AGWATER SOLUTIONS
Improved livelihoods for smallholder farmers

REGIONAL ANALYSIS OF IN-SITU WATER HARVESTING

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 often been regarded as a promising solution to boost levels of agricultural productivity in SSA.

In-situ water harvesting is one method of water management that could potentially be improved and expanded throughout the region. The objective of in-situ water harvesting is to retain runoff in order to increase infiltration and soil moisture on crop lands. This goal can be achieved through conservation tillage, terracing, tied ridging, mulching, and other, similar methods. Under many circumstances, the implementation of in-situ water harvesting also has implications for soil properties, improving soil quality by increasing the soil water-holding capacity.

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 in-situ water harvesting 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 in-situ water harvesting, the environmental suitability criteria for ex-ante GIS analysis are shown in Table 1.

A pixel with a score greater than 44 is considered to have potential for in-situ water harvesting. 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 in-situ water harvesting 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). This analysis assumes that in-situ water harvesting is primarily used to enhance the productivity of existing rainfed agriculture. Under this assumption, the SWAT and DREAM models were run to simulate the effects of in-situ water harvesting and forecast price shifts in agricultural commodities as a result of increased supply. The results produced from the SWAT–DREAM predictive analysis allow for cost–benefit analysis for in-situ water harvesting, and further constrain the potential for in-situ water harvesting expansion compared to the ex-ante analysis.

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

- *Cultivation of Particular Crops*. Based on evidence from field studies and literature reviews, the assessment assumes that in-situ water harvesting is primarily used for the cultivation of rainfed cereal crops. Three main rainfed cereal crops grown in SSA are included in this study: maize, sorghum, and millet.

- *Effects of In-situ Water Harvesting.* As noted above, in-situ water harvesting helps retain runoff and ameliorates soil quality. These effects are represented by reducing the Soil Conservation Service curve number value (by six) and by assuming that the soil water holding capacity increases by 25 percent in the simulation.

- *Fertilizer Input*. Agricultural production in SSA is characterized by the wide presence of low-input farming systems.

Table 1. Ex-ante GIS analysis criteria for in-situ water harvesting

Criteria for in-situ water harvesting	Scoring scheme
Topography	0 - 4% = 33, 4 - 16% = 16, 16% < = 0
Rainfall	0 - 200 mm/yr = excluded, 200 - 500 mm/yr = 11, 500 – 1,100 mm/yr = 22, > 1,100 mm/yr = 33
FAO soil moisture capacity	5 km = 10 minutes = 17, 10 km = 20 minutes = 11, 20 km = 40 minutes = 6, 30 km = 60 minutes = 0, 60 km = 120 minutes = 0

There exists strong synergy between water and nutrient management; yield improvements brought about by in-situ water harvesting are much more pronounced as fertilizer application rates increase, ranging from 1-22 percent at different levels of *N*-application. For this assessment, we therefore assumed that adoption of in-situ water harvesting is accompanied by medium-level increases of fertilizer use. 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 (next page).

- *Production and Irrigation Costs*. The assumed costs of production, including moderate application of fertilizers, for selected crops are shown in Table 2. The costs due to increased use of fertilizers are assumed to be 20 percent of the production costs shown in this table. A cost for irrigation of US$192 per hectare per year was also assumed, with average amortized capital investment costs of $42/ha-yr and labor and operating costs of $150/ha-yr. The cost–benefit results are very sensitive to these cost assumptions. A sensitivity analysis in which costs for in-situ water harvesting were increased or decreased by 50 percent was therefore conducted.

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)
Maize	60	600
Millet	40	350
Soghum	40	350

Source: IFPRI Team based on project input and secondary sources

It is expected that in-situ water harvesting 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 the expansion of in-situ water harvesting, 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 water harvesting 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.

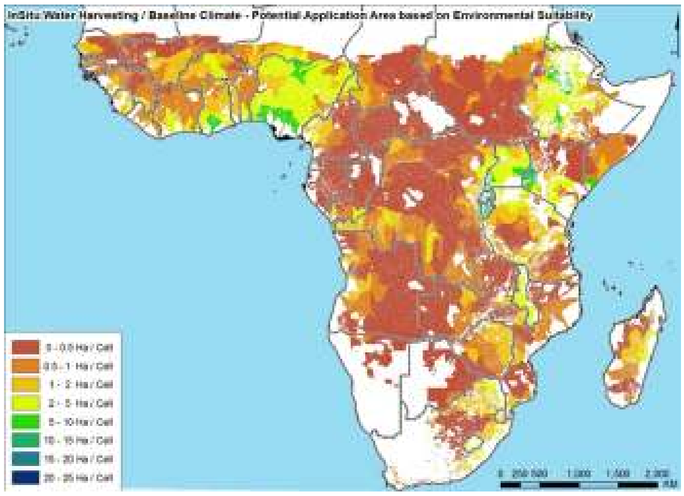

Figure 1: Suitable area for expansion of in-situ water harvesting, ex-ante results
Source: IFPRI Team

Potential for in-situ water harvesting expansion in SSA

The ex-ante assessment shows that in-situ water harvesting could be expanded to 52 million ha, potentially reaching a rural population of more than 500 million (Table 4). The potential for expansion of in-situ water harvesting is highest in the Eastern and Indian Ocean countries, with potential expansion of 15 million ha reaching 148 million people. The Gulf of Guinea area also shows considerable potential with 14 million ha and the potential of reaching 136 million people.

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 in-situ water harvesting in the region compared to the ex-ante assessment (Figure 2).

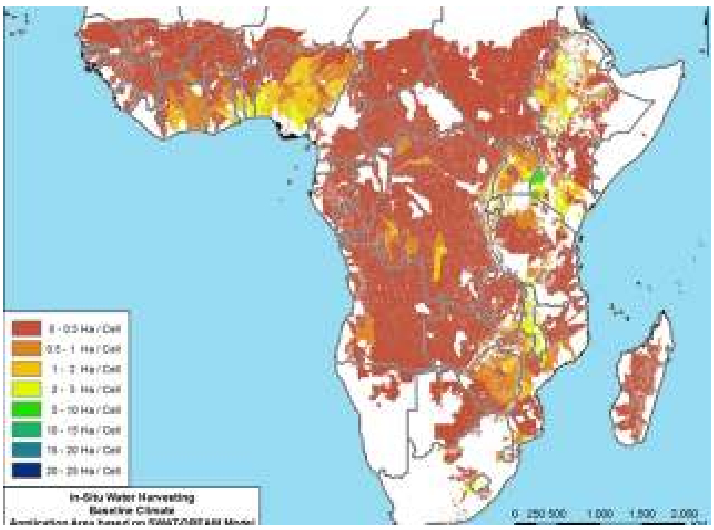

Figure 2: Suitable Area for expansion of in-situ water harvesting, SWAT-DREAM results
Source: IFPRI Team.

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	Maize		Sorghum		Millet	
	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)
Central Africa						
Angola	0.6	586	0.1	2,049	0.4	188
Cameroon	1.8	139	1.2	176	0.8	193
Central African Republic	0.9	362	0.7	391	0.6	250
Republic of Congo	0.6	514	0.1	1,989	0.2	662
Democratic Republic of Congo	0.6	486	0.5	467	0.6	185
Equatorial Guinea	-	-	-	-	-	-
Gabon	1.6	113	-	-	0.4	399
Eastern and Indian Ocean countries						
Burundi	1.2	229	0.7	282	0.7	182
Ethiopia	1.4	190	1.1	181	1.0	124
Kenya	1.2	247	0.6	412	0.6	243
Madagascar	0.8	502	0.4	707	-	-
Rwanda	0.6	666	1.2	175	0.1	2,278
Tanzania	2.3	76	0.8	229	0.9	92
Uganda	0.9	365	1.1	205	1.2	92
Gulf of Guinea						
Benin	1.1	307	0.8	332	0.8	217
Côte d'Ivoire	1.0	354	0.6	467	0.6	262
Ghana	1.4	226	0.8	315	0.7	244
Guinea	1.0	311	0.7	401	0.7	234
Guinea-Bissau	1.0	351	0.7	330	1.1	105
Liberia	0.3	1,142	0.2	1,253	0.3	702
Nigeria	1.2	276	1.0	240	1.1	140
Sierra Leone	1.0	308	1.1	163	0.9	124
Togo	1.4	241	0.7	373	0.6	278
Southern Africa						
Botswana	0.2	2,217	0.2	1,579	0.1	1,980
Lesotho	1.4	212	0.9	292	-	-
Malawi	1.6	202	0.6	540	0.5	382
Mozambique	0.9	430	0.5	625	0.4	574
Namibia	0.6	403	0.3	1,022	0.3	646
South Africa	2.1	106	2.0	55	-	17,419
Swaziland	1.5	203	0.9	295	-	-
Zambia	1.4	240	0.7	399	0.7	270
Zimbabwe	1.1	275	0.4	602	0.2	1,049

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	Maize		Sorghum		Millet	
	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)
Sudano-Sahelian region						
Burkina Faso	1.8	163	0.8	319	0.6	300
Chad	0.8	466	0.7	385	0.3	597
Eritrea	0.7	266	0.4	387	-	-
Gambia	1.2	297	1.3	161	1.3	82
Mali	1.2	282	0.9	253	0.8	177
Mauritania	0.7	452	0.5	424	0.4	409
Niger	0.5	364	0.2	1,396	0.3	624
Senegal	0.8	378	0.8	269	0.6	273
Somalia	0.7	471	0.3	768	0.4	0
Sudan	0.7	477	1.1	150	0.4	443

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 in-situ water harvesting in SSA, assuming 100 percent adoption

Country Name	Potential application area (1000 ha)	Rural population reached (thousand people)
Central	8,481	82,927
Eastern and Indian Ocean Countries	14,730	148,020
Gulf of Guinea	14,296	135,966
Southern Africa	6,021	54,023
Sudano-Sahelian	8,090	99,767
All SSA	51,619	523,703

Source: IFPRI team

The results of the SWAT–DREAM assessment for in-situ water harvesting are summarized in Table 5 for the baseline scenario.

The results indicate a potential area expansion of only 15 million ha, reaching 147 million people across Sub-Saharan Africa, with the greatest potential again found in the Gulf of Guinea and the Eastern and Indian Ocean countries. This suggests that there are considerable environmental and economic constraints to the expansion of in-situ water harvesting schemes throughout the region.

Total net revenues as a result of the expansion of in-situ water harvesting throughout the region would be US$8.6 billion per year, with revenues highest in the Gulf of Guinea. The total increase in water consumption as a result of the expansion of in-situ water harvesting in SSA is estimated at 3 billion m^3/yr, a modest 4 percent increase over current consumption levels.

The results of the sensitivity analysis (Table 6) show that estimated application areas, net revenues, and rural population reached increase with decreasing costs for in-situ water harvesting and higher food prices, and vice versa.

However, the results for in-situ water harvesting are less sensitive to these costs and crop price changes compared to other agricultural water management interventions. With a 50 percent reduction in intervention cost, the application area would increase by 0.6 million ha, net revenues would increase by $1.5 billion per year, and rural population reached would increase by 6 million.

Table 5. Predictive modeling results for the potential expansion of in-situ water harvesting, 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	397	0.30	4,051	0.10	13.06
Cameroon	143	0.03	1,431	0.03	2.81
Central African Republic	104	0.08	917	0.03	21.162
Congo	20	0.02	155	0.002	0.46
Congo, DRC	1,507	0.79	15,677	0.17	47.86
Equatorial Guinea	1	0.0002	9	0.0001	0.09
Gabon	9	0.003	81	0.001	1.89
Central Africa	**2,181**	**1.22**	**22,321**	**0.32**	**11.50**
Burundi	49	0.03	504	0.002	0.55
Ethiopia	1,387	0.60	14,428	0.34	19.01
Kenya	1,388	0.60	12,765	0.48	28.54
Madagascar	56	0.03	541	0.001	0.04
Rwanda	63	0.06	570	0.002	1.85
Tanzania	744	0.25	7,742	0.06	3.33
Uganda	6.26	0.44	6,383	0.23	34.35
Eastern and Indian Ocean Countries	**4,314**	**2.01**	**42,933**	**1.11**	**11.73**
Benin	402	0.31	4,262	0.07	30.02
Côte d'Ivoire	623	0.43	7,107	0.18	33.63
Ghana	408	0.29	3,261	0.10	34.89
Guinea	92	0.02	1,099	0.02	3.46
Guinea-Bissau	9	0.03	108	0.002	2.09
Liberia	11	0.01	120	0.004	16.38
Nigeria	2,672	1.74	24,579	0.45	3.52
Sierra Leone	6	0.003	69	0.001	0.07
Togo	174	0.14	1,947	0.03	27.47
Gulf of Guinea	**4,395**	**2.97**	**42,551**	**0.85**	**5.50**
Botswana	65	0.05	547	0.02	18.65
Lesotho	62	0.03	521	0.03	74.70
Malawi	801	0.42	7,534	0.00003	0.01
Mozambique	1,006	0.52	9,052	0.08	7.97
Namibia	19	0.02	184	0.01	4.01
South Africa	207	0.06	1,660	0.09	1.47
Swaziland	21	0.01	222	0.01	1.15
Zambia	418	0.31	4,015	0.01	1.09
Zimbabwe	780	0.51	7,176	0.13	8.95

Table 5. Predictive modeling results for the potential expansion of in-situ water harvesting, 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	**3,379**	**1.94**	**30,911**	**0.38**	**3.35**
Burkina Faso	182	0.22	2,440	0.04	2.99
Chad	75	0.07	797	0.01	1.69
Eritrea	17	0.01	163	0.002	3.10
Mali	171	0.05	1,947	0.04	0.60
Mauritania	7	0.01	89	0.001	0.08`
Niger	30	0.04	365	0.01	0.61
Senegal	25	0.03	523	0.01	0.44
Somalia	4	0.002	41	0.001	0.02
Sudan	115	0.11	1,423	0.02	0.13
The Gambia	2	0.001	51	0.0004	1.12
Sudano-Sahelian region	**628**	**0.41**	**7,840**	**0.13**	**0.43**
All SSA	**14,897**	**8.55**	**146,556**	**2.79**	**4.10**

Source: IFPRI Team
Note: Water consumption for this intervention refers to increased crop water evapotranspiration.

Conversely, application area decreases by 0.6 million ha, net revenues decline by $1.4 billion, and the number of people reached decreases by 6 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 0.5 million ha, an increase in net revenues of $4 billion, and an additional 5 million people reached; while a decrease in the initial crop price results in a lower application area (by 1 million ha), a reduction in net revenues (by $4 billion), and fewer people reached (by 9 million), compared to the baseline.

In terms of water use, water consumption (expressed as crop water evapotranspiration) ranges from 2.5 billion m³/yr to 3 billion m³/yr under the different scenarios.

The impact of climate change on the application potential of in-situ water harvesting 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

Table 6. Predictive modeling results for the potential expansion of in-situ water harvesting, scenario results

	Baseline	-50% irrigation cost	+ 50% irrigation costs	-30% initial crop price	+ 30% initial crop price
Area (thousand ha.)	14,897	15,509	14,257	13,945	15,408
Rural population reached (thousand people)	146,556	152,520	140,539	137,558	151,459
Net revenue (US$ billion)	8.55	10.02	7.12	4.59	12.54
Water consumption (billion m³ /yr)	2.79	2.98	2.59	2.53	2.96
Irrigation water consumption increase (%)	4.10	4.37	3.80	3.72	4.34

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

emissions scenario, which is considered moderate. The results in Table 7 show that changes in the estimated application area due to climate change are minor.

Conclusions

The ex-ante analysis reveals large expansion potential for in-situ water harvesting in SSA in terms of application area and rural population reached. However, when additional constraints are introduced, the potential is significantly reduced. The potential is also limited as we only assumed use for three cereal crops.

We assumed moderate levels of fertilizer applications together with in-situ water harvesting, even though this intervention is not a typical irrigation method, where increased fertilizer applications are almost always used; the reason being that yield improvements are significantly higher for this intervention when nutrient levels are enhanced. Therefore, the results reflect the combined costs and benefits of both activities: increased fertilizer use and in-situ water harvesting. In-situ water harvesting remains an important, climate-resilient water management intervention for key cereal crops in Sub-Saharan Africa.

Table 7. Ex-ante and predictive modeling results for the potential expansion of in-situ water harvesting under climate change

	Ex-Ante			SWAT+DREAM		
	Baseline	Csia	Cnra	Baseline	Csia	Cnra
Area (thousand ha)	51,619	51,062	51,144	14,897	14,830	14,850
Rural population reached (thousand people)	505,143	498,772	499,012	146,556	145,881	146,050
Net revenue (billion dollars)	-	-	-	8.55	8.66	8.44
Water consumption (billion m3/year)	-	-	-	2.79	2.53	2.48
Irrigation water consumption increase (%)	-	-	-	4.10	3.71	3.64

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

Conserving the water that falls on the soil means famers can grow more and earn more.