	-9	0.4	-42	0.5	904	1.8	147	0.2	791
Senegal	5.3	68	-	-	1.1	287	0.7	394	0.7	149
Somalia	-	-	0.3	-77	0.7	525	-	-	0.7	179
Sudan	2.6	251	1.9	-86	0.8	448	1.6	124	0.5	376

Source: IFPRI Team

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

regions, respectively. After Nigeria, the potential for small reservoir expansion is greatest in the Democratic Republic of the Congo, followed by Ethiopia (Table 4).

Table 4. Ex-ante potential for the expansion of communal river diversions in SSA, assuming 100 percent adoption

Country Name	Potential application area (1000 ha)	Rural population reached (thousand people)
Central Africa	5,087	85,902
Eastern and Indian Ocean Countries	7,474	125,823
Gulf of Guinea	8,550	135,546
Southern Africa	3,110	46,837
Sudano-Sahelian	2,917	60,882
All SSA	27,139	454,989

Source: IFPRI team

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 small reservoirs in the region compared to the ex-ante assessment (Figure 2). The results of the SWAT–DREAM assessment for small reservoirs are summarized in Table 5 for the baseline

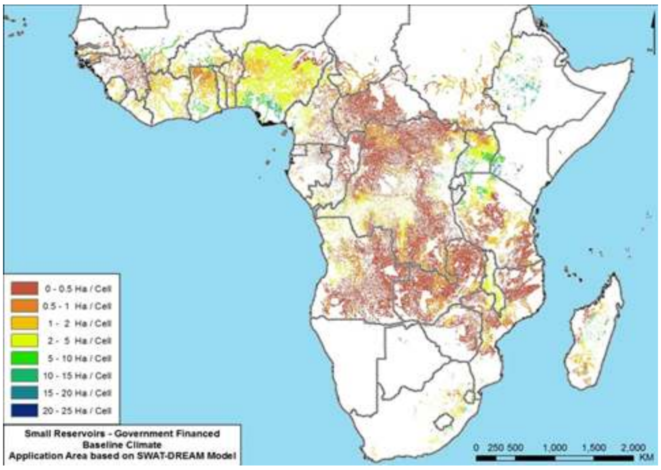

Figure 2: Suitable area for expansion of small reservoirs, SWAT-DREAM results
Source: IFPRI Team.

scenario. The results indicate a potential area expansion of 22 million ha, reaching a rural population of 369 million, with the greatest potential found in the Gulf of Guinea region.

Total net revenues as a result of the expansion of small reservoirs throughout the region would be US$20 billion per year, with revenues highest in the Eastern, Gulf of Guinea, , and Southern regions. There are implications of this expansion for water use in the region. Specifically, the total increase in water consumption as a result of the expansion of small reservoirs in SSA is estimated at 59 billion m^3/yr, which represents an increase of 86 percent over current water consumption.

Table 5. Predictive modeling results for the potential expansion of small reservoirs, baseline scenario results

Country	Application area (thousand ha)	Net revenue (US$ billion/yr)	Rural population reached (thousand people)	Water consumption (billion m^3/yr)	Water consumption Increase %
Angola	817	0.70	13,886	3.56	453.0
Cameroon	638	0.14	10,636	1.22	135.2
Central African Republic	229	0.14	3,364	0.61	517.9
Congo	18	0.22	2,836	0.21	42.9
Congo, DRC	2,830	1.46	49,052	4.85	1,394.2
Equatorial Guinea	2	0.001	55	0.002	2.2
Gabon	47	0.03	742	0.04	65.8
Central Africa	**4,782**	**2.69**	**80,572**	**10.49**	**373.1**
Burundi	122	0.25	2,06	0.45	122.9
Ethiopia	1,702	3.22	29,493	6.65	373.3
Kenya	826	1.35	12,672	2.03	121.7
Madagascar	546	0.17	8,736	1.32	42.9
Rwanda	99	0.22	1,487	0.30	234.8
Tanzania	1,433	1.46	24,843	5.41	307.5
Uganda	1,219	1.13	20,726	2.37	353.0`
Eastern and Indian Ocean Countries	**5,947**	**7.81**	**100,024**	**18.53**	**195.9**
Benin	263	0.17	4,653	0.82	349.5
Côte d'Ivoire	648	0.38	12,321	1.64	307.1
Ghana	965	0.92	12,866	2.62	920.2
Guinea	72	0.05	1,444	0.17	38.7
Guinea-Bissau	14	0.06	297	0.02	20.3
Liberia	107	0.08	2,034	0.24	1,097.3
Nigeria	4,795	2.43	73,519	9.56	74.1
Sierra Leone	98	0.07	1,953	0.34	37.6
Togo	161	0.10	3,000	0.29	261.2
Gulf of Guinea	**7,123**	**4.27**	**112,087**	**15.70**	**101.0**
Botswana	10	0.01	144	0.03	22.6
Lesotho	34	0.05	475	0.04	112.6
Malawi	538	1.80	8,434	2.44	412.5
Mozambique	695	0.44	10,427	1.55	158.0
Namibia	4	0.002	71	0.01	7.9
South Africa	400	0.62	5,338	1.21	19.8
Swaziland	22	0.03	391	0.97	10.0
Zambia	526	0.56	8,415	2.97	266.1
Zimbabwe	127	0.14	1,943	0.60	40.7

Table 5. Predictive modeling results for the potential expansion of small reservoirs, 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 %
Southern Africa	**2,357**	**3.63**	**35,638**	**8.92**	**79.0**
Burkina Faso	572	0.37	12,674	1.77	145.2
Chad	255	0.13	4,500	0.44	63.2
Eritrea	6	0.01	97	0.03	33.9
Mali	448	0.05	8,504	0.61	10.2
Mauritania	6	0.004	117	0.01	0.7
Niger	98	0.07	1,957	0.15	7.4
Senegal	56	0.04	1,907	0.08	5.8
Somalia	2	0.001	46	0.002	0.1
Sudan	522	1.09	10,794	2.00	14.3
The Gambia	4	0.002	203	0.004	11.5
Sudano-Sahelian region	**1,968**	**1.76**	**40,889**	**5.10**	**17.5**
All SSA	**22,176**	**20.16**	**369,211**	**58.74**	**86.2**

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 vice versa. With a 50 percent reduction in the cost of irrigation, the application area would increase by 0.5 million ha, net revenues would increase by $2 billion per year, and rural population reached would increase by 1 million. Conversely, the application area decreases by 1 million ha, net revenues decline by $2 billion, and the number of people reached decreases by 17 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 almost unchanged application area and rural population reached, but a significant increase in annual net revenues of $13 billion; while a decrease in the initial crop price results in a lower application area (by 5 million ha), a reduction in net revenues (by $13 billion), and fewer people reached (by 86 million), compared to the baseline.

The sensitivity analysis also shows that without government or donor financing of small reservoir construction, the potential for the expansion of this agricultural water management strategy is greatly reduced. When farmers assume all capital costs, the application area decreases by 13 million ha, rural population reached declines by 223 million, and net revenues decrease by $13 billion.
In terms of water use, water consumption varies from 31 billion m³/yr to 60 billion m³/yr across different scenarios in the sensitivity analysis.

Table 6. Predictive modeling results for the potential expansion of small reservoirs, scenario results

	Baseline	-50% irrigation cost	+ 50% irrigation costs	-30% initial crop price	+ 30% initial crop price	Farmer financing
Area (thousand ha.)	22,176	22,230	21,176	16,927	21,925	8,851
Population reached (thousand people)	369,211	370,174	352,117	283,599	365,176	146,024
Net revenue (US$ billion)	20.16	22.38	17.96	7.64	33.16	7.09
Water consumption (billion m³/yr)	58.74	58.77	57.47	46.69	60.23	31.33
Irrigation water consumption increase (%)	86.18	86.223	84.32	68.50	88.38	45.97

Source: IFPRI Team

Note: Results shown are for all of SSA

The impacts of climate change on the application potential of small reservoirs across SSA were 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. The A2 SRES emissions scenario was used, which is considered moderate. The results in Table 7 show that changes in the estimated application area due to climate change range from -4 percent to +6 percent.

Conclusions

The ex-ante analysis reveals a large expansion potential for small reservoirs in SSA in terms of application area, net revenue, and rural population reached. Taking hydrology and changes in crop prices as a result of increased crop production under aggressive development of small reservoirs into account has only small impacts on potential for area expansion in SSA, reducing the potential by 5 million ha. Long-term climate change also has limited impacts on final outcomes for this intervention.

The baseline assessment is based on the assumption that farmers do not bear the capital costs but rather that small reservoirs require investment of capital costs by governments, donors, or NGOs to achieve significant expansion in the region. When small farmers assume all capital costs, the potential for the expansion of small reservoirs is significantly reduced. Development of small reservoirs is highly knowledge intensive and requires great care during project planning and implementation.

Small reservoirs offer whole communities the opportunity to irrigate their crops and diversify with livestock.

Table 7. Ex-ante and predictive modeling results for the potential expansion of small reservoirs under climate change

	Ex-Ante			SWAT+DREAM		
	No climate	Csia	Cnra	Baseline	Csia	Cnra
Area (thousand ha)	27,139	26,847	27,179	22,176	21,215	23,547
Rural population reached (thousand people)	454,989	447,725	453,969	369,211	352,885	390,717
Net revenue (billion dollars)	-	-	-	20.16	18.49	18.91
Water consumption (billion m^3/year)	-	-	-	58.74	57.06	62.21
Irrigation water consumption increase (%)	-	-	-	86.18	83.72	91.28

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