International Water Management Institute

Project Brief

# Assessing the potential for sustainable expansion of small-scale solar irrigation in Ségou and Sikasso, Mali

Nearly 80% of Mali's population is dependent on agriculture. Most of these people are smallholders who own less than 10 hectares (ha) of land and practice subsistence farming (FAO 2017). Due to their limited resources, smallholders are unable to invest in agricultural practices and technologies, such as fertilizer application and irrigation, that would increase their production. As a result, these farmers face a range of threats to their livelihoods, most notably water scarcity, climate variability, repeated cycles of floods and droughts, and poor soil fertility (Andrieu et al. 2017).

While irrigation is limited to cotton, sugarcane and rice in the Office du Niger area and along the Niger River in central Mali, rain-fed cultivation of coarse grain cereals is widespread in the Niger River Basin, covering around 5.8 million ha or 90% of Mali's arable land (FAO 2017). However, the quantity of grain produced by smallholders is insufficient to meet their dietary requirements, resulting in food insecurity and malnourishment, particularly in the districts of Sikasso, Ségou, Mopti, Koulikoro and Kayes.

A solar-run technology park set up to demonstrate the potential of crops in the village of N'Golonianasso, Mali (*photo:* Amadou Sidibé).

USAID FROM THE AMERICAN PEOPLE
FEED THE FUTURE The U.S. Government's Global Hunger & Food Security Initiative
INNOVATION LAB FOR Small Scale Irrigation
CGIAR RESEARCH PROGRAM ON Water, Land and Ecosystems

IWMI (2019) showed that Ségou and Sikasso have some of the largest areas suitable for solar-powered irrigation. Furthermore, more than 90% of the agricultural area in these districts is under rain-fed cultivation and malnutrition rates are high (Cooper and West 2017). Therefore, Ségou and Sikasso were selected to investigate water availability for small-scale solar-powered irrigation systems (SPIS) as part of a study conducted under the Innovation Lab for Small-Scale Irrigation (ILSSI) project.

## Challenges for irrigation expansion

The ILSSI project has identified the challenges to expanding irrigation as finding equitable, economically viable, environmentally sustainable and scalable solutions. Small-scale farmer-led irrigation practices are cost-effective and scalable agricultural water management solutions that have been proven to improve the food security and livelihoods of smallholders in sub-Saharan Africa (Lefore et al. 2019). Recent initiatives have introduced frameworks for identifying suitable locations for SPIS as part of farmer-led irrigation practices (Schmitter et al. 2018; Lefore et al. 2021). However, while individual SPIS technologies might consume a small amount of water, collectively, this can add up to significant water withdrawals. Therefore, the sustainability of agricultural expansion strategies depends on water resources being available for use in both wet and dry seasons, after accounting for all existing demands (including the environment).

The study outlined in this brief combines the outputs from the water accounting plus (WA+) modeling and solar suitability mapping carried out by IWMI (2019) along with other remote sensing and hydrologic modeling-based datasets (Sutanudjaja et al. 2018; Li et al. 2019; MacDonald et al. 2021) to understand the availability of surface water and groundwater resources and the limits for sustainably expanding SPIS in Mali (Figure 1).

## What is the extent of the area suitable for SPIS?

The area suitable for SPIS (based on the availability of surface water and shallow groundwater up to a depth of 7 meters for pumps with a capacity of 0.5-1 kWh) (IWMI 2019) was analyzed for various cercles (subdistrict-level administrative units) in Ségou and Sikasso (Figure 2). The Bougouni cercle in Sikasso has the largest area suitable for SPIS (195,500 ha). The total area identified as suitable for SPIS in Ségou and Sikasso is 145,000 ha and 655,000 ha, respectively. Up to 33% of existing

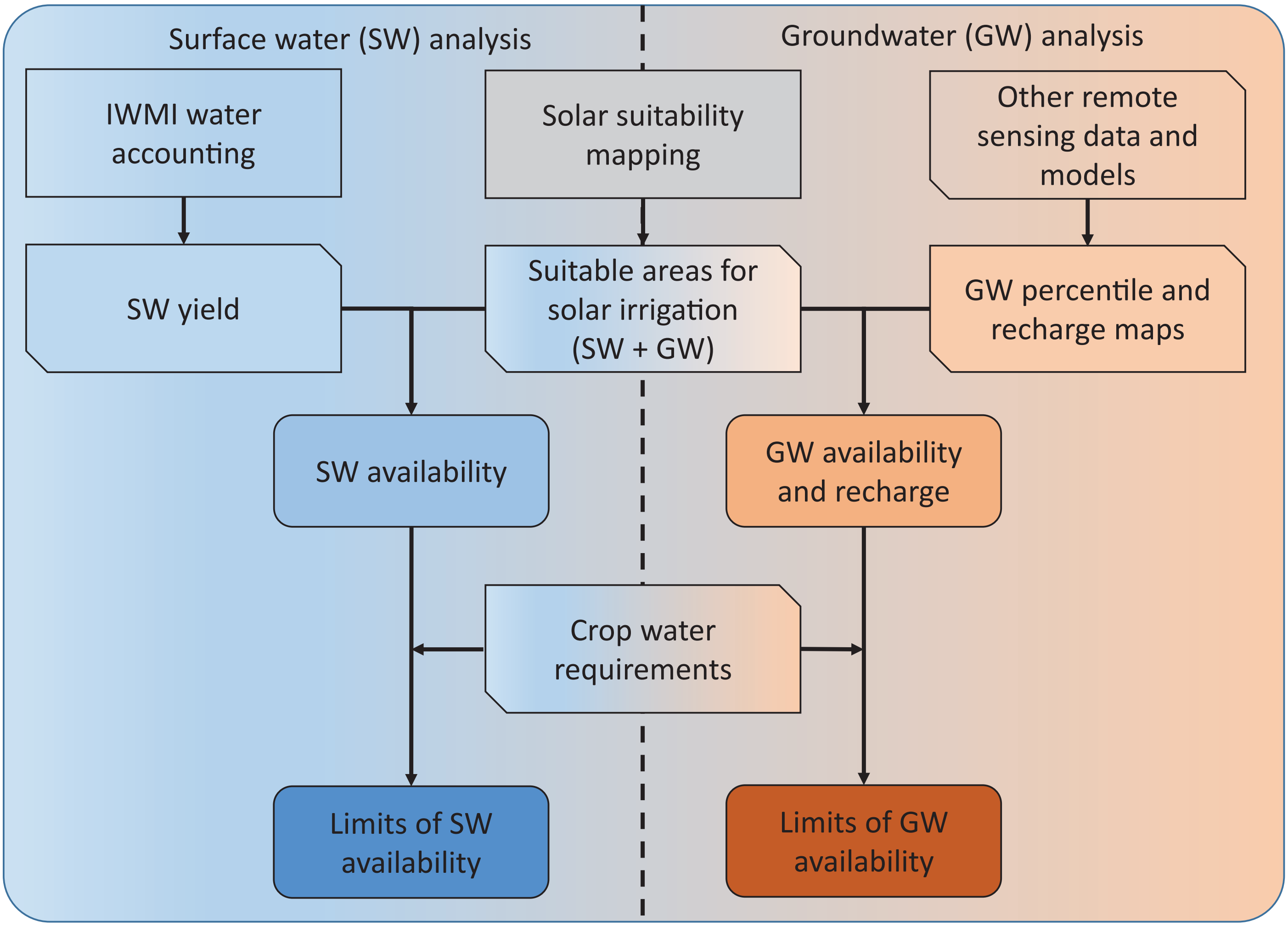


**Figure 1.** Schematic representation of the approach to assess the potential for expanding small-scale solar irrigation in Mali.

croplands in Ségou and 43% in Sikasso are suitable for SPIS. Existing grasslands, mixed shrublands, and barren and sparsely vegetated areas (up to 67% in Ségou and 56% in Sikasso) are also suitable for SPIS.

## How much surface water is available to support SPIS?

The surface water yield, computed as the difference between precipitation and rainfall-based evapotranspiration (P - $ET_{rain}$), was obtained from the WA+ framework. Figure 3 shows the surface water yield for different cercles in Ségou and Sikasso.

In Ségou, Bla and San cercles have more surface water yield available during the wet season than other cercles (up to 800 mm), making these areas most suitable for SPIS expansion. Conversely, Niono and Tominian cercles have no surface water yield, making these areas unsuitable for SPIS expansion. Meanwhile, Sikasso has relatively more surface water yield during the wet season than Ségou. Yanfolila and Sikasso cercles have the highest surface water yield (up to 500-800 mm), making these areas most suitable for SPIS expansion. Other cercles have uniform surface water yield up to 500 mm in the wet season. Unlike surface water availability in the wet season, both Ségou and Sikasso have no (negative) surface water yield during the dry season.

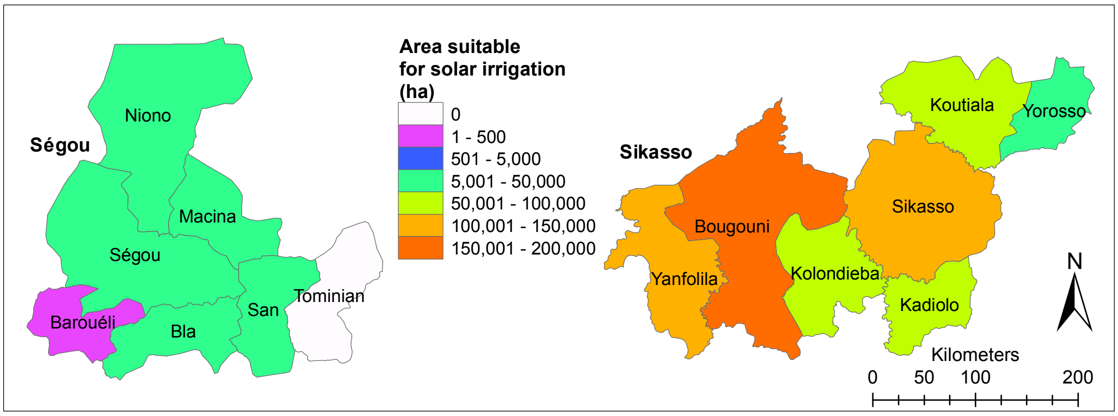


**Figure 2.** Area (ha) identified as suitable for small-scale solar irrigation for cercles in Ségou and Sikasso, Mali.

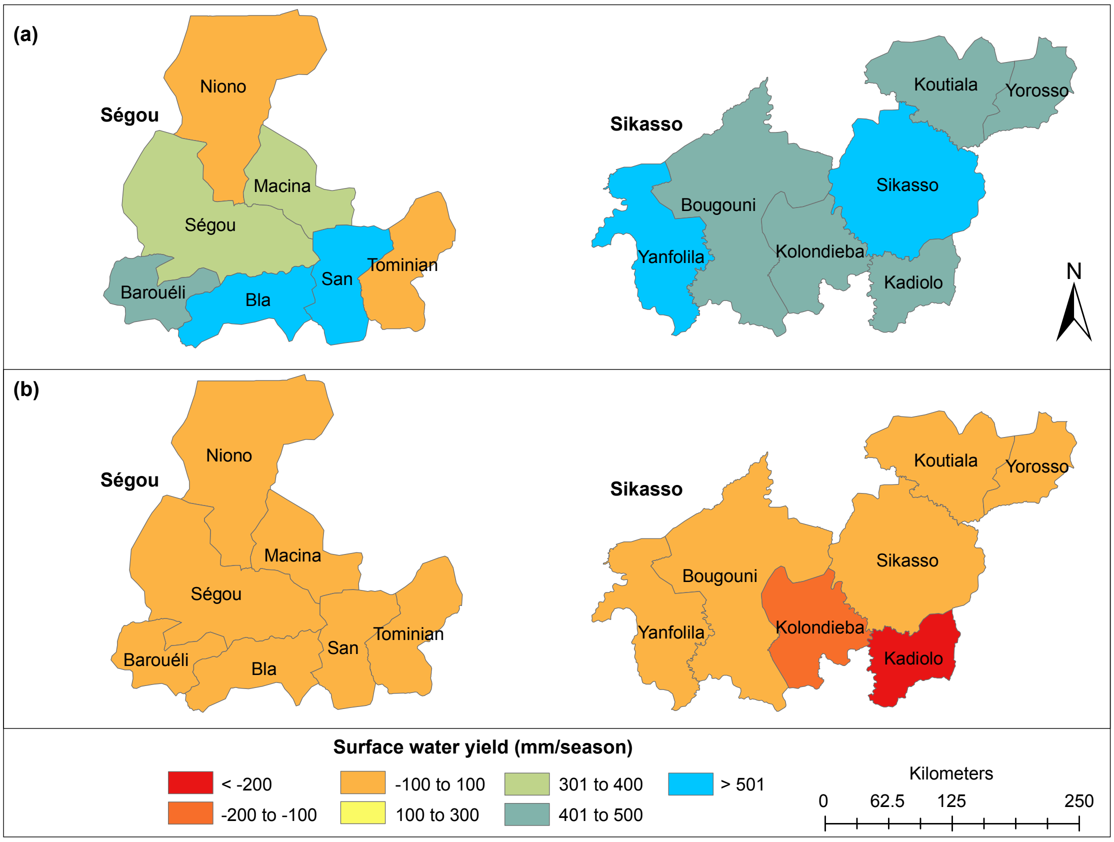


**Figure 3.** Surface water yield (P - $ET_{rain}$) for cercles in Ségou and Sikasso, Mali, during the (a) wet (June-November) season, and (b) dry (December-May) season.

## How much groundwater is available to support SPIS?

Groundwater percentile maps (Li et al. 2019) were used to understand groundwater availability. Each cercle was classified into low (0-40), medium (41-60), medium-high (61-80) and high (81-100) classes of groundwater availability based on groundwater percentiles. Figure 4(a) indicates that all the cercles in Ségou and four cercles in Sikasso have medium-high groundwater availability, and three cercles in Sikasso (Yanfolila, Kolondieba and Kadiolo) have medium groundwater availability.

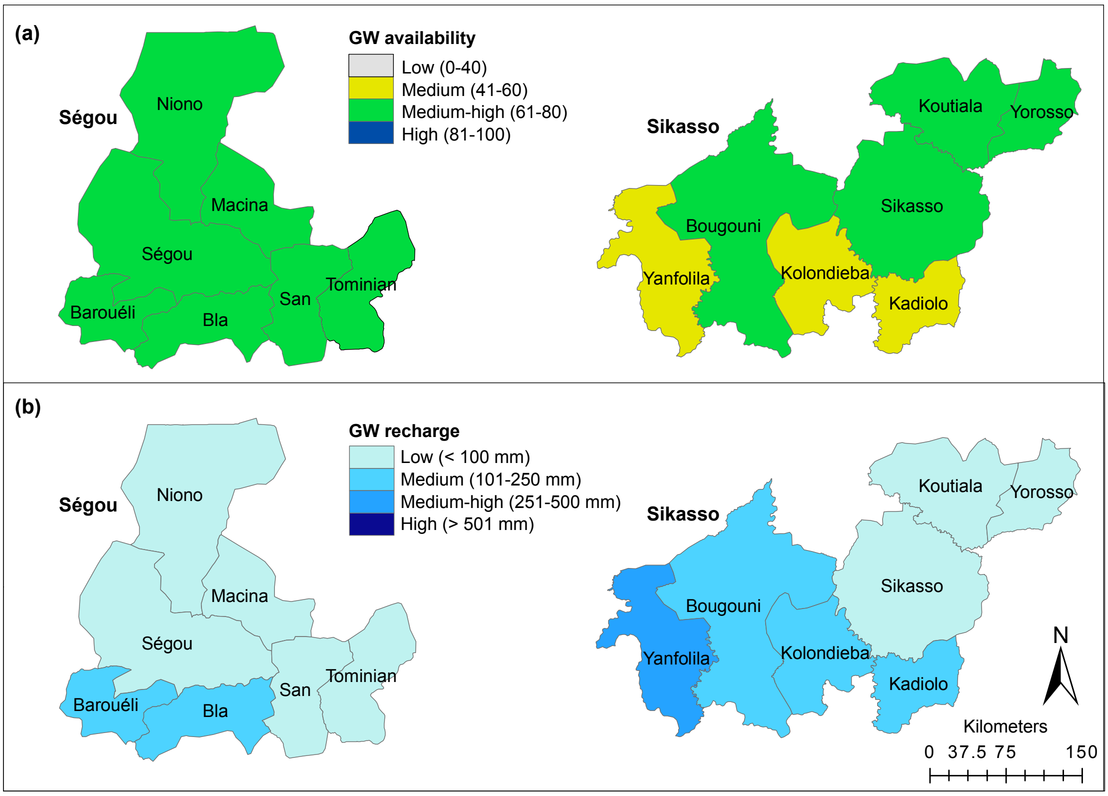


**Figure 4.** (a) Groundwater availability, and (b) groundwater recharge summarized for cercles in Ségou and Sikasso, Mali.

Groundwater recharge data obtained from the PCRaster GLOBal Water Balance (PCR-GLOBWB) model (Sutanudjaja et al. 2018) and recently published groundwater recharge data based on field observations (MacDonald et al. 2021) were analyzed to understand the sustainable limits of groundwater irrigation. Each cercle was grouped into low (< 100 mm), medium (101-250 mm), medium-high (251-500 mm) and high (> 501) classes based on annual groundwater recharge estimates. Figure 4(b) shows that some cercles in Ségou (Barouéli and Bla) and Sikasso (Yanfolila, Bougouni, Kolondieba and Kadiolo) have medium to medium-high annual groundwater recharge. Other cercles have low annual groundwater recharge.

Solar-powered drip irrigation is an efficient means to irrigate crops in water-scarce areas of Africa (*photo:* David Brazier/IWMI).

## What area of crops can be supported by SPIS?

The water requirements of commonly grown vegetable crops in the region were used to understand the availability and sustainable limits of both surface water and groundwater irrigation. Table 1 provides a list of crops, water availability and water source for the areas identified as suitable for SPIS based on the crop growing periods and crop water requirements obtained from the literature.

During the wet season, surface water yield can support vegetable crops with low water requirements (~300-550 mm/season) in Ségou and Sikasso. In addition, most cercles have no (negative) surface water yield in the dry season. Thus, crops with low water requirements can be grown during the dry season, provided that there are check dams, ponds or other structures that can store wet season water surpluses (~250-300 mm) and groundwater is available for supplemental irrigation.

Groundwater availability data shows that Ségou has more groundwater than Sikasso. However, annual groundwater recharge rates are higher in Sikasso than in Ségou (Figure 4). Our analysis indicates that supplemental irrigation from groundwater is essential to avoid crop failures. Assuming sustainable groundwater yield is about 50% of annual groundwater recharge (Altchenko and Villholth 2015), groundwater resources are available to provide supplemental irrigation in the wet season and meet most of the crop water requirements during the dry season for an area of about 270,000 ha in Sikasso and about 80,000 ha in Ségou. Since this analysis uses coarse resolution continental-scale groundwater recharge data, additional studies are needed to monitor groundwater levels, and evaluate changes in surface water and groundwater availability and crop water demand, as this will help to fully understand the potential of groundwater irrigation.

A farmer using a solar pump to irrigate her crops in Africa (*photo:* David Brazier/IWMI).

**Table 1.** List of crops that can be grown during the wet (June-November) and dry (December-May) seasons using surface water (SW) or groundwater (GW).

| Crop | Growing period (days) | Crop water requirement (mm) | Water availability | | | |
|---|---|---|---|---|---|---|
| | | | Ségou (wet season) | Ségou (dry season) | Sikasso (wet season) | Sikasso (dry season) |
| Tomatoes | 135-180 | 400-800 | SW* | GW** | SW* | GW** |
| Onions | 150-210 | 350-550 | SW* | SW/GW* | SW* | GW** |
| Okra | 70-90 | 350-500 | SW* | SW/GW* | SW* | GW** |
| Eggplant | 120-150 | 300-500 | SW* | SW/GW* | SW* | GW** |
| Cabbage | 120-140 | 350-550 | SW* | SW/GW* | SW* | GW** |
| Carrots | 100-150 | 450-600 | SW* | GW** | SW* | GW** |
| Beans | 75-90 | 300-550 | SW* | SW/GW* | SW* | GW** |
| Cassava | 180-360 | 500-700 | SW* | GW** | GW** | GW** |
| Sweet potatoes | 150-160 | 350-550 | SW* | SW/GW* | SW* | GW** |
| Groundnut | 130-140 | 500-700 | SW* | GW** | SW* | GW** |

*Notes:* * sustainable; ** sustainable over limited area.

## Summary of key findings

The key findings for Ségou and Sikasso are summarized in Figure 5.

### (a) Ségou

**Area suitable for small-scale solar-powered irrigation systems (SPIS)**
The total area identified as suitable for SPIS in Ségou is 145,000 ha.

**Water requirement for SPIS**
Assuming an average crop water requirement of 350-550 mm/season (for major vegetable/cereal crops) and an irrigation efficiency of 60%, the total irrigation water required is about 600-920 mm/season.

**Area feasible for SPIS**
Based on the irrigation requirement, we estimate that it would be feasible to irrigate crops with a low to medium water requirement.

**Surface water availability**
Surface water yield up to 800 mm is available during the wet season. Surface water can meet most crop water requirements during the wet season (for a crop with a low to medium water requirement) on 100% of the land identified as suitable for solar irrigation.

**Groundwater availability**
All the areas identified as suitable for solar irrigation have medium (41-60) to medium-high (61-80) percentile groundwater availability. Irrigation from groundwater sources is essential to avoid crop failures. In Ségou, groundwater resources can support crops covering an area of about 80,000 ha.

### (b) Sikasso

**Area suitable for small-scale solar-powered irrigation systems (SPIS)**
The total area identified as suitable for SPIS in Sikasso is 655,000 ha.

**Water requirement for SPIS**
Assuming an average crop water requirement of 350-550 mm/season (for major vegetable/cereal crops) and an irrigation efficiency of 60%, the total irrigation water required is about 600-920 mm/season.

**Area feasible for SPIS**
Based on the irrigation requirement, we estimate that it would be feasible to irrigate crops with a low to medium water requirement.

**Surface water availability**
Surface water yield up to 800 mm is available during the wet season. Surface water can meet most crop water requirements during the wet season (for a crop with a low to medium water requirement) on ~80% of the land identified as suitable for solar irrigation.

**Groundwater availability**
All the areas identified as suitable for solar irrigation have medium (41-60) to medium-high (61-80) percentile groundwater availability. Irrigation from groundwater sources is essential to avoid crop failures. In Sikasso, groundwater resources can support crops covering an area of about 270,000 ha.

**Figure 5.** Summary of the key findings for (a) Ségou, and (b) Sikasso, Mali.

## Conclusions

In this study, outputs from the WA+ framework were combined with solar suitability maps and other groundwater datasets to understand the availability of surface water and groundwater resources and the limits for sustainably expanding SPIS in Ségou and Sikasso districts in Mali. The total area identified as suitable for SPIS in Ségou and Sikasso is about 145,000 ha and 655,000 ha, respectively. Results of the study show that surface water yield up to 800 mm is available during the wet season in both Ségou and Sikasso, indicating sufficient water availability for irrigating crops with low water requirements. On the other hand, there was almost no surface water yield during the dry season in both these districts, suggesting insufficient water availability for irrigating crops in the dry season. However, provided that there are check dams, ponds or other structures that can store wet season water surpluses, surface water yield from the wet season can support dry season vegetable crops to some extent. The results indicate that supplemental irrigation using groundwater is essential to avoid crop failure. Considering the maximum groundwater recharge and sustainable yield estimates, groundwater resources can support the irrigation water demand of crops covering an area of about 80,000 ha in Ségou and about 270,000 ha in Sikasso. However, any large-scale investment in SPIS in the two districts would require local verification of current water availability and use as well as guidelines on irrigation to help smallholder farmers make the most of every drop.

Solar irrigation in a farmer's field in the village of Sirakélé, Sikasso district, Mali (*photo:* Amadou Sidibé).

## References


Altchenko, Y.; Villholth, K.G. 2015. Mapping irrigation potential from renewable groundwater in Africa – a quantitative hydrological approach. *Hydrology and Earth System Sciences* 19(2): 1055–1067. https://doi.org/10.5194/hess-19-1055-2015

Andrieu, N.; Sogoba, B.; Zougmoré, R.; Howland, F.; Samake, O.; Bonilla-Findji, O.; Lizarazo, M.; Nowak, A.; Dembele, C.; Corner-Dolloff, C. 2017. Prioritizing investments for climate-smart agriculture: Lessons learned from Mali. *Agricultural Systems* 154: 13–24. https://doi.org/10.1016/j.agsy.2017.02.008

Cooper, M.W.; West, C.T. 2017. Unraveling the Sikasso paradox: Agricultural change and malnutrition in Sikasso, Mali. *Ecology of Food and Nutrition* 56(2): 101–123. https://doi.org/10.1080/03670244.2016.1263947

FAO (Food and Agriculture Organization of the United Nations). 2017. *Country fact sheet on food and agriculture policy trends – Mali*. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). 6p. http://www.fao.org/3/i7617e/i7617e.pdf

IWMI (International Water Management Institute). 2019. *Suitability for farmer-led solar irrigation development in Mali*. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE). 4p. https://hdl.handle.net/10568/101594

Lefore, N.; Giordano, M.; Ringler, C.; Barron, J. 2019. Sustainable and equitable growth in farmer-led irrigation in sub-Saharan Africa: What will it take? *Water Alternatives* 12(1): 156–168. http://www.water-alternatives.org/index.php/alldoc/articles/vol12/v12issue1/484-a12-1-10

Lefore, N.; Closas, A.; Schmitter, P. 2021. Solar for all: A framework to deliver inclusive and environmentally sustainable solar irrigation for smallholder agriculture. *Energy Policy* 154: 112313. https://doi.org/10.1016/j.enpol.2021.112313

Li, B.; Rodell, M.; Kumar, S.; Beaudoing, H.K.; Getirana, A.; Zaitchik, B.F.; de Goncalves, L.G.; Cossetin, C.; Bhanja, S.; Mukherjee, A.; Tian, S.; Tangdamrongsub, N.; Long, D.; Nanteza, J.; Lee, J.; Policelli, F.; Goni, I.B.; Daira, D.; Bila, M.; de Lannoy, G.; Mocko, D.; Steele-Dunne, S.C.; Save, H.; Bettadpur, S. 2019. Global GRACE data assimilation for groundwater and drought monitoring: Advances and challenges. *Water Resources Research* 55(9): 7564–7586. https://doi.org/10.1029/2018WR024618

MacDonald, A.M.; Lark, R.M.; Taylor, R.G.; Abiye, T.; Fallas, H.C.; Favreau, G.; Goni, I.B.; Kebede, S.; Scanlon, B.; Sorensen, J.P.R.; Tijani, M.; Upton, K.A.; West, C. 2021. Mapping groundwater recharge in Africa from ground observations and implications for water security. *Environmental Research Letters* 16(3): 034012. https://doi.org/10.1088/1748-9326/abd661

Schmitter, P.; Kibret, K.S.; Lefore, N.; Barron, J. 2018. Suitability mapping framework for solar photovoltaic pumps for smallholder farmers in sub-Saharan Africa. *Applied Geography* 94: 41–57. https://doi.org/10.1016/j.apgeog.2018.02.008

Sutanudjaja, E.H.; van Beek, R.; Wanders, N.; Wada, Y.; Bosmans, J.H.C.; Drost, N.; van der Ent, R.J.; de Graaf, I.E.M.; Hoch, J.M.; de Jong, K.; Karssenberg, D.; Lopez, P.L.; Peßenteiner, S.; Schmitz, O.; Straatsma, M.W.; Vannametee, E.; Wisser, D.; Bierkens, M.F.P. 2018. PCR-GLOBWB 2: A 5 arcmin global hydrological and water resources model. *Geoscientific Model Development* 11(6): 2429–2453. https://doi.org/10.5194/gmd-11-2429-2018

## Project

The Innovation Lab for Small-Scale Irrigation (ILSSI) project is funded by the United States Agency for International Development (USAID) as part of the Feed the Future initiative. The project is led by the Norman Borlaug Institute for International Agriculture at Texas A&M University, USA, in partnership with the International Water Management Institute (IWMI), International Livestock Research Institute (ILRI), International Food Policy Research Institute (IFPRI), World Vegetable Center, and Household Water Insecurity Experiences – Research Coordination Network (HWISE-RCN). IWMI leads the scaling research component of the project.

## Acknowledgments

This brief was made possible through support provided by the Feed the Future Innovation Lab for Small-Scale Irrigation (ILSSI) project, funded by the United States Agency for International Development (USAID) (Grant: AID-OAA-A-13-00055). The opinions expressed herein are those of the authors and do not necessarily reflect the views of USAID. This research was carried out as part of the CGIAR Research Program on Water, Land and Ecosystems (WLE) and supported by Funders contributing to the CGIAR Trust Fund (https://www.cgiar.org/funders/).

## Contacts

Naga Velpuri, Senior Researcher – Water Accounting, IWMI (n.velpuri@cgiar.org)
Mansoor Leh, Researcher – Spatial Hydrology, IWMI (m.leh@cgiar.org)
Lisa-Maria Rebelo, Principal Researcher – Earth Observation for Sustainable Development, IWMI (l.rebelo@cgiar.org)
Petra Schmitter, Principal Researcher – Agricultural Water Management, IWMI (p.schmitter@cgiar.org)
Thai Thi Minh, Senior Researcher – Innovation Scaling, IWMI (t.minh@cgiar.org)

IWMI International Water Management Institute

IWMI is a CGIAR Research Center

The International Water Management Institute (IWMI) is an international, research-for-development organization that works with governments, civil society and the private sector to solve water problems in developing countries and scale up solutions. Through partnership, IWMI combines research on the sustainable use of water and land resources, knowledge services and products with capacity strengthening, dialogue and policy analysis to support implementation of water management solutions for agriculture, ecosystems, climate change and inclusive economic growth. Headquartered in Colombo, Sri Lanka, IWMI is a CGIAR Research Center and leads the CGIAR Research Program on Water, Land and Ecosystems (WLE).

**International Water Management Institute (IWMI)**

**Headquarters**
127 Sunil Mawatha, Pelawatte, Battaramulla, Sri Lanka

Mailing address:
P. O. Box 2075, Colombo, Sri Lanka
Tel: +94 11 2880000
Fax: +94 11 2786854
Email: iwmi@cgiar.org
www.iwmi.org

Published: November 2021