AGWATER SOLUTIONS
Improved livelihoods for smallholder farmers

REGIONAL ANALYSIS OF MOTOR PUMPS

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

Motor pumps are one example of a promising agricultural water management technology. These pumps generally consist of either diesel or electric engines coupled with a low-lift centrifugal pump. The major advantage of motorized pumps is their considerable capacity relative to traditional water-lifting means, making it possible to expand irrigated surface areas. Their flexibility to move among different water sources and many farmers is another advantage. Disadvantages include high capital costs, high recurrent costs, high maintenance levels, and the emission of greenhouse gases.

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

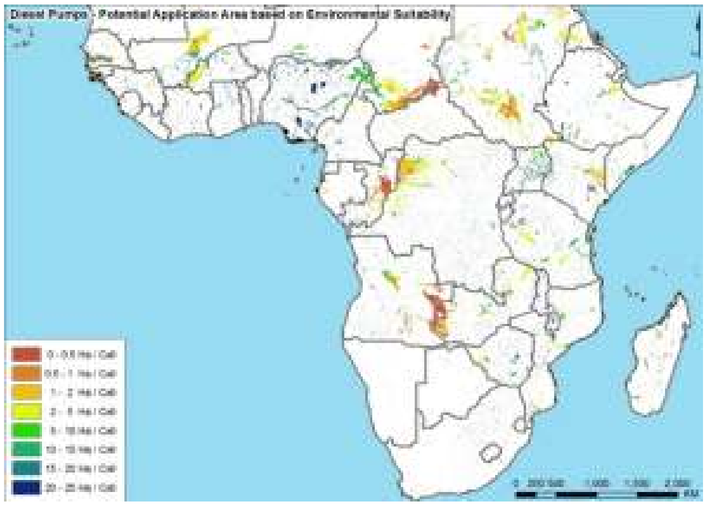

Figure 1: Suitable area for expansion of motor pumps, ex-ante results

Source: IFPRI Team

A pixel with a score greater than 55 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 estimate.

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 motor pumps 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 motor pumps

Criteria for motor pumps	Scoring scheme
FAO Fluvisols	False = 0, 1 - 15 % = 11, 16 - 50 % = 22, 51 - 100 % = 33
Market access	5 km = 10 minutes = 33, 10 km = 20 minutes = 22, 20 km = 40 minutes = 11, 30 km = 60 minutes = 0, 60 km = 120 minutes = 0
Distance to surface water	< 0.5 km = 33.333, > 0.5 km = 0

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

- *Water Availability.* Both groundwater and surface water can be used for irrigation. The groundwater abstraction rate is restricted so as not to exceed the recharge rate. Moreover, 20 percent of runoff is reserved for environmental flows.

- *Cultivation of Particular Crops*. The assessment assumes that motor pumps 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$263 per hectare per year was also assumed, with average amortized capital investment costs of $78/ha-yr (original capital investment: $269 and a reinvestment timeframe of eight years) and operating costs of $185/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.

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.

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

Potential for the expansion of motor pumps in SSA

The ex-ante assessment shows that the potential for the expansion of motor pumps is 48 million ha, potentially reaching a rural population of 309 million people (Figure 1 and Table 4). The potential for motor pump expansion is highest in the Gulf of Guinea region, with a potential expansion of over 12 million ha reaching 74 million people, driven primarily by the large potential in Nigeria. The Eastern and Indian Ocean countries and the Sudano–Sahelian region also show considerable potential for expansion of the technology, with 67 and 79 million people potentially reached in each of these regions, respectively. Compared to the Gulf of Guinea, the potential is spread more evenly across countries in the Eastern and Sudano–Sahelian regions, with significant potential found in Ethiopia, Kenya, Madagascar, Tanzania, and Uganda in the Eastern region and Burkina Faso, Chad, Mali, Niger, and Sudan in the Sudano–Sahelian region.

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).

Table 4. Ex-ante potential for the expansion of motor pumps in SSA, assuming 100 percent adoption

Country Name	Potential application area (1000 ha)	Rural population reached (thousand people)
Central	8,579	54,102
Eastern and Indian Ocean Countries	10,617	66,193
Gulf of Guinea	12,363	74,059
Southern Africa	6142	34,938
Sudano-Sahelian	10,239	79,019
All SSA	47,939	309,031

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 lower potential for adoption of motor pumps in the region compared to the ex-ante assessment (Figure 2). The results of the SWAT–DREAM assessment for motor pumps are summarized in Table 5 for the baseline scenario. The results indicate a potential area expansion of 29.6 million ha, which is less than two thirds of the area potential shown in the ex-ante analysis.

The total number of people reached is reduced to 185 million, compared to 309 million in the ex-ante assessment. Total net revenues as a result of the expansion of motor pumps throughout the region would be $22 billion per year, with revenues highest in the Eastern and Indian Ocean countries, Southern Africa, and the Gulf of Guinea. This expansion would be accompanied by a significant increase in water consumption. The total increase in water consumption as a result of the expansion of motor pumps in SSA is estimated at 67 billion m^3/yr, which amounts to a 98-percent increase.

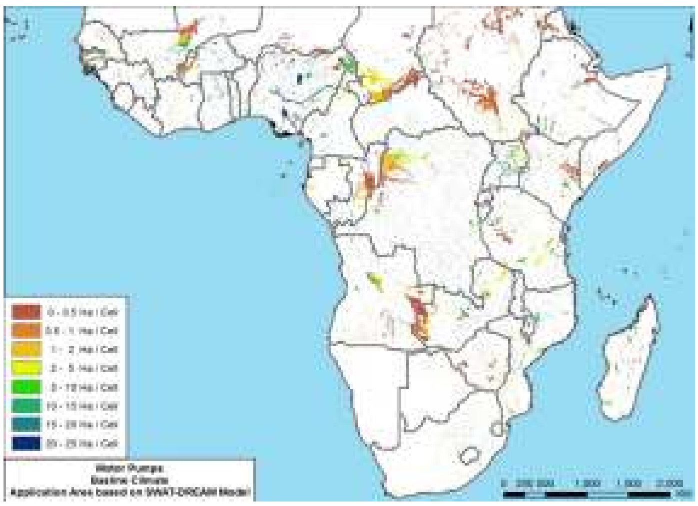

Figure 2: Suitable Area for expansion of motor pumps, SWAT-DREAM results
Source: IFPRI Team.

Table 5. Predictive modeling results for the potential expansion of communal motor pumps, 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	1,137	0.91	7,251	4.24	539.1
Cameroon	803	0.23	5,020	1.41	156.1
Central African Republic	442	0.23	2.431	0.89	757.6
Congo	381	0.39	1,857	0.26	53.6
Congo, DRC	3,521	1.41	22,885	6.14	1,764.9
Equatorial Guinea	3	0.002	28	0.003	2.7
Gabon	108	0.05	633	0.07	132.1
Central Africa	**6,395**	**3.23**	**40,106**	**13.02**	**462.9**
Burundi	58	0.12	368	0.195	51.5
Ethiopia	1,959	3.20	12,732	6.47	363.2
Kenya	844	1.12	4,852	2.17	130.1
Madagascar	1,020	0.20	6,120	2.03	65.8
Rwanda	67	0.14	374	0.17	134.2
Tanzania	1,607	1.51	10,447	4.81	273.7
Uganda	1,824	1.37	11,627	2.72	405.6
Eastern and Indian Ocean Countries	**7,378**	**7.66**	**46,520**	**18.56**	**196.3**
Benin	221	0.12	1,463	0.44	186.7
Côte d'Ivoire	480	0.29	3,418	1.02	191.5
Ghana	1,021	0.87	5,103	2.59	911.6
Guinea-Bissau	11	0.05	84	0.01	41.6
Liberia	159	0.11	1,136	0.32	1,474.6
Nigeria	6,398	2.34	36,789	10.9	85.1
Sierra Leone	200	0.14	1,496	0.61	66.9
Togo	224	01.2	1,571	0.28	251.4
Gulf of Guinea	**8,789**	**4.08**	**51,625**	**16.44**	**105.9**
Botswana	34	0.02	178	0.06	47.9
Lesotho	14	0.02	74	0.02	41.3
Malawi	940	2.78	5,522	3.46	584.9
Mozambique	1,054	0.29	5,928	1.83	186.9
Namibia	11	0.005	70	0.03	16.2
South Africa	493	0.79	2,463	1.33	21.8
Swaziland	17	0.02	115	0.05	7.2
Zambia	1,337	1.17	8,023	6.12	548.0
Zimbabwe	127	0.11	789	0.52	35.1
Southern Africa	**4,037**	**5.20**	**23,161**	**13.41**	**118.7**

Table 5. Predictive modeling results for the potential expansion of communal motor pumps, 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 %
Burkina Faso	1,066	0.54	8.926	2.59	212.3
Chad	671	0.27	4,445	0.94	135.1
Eritrea	5	0.01	32	0.02	24.3
Mali	670	0.04	4,775	0.68	11.2
Mauritania	7	0.005	56	0.01	0.8
Niger	136	0.11	1,019	0.12	6.1
Senegal	150	0.19	1,933	0.18	13.1
Somalia	6	0.004	43	0.02	0.6
Sudan	340	0.70	2,637	1.05	7.5
The Gambia	11	0.01	201	0.01	23.5
Sudano-Sahelian region	**3,062**	**1.88**	**24,068**	**5.62**	**19.3**
All SSA	**29,661**	**22.06**	**185,480**	**67.05**	**98.4**

Source: IFPRI Team

The results of sensitivity analysis (Table 6) show that 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 1.6 million ha, net revenues would increase by $4 billion per year, and the rural population reached would increase by 10 million, compared to the baseline. Conversely, application area decreases by 4 million ha, net revenues decline by $4 billion, and the number of people reached is reduced by 27 million when irrigation costs increase by 50 percent.

The potential for motor pumps is even more sensitive to changes in the initial crop price. Under the different crop price scenarios, a 30 percent increase in initial crop price results in an additional potential application area of 1.5 million ha, an increase in net revenues of $17 billion, and an additional 9 million people reached.

A decrease in the initial crop price results in a lower application area (by 11.5 million ha), a reduction in net revenues (by $15 billion), and a decline in rural population reached (by 71 million), compared to the baseline.

Table 6. Predictive modeling results for the potential expansion of motor pumps, scenario results

	Baseline	-50% irrigation cost	+ 50% irrigation costs	-30% initial crop price	+ 30% initial crop price	No groundwater aavailability
Area (thousand ha.)	29,661	31,245	25,344	18,140	31,117	21,929
Rural population reached (thousand people)	185,480	195,663	158,564`	114,521	194,405	136,748
Net revenue (US$ billion)	22.06	26.13	18.36	7.30	38.83	18.27
Water consumption (billion m³/yr)	67.05	68.44	61.47	45.05	70.07	51.27
Irrigation water consumption increase (%)	98.37	100.41	90.18	66.09	102.80	75.22

Source: IFPRI Team

Note: Results shown are for all of SSA

Water consumption increases significantly under scenarios resulting in an increase in motor pump expansion. A 50 percent decrease in irrigation costs or a 30 percent increase in initial crop price would increase water use by an additional 1 and 3 billion m^3/yr compared to the baseline, respectively.

Groundwater resources are important to the expansion of motor pumps. The baseline scenario assumed that groundwater was available to support the expansion of motor pumps up to the groundwater recharge level. However, when groundwater is excluded as a water source, area potential for motor pumps drops substantially, to 22 million ha for all of SSA. This result also suggests that the potential estimates obtained after SWAT–DREAM modeling is heavily constrained by the physical availability of water resources, with variations across countries and basins.

The impacts of climate change on the application potentials of motor pumps, the application areas, rural population reached, net revenue, and water use 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. We use the A2 SRES scenario, which is considered moderate.

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

	SWAT+DREAM		
	Baseline	Csia	Cnra
Area (thousand ha)	29,661	26,787	31,367
Rural population reached (thousand people)	185,480	167,474	196,319
Net revenue (billion dollars)	22,06	19.47	20.81
Water consumption (billion m3/year)	67.05	61.07	72.08
Irrigation water consumption increase (%)	98.37	89.60	105.75

Source IFPRI Team.
Note: Results shown are for all of SSA. Climate factors were not part of the ex-ante analysis criteria for motor pumps.

The results in Table 7 show that changes in the estimated application area due to climate change range from -10 percent to +6 percent.

Motor pumps have a very large potential for expansion in SSA, but unregulated adoption could undermine the sustainability of the water reserves.

Conclusions

Motor pumps have a very large potential for expansion in SSA in terms of application area and rural population reached, although the estimated numerical values are highly sensitive to the assumptions we made in the assessment.

The expansion of motor pumps may be constrained by various factors, including the physical scarcity of water in the dry season. Both "hard" and "soft" constraints on water availability were imposed in the assessment, with groundwater withdrawals limited to recharge levels and a reserve of 20 percent of runoff for environmental flows. Under these constraints, the expansion of motor pumps in SSA would consume an additional 67 billion m^3 of water per year, a 98-percent increase over current water use.

Unregulated adoption of motor pumps will likely result in larger expansion, which could create significant tension over water allocation and undermine the sustainability of aquatic environments. To address the concerns associated with motor pump expansion, regulations and policies that help to internalize externalities of irrigation development should be developed hand-in-hand with investments in this area.