REGIONAL ANALYSIS OF COMMUNAL RIVER DIVERSION

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.

Communal river diversion is a traditional irrigation method that could potentially be improved and expanded throughout the region. Communal river diversion refers to different schemes for diverting surface water from rivers through traditional furrows or canals to farmers' fields. Traditional communal river diversion schemes are initiated and operated by farmers, without any external intervention. They are often characterized by poor infrastructure, poor water management, and low yields. Improved river diversion schemes sometimes benefit from external interventions like construction of new canals, but they are still managed by the communities.

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 communal river diversions 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 communal diversions, the environmental suitability criteria for ex-ante GIS analysis are shown in Table 1.

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 dominantly rainfed and farming activities concentrate in the rainy seasons. This analysis assumes that communal diversions 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 communal river diversions

Criteria for motor pumps	Scoring scheme
FAO Fluvisols	False = 0, 1 - 15 % = 6, 16 - 50 % = 11, 51 - 100 % = 17
Topography	0-4% = 16, 4-10% = 8, 10% < = 0
Runoff	1 - 25 mm = 0, 25 - 45 mm = 4, 45 - 75 mm = 9, 75 - 110 mm = 13, > 110 mm = 17
Market access	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
Distance to surface water	< 5 km = 16, >5 km = excluded
Population density	0 - 5 = excluded, > 5 = 17

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

- *Water Availability.* No associated runoff storage capacity is assumed for communal river diversions. Moreover, 20 percent of runoff is reserved for environmental flows.

- *Cultivation of Particular Crops*. The assessment assumes that communal diversions 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, ground nuts, 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.

- *Production and Irrigation Costs*. Assumed costs of production for the selected crops are shown in Table 2. A cost for irrigation of US$640 per hectare per year was also assumed, with average amortized capital investment costs of $440/ha-yr (original capital investment: $3,500 and reinvestment timeframe of 35 years) and labor and operating costs of $200/ha-yr. 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.

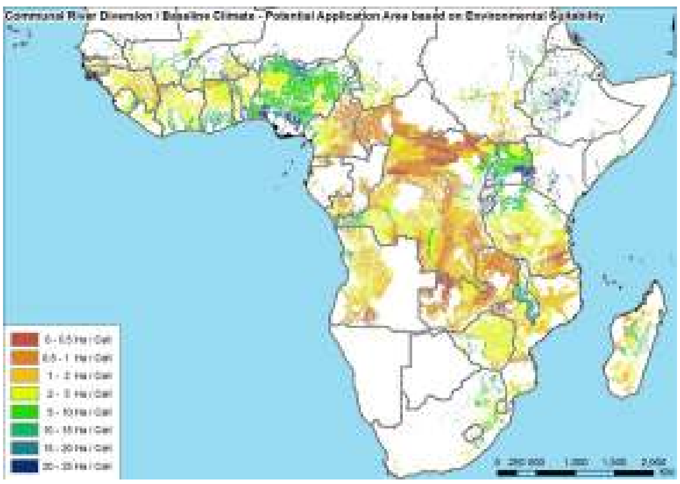

Figure 1: Suitable area for expansion of communal river diversions, ex-ante results
Source: IFPRI Team

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 communal river diversions in SSA

The ex-ante assessment shows that communal river diversions could be expanded to 82 million ha, potentially reaching a rural population of 457 million people. The potential for expansion of communal river diversions is highest in the Gulf of Guinea region, with potential expansion of over 25 million ha reaching 132 million people, driven largely by huge potential in Nigeria. The Eastern and Central regions also show considerable potential for expansion of the technology, with 122 and 85 million people potentially reached in these regions, respectively. After Nigeria, the potential is greatest in the Democratic Republic of the Congo and Ethiopia (Table 4).

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)
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

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)	Rainfe d 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).

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	15,005	84,618
Eastern and Indian Ocean Countries	21,821	122,280
Gulf of Guinea	25,050	132,470
Southern Africa	9,848	49,383
Sudano-Sahelian	9,997	68,731
All SSA	81,721	457,481

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

The results indicate a potential area expansion of 20 million ha, reaching 113 million people, with the greatest potential found in the Gulf of Guinea region.
This represents about one quarter of the area potential shown in the ex-ante analysis, suggesting that there are considerable environmental and economic constraints to the expansion of communal river diversion schemes throughout the region.

Total net revenues as a result of the expansion of communal river diversions throughout the region would be US$14 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 communal river diversions in SSA is estimated at 61 billion m^3/yr, representing an increase of 89 percent over current water consumption.

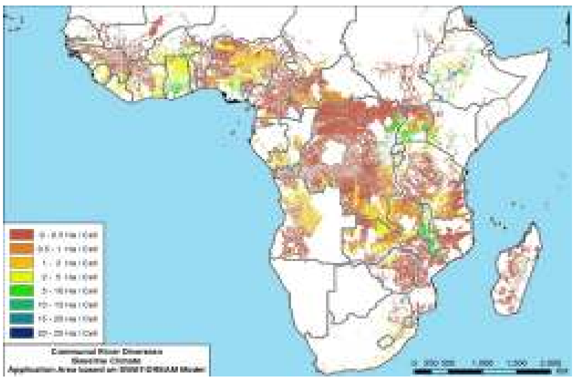

Figure 2: Suitable Area for expansion of communal river diversions, SWAT-DREAM results
Source: IFPRI Team.

Table 5. Predictive modeling results for the potential expansion of communal river diversions, 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	876	0.40	4,965	3.89	494.4
Cameroon	97	0.03	536	0.16	17.3
Central African Republic	405	0.07	1,982	0.94	798.9
Congo	531	0.29	2,302	0.53	108.3
Congo, DRC	2,278	0.75	13,163	6.26	1,798.9
Equatorial Guinea	11	0.002	106	0.01	10.7
Gabon	81	0.01	424	0.07	133.2
Central Africa	**4,280**	**1.55**	**23,479**	**11.85**	**421.5**
Burundi	48	0.07	271	0.18	49.2
Ethiopia	2,398	2.71	13,858	8.40	472.1
Kenya	512	0.62	2,619	1.31	78.5
Madagascar	76	0.01	406	0.26	8.3
Rwanda	56	0.10	281	0.17	129.6
Tanzania	923	0.77	5,332	3.50	199.2
Uganda	1,399	0.68	7,928	2.39	355.5
Eastern and Indian Ocean Countries	**5,413**	**4.94**	**30,695**	**16.21**	**171.4**
Benin	99	0.02	585	0.20	83.9
Côte d'Ivoire	680	0.11	4,307	1.59	298.6
Ghana	1,690	0.69	7,512	4.16	1,461.5
Guinea	198	0.05	1,321	0.55	121.7
Guinea-Bissau	41	0.17	289	0.05	58.2
Liberia	317	0.09	2,007	0.71	3,231.1
Nigeria	2,416	0.41	12,350	4.44	34.4
Sierra Leone	271	0.08	1,808	0.92	101.1
Togo	180	0.04	1,120	0.32	290.3
Gulf of Guinea	**5,893**	**1.67**	**31,299**	**12.93**	**83.2**
Botswana	7	0.002	32	0.02	15.0
Lesotho	139	0.07	650	0.06	147.7
Malawi	1,196	3.14	6,243	5.54	937.0
Mozambique	290	0.54	1,451	1.14	116.0
Namibia	2	0.001	13	0.01	4.9
South Africa	503	0.59	2,234	1.36	22.3
Swaziland	16	0.01	94	0.05	7.7
Zambia	1,480	0.68	7,892	7.98	715.0

Table 5. Predictive modeling results for the potential expansion of communal river diversions, 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	149	0.07	763	0.74	49.7
Southern Africa	**3,782**	**5.12**	**19,372**	**16.89**	**149.5**
Burkina Faso	632	0.12	4,706	1.82	148.8
Chad	169	0.02	994	0.24	33.8
Eritrea	7	0.003	38	0.04	39.7
Mali	21	0.002	130	0.03	0.4
Mauritania	3	0.001	22	0.005	0.5
Niger	6	0.004	43	0.02	0.9
Senegal	57	0.03	653	0.10	7.4
Somalia	25	0.01	157	0.07	2.7
Sudan	145	0.23	1,.000	0.45	3.2
The Gambia	9	0.001	155	0.01	20.4
Sudano-Sahelian region	**1,074**	**0.42**	**7,897**	**2.77**	**9.5**
All SSA	**20,442**	**13.70**	**112,743**	**60.65**	**89.0**

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 6 million ha, net revenues would increase by $8 billion per year, and rural population reached would increase by 31 million.

Conversely, application area decreases by 10 million ha, net revenues decline by $5 billion, and the number of people reached decreases by 54 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 5 million ha, an increase in net revenues of $15 billion annually, and an additional 30 million people reached; while a decrease in the initial crop price results in a lower application area (by 14 million ha), a reduction in net revenues (by $10 billion), and fewer people reached (by 80 million), compared to the baseline

Table 6. Predictive modeling results for the potential expansion of communal river diversions, scenario results

	Baseline	-50% irrigation cost	+ 50% irrigation costs	-30% initial crop price	+ 30% initial crop price
Area (thousand ha.)	20,442	26,097	10,929	6,151	25,926
Rural population reached (thousand people)	112,743	143,636	59,210	33,227	142,629
Net revenue (US$ billion)	13.70	21.39	8.66	3.81	28.71
Water consumption (billion m³/yr)	60.65	71.36	39.24	23.18	73.92
Irrigation water consumption increase (%)	88.98	104.69	57.57	34.01	108.46

Source: IFPRI Team

Note: Results shown are for all of SSA

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)	81,720	81,553	81,671	20,442	17,993	21,471
Rural population reached (thousand people)	457,481	455,615	456,057	112,743	99,703	118,175
Net revenue (billion dollars)	-	-	-	13.70	12.52	12,75
Water consumption (billion m3/year)	-	-	-	60.65	58.65	69.47
Irrigation water consumption increase (%)	-	-	-	88.98	86.06	101.92

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

Water consumption increases significantly under scenarios resulting in an expansion of communal river diversions. A 50 percent decrease in irrigation costs or a 30 percent increase in initial crop price would increase water use by an additional 11 billion or 13 billion m^3/yr, respectively, compared to the baseline.

The impacts of climate change on the application potential of communal river diversions 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. 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 climate change range from -12 percent to +5 percent.

Conclusions

The ex-ante analysis reveals large expansion potential for communal river diversions in SSA in terms of application area and rural population reached. However, when additional constraints are introduced, the potential is significantly reduced—from 82 million ha to 20 million ha.

The main constraint to the expansion of communal river diversions is the limited availability of runoff, as no associated storage capacity is assumed and 20 percent of runoff is reserved for environmental flows. Moreover, investment costs are also significant.

Creating a river diversion need not be sophisticated. Here, a simple channel for diverting river water has been dug in the mud.