Solar powered irrigation system in Upper East Region, Ghana –2022 (Photo credit: IWMI)

Feed the Future Innovation Laboratory for Small Scale Irrigation

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Submitted by the Norman Borlaug Institute for International Agriculture and Development, The Texas A&M University System & AgriLife Research

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Contents

Executive Summary

The Innovation Lab for Small Scale Irrigation (ILSSI), a cooperative agreement led by the Borlaug Institute for International Agriculture Development at Texas A & M University, made progress in both lessons and research-based impact across objectives.

Objective 1, Identify and Test Approaches to Sustainably Scale Small Scale Irrigation through Reducing Constraints and Strengthening Opportunities for Access. Research and market-based activities with private partners in Ghana, Ethiopia and Mali show high potential for solar irrigation development. Solar suitability mapping, market segmentation analysis, and demand-supply linkage workshops have benefited companies' market growth and filled a knowledge gap; thousands of farmers were reached across the countries. Global and national crises negatively affected farmers and lowered ability to invest in irrigation. Sales targets were met in Mali despite constraints from the economic sanctions, while targets were not met in Ethiopia amid supply chain, forex and conflict-related constraints. In Ghana, sales targets were met, but the private partner exited the SPIS market amid tax reforms and demands for high returns by equity investors. Multi-stakeholder dialogues enabled market linkages between private actors in value chains and irrigation equipment supply, farmers, and public agencies and research institutions. Research results have been integrated into irrigation initiatives (e.g. World Bank), and scaling solar irrigation (e.g. Water and Energy for Food, GIZ program in Ghana, AICCRA, and Power Africa Off Grid Project).

Objective 2, Identify and test approaches to scale Small Scale Irrigation to be sustainable and support resilience. ILSSI climate and water resource analysis in West Africa shows growing limitations for rainfed production and the need for supplemental and dry season irrigation. Analysis on the energy-water-food nexus show increasing feasibility and returns for solar irrigation under climate change scenarios, particularly with increased energy costs. While initially focused on dry season irrigated, high value crops, legumes have been added to modeling analysis. In Ethiopia, field trials continued on climate resilient irrigated fodder varieties. In Mali, researchers began modelling vegetable and seed production.

Objective 3, Identifying and testing approaches to maximize inclusivity, effective governance, women's empowerment, and involvement of youth for nutrition-sensitive irrigated production. ILSSI continued work with private companies to reach more women and youth, particularly related to marketing approaches and finance tools, but private partners identified more constraints to reaching women and youth that require further refinement of their business models. Results of ILSSI's research on gender are being applied in several other development projects. In Ethiopia, analysis on irrigated fodder to dairy value chains showed that irrigated fodder can be more profitable than irrigated vegetable production and has multiple nutritional benefits. The fodder suitability maps and the value chain analysis are being used in a World Bank and Dutch-funded projects to scale. Towards inclusive resilience, ILSSI completed fieldwork on community-level water governance in Ethiopia, but expanded water governance activities in Ghana on demand to scale experiential games to more farmers and to initiate South-South knowledge exchange between countries. On nutrition, ILSSI research highlighted that irrigating households tend to have better women's dietary diversity and children's HWZ scores, as well as resilience to drought; knowledge sharing was expanded on irrigation as a nutrition-sensitive investment.

Objective 4, Achieve impact through uptake of ILSSI research results and methods. ILSSI organized and/or were invited to national and global forums targeted at policy makers and investment planners, including with the African Union, World Bank, UN Working Group on Nutrition, among others. ILSSI continually updates the project website, open access library repository and produces a quarterly newsletter. Trainings targeted private companies, young scientists, extension and farmers. More knowledge products were produced in French and English, including policy briefs and videos.

1. Introduction

The Feed the Future Innovation Lab for Small Scale Irrigation (ILSSI) is a cooperative agreement led by the Norman Borlaug Institute for International Agriculture Development (BIIAD) at Texas A & M University (TAMU) Agrilife Research. ILSSI's vision is to contribute to an increase of profitable, sustainable and gender-sensitive irrigation to support inclusive agricultural growth, resilient food systems, and nutrition and health outcomes, particularly for vulnerable populations. The project works in Ethiopia, Ghana, and Mali; Bureau for Humanitarian Affairs supports buy-in activities in Ethiopia and Mali. Limited analysis of data continues for Tanzania. ILSSI has sub-awards with the International Water Management Institute, International Food Policy Research Institute, International Livestock Research Institute, the World Vegetable Center, Kwame Nkrumah University for Science and Technology, University of Ghana and private sector partners PEG Africa (Ghana), Rensys Engineering (Ethiopia), and EMICOM and Ecotech in Mali. This report describes progress toward objectives in fiscal year 2022, the ninth year of the cooperative agreement.

2. Progress toward objectives (based on components of Areas of Inquiry)

Objective 0: Effectively plan, coordinate, and organize multi-institutional activities

- Management Entity (ME) at BIIAD/TAMU maintained 10 sub-agreements and leveraged several funded and unfunded collaborations.
- Budget burn rate improved with stronger monitoring of sub-agreement expenditure rates.
- Convened regular virtual Project Management and External Advisory Committee meetings.
- Engaged with the USAID Missions in Ghana, Ethiopia and Mali; Mission representatives attended ILSSI workshops; engaged Mission supported projects (Mali, Ghana, Rwanda and Malawi).
- Worked with the USAID supported Sene Yiriwa project in the Inner Niger Delta in Mali; TAMU is providing environmental assessments.
- Engaged as a technical partner in the Horticulture Innovation Lab with UCDavis.
- Completed work in Nepal in a complementary activity through a USAID Mission buy-in to the Cereal Systems Initiative for South Asia (CSISA).

Objective 1: Identify and test approaches to sustainably scale SSI through reducing constraints and strengthening opportunities for access

Activity 1.1: Identify upscaling opportunities for resilient SSI systems

Sub-Activity 1.1.1. Joint research scaling activity with private sector entities

ILSSI's private partners made mixed progress against milestones and offered lessons relevant to solar irrigation scaling and market development (SPIS), See Annex 1. Information and research results were shared with World Bank, GIZ, CLASP, Bill and Melinda Gates Foundation, Power Africa Off Grid Project and AICCRA for scaling. The spike in fuel prices and decreased access to fuel increased demand for SPIS, but unfavorable exchange rates, high inflation and increased input costs (e.g. fertilizer) reduced farmer ability to pay and increased risk aversion that lowered access to credit. ILSSI sub-awardee IWMI collaborates with and provides technical and marketing support to private sector partners (PEG, Rensys, EMICOM, ECOTECH, as well as unfunded partnership with PumpTech and Tech2 in Ghana), as follows:

Private sector partner activities include:

- Adapting marketing, distribution, and finance, approaches to reach women and youth
- Testing more business models and finance modalities to reach different market segments
- Adapting credit scoring tools to contextual factors and to be more gender sensitive
- Taking on extension, financial education and marketing roles, e.g. educating farmers on financial literacy and agronomy, for client acquisition and reduced risk of default
- Identifying demand for mixed uses, e.g fruits, vegetables, poultry, livestock/dairy, fish farming
- Forming partnerships with related services and suppliers (borehole, pipe/sprinkler suppliers)
- Finding mixed results in efforts to partner with produce off-takers; Most farmers report that markets are available, but they face cartels and low bargaining power with buyer-aggregators

Constraints include:

- Supply chain issues: shortage of chips for PAYGO pumps
- Political insecurity: sanctions in Mali; conflict in Ethiopia
- Unfavorable tax environment: Ghana's revised tax code reduced company profit margins
- High costs of navigating tax exemptions and access to foreign exchange (Ethiopia, Mali)
- High costs of inputs (fertilizer) reduced ability of farmers to invest in pumps
- Increased financial risk decreased distributors' willingness to provide farmer credit
- Lack of cellular network coverage disrupts mobile money payment, PAYGO pump control

Ghana

- market segmentation was completed in Upper West, Northern, North-eastern, Savannah
- co-organized demand-supply linkage workshops and field demonstrations

Ethiopia

- digitalization of credit assessment scorecard and inclusive marketing approach
- co-organized demand-supply linkage workshop and field demonstrations in Hossana and Lemo
- segmentation of market for SPIS bundles in Oromia and Amhara regions

Mali

- EMICOM ramped up marketing and the distribution network. Despite agreement with Angaza and BNDA, multiple crises reduced access to credit and increased interest rates.
- High demand by the youth was constrained by family elders who decide on assets, investments; marketing strategy is being adapted to also target information toward elders
- Cotton sanctions reduced farmers income and farmers could not complete pre-orders
- ECOTECH's SPIS shipment was refused entry (sanctions); the company had to reorder/reship

Sub-Activity 1.1.2. Qualitative survey with private and public sectors to assess information requirements and format

IWMI analyzed data from semi-structured interviews (Ghana, Ethiopia) and online survey with 140 company respondents. The findings (draft article 'Enabling private and public sector investment into farmer-led irrigation: What information is necessary?') highlight:

- Companies most frequently consider water availability and quality (75%), and network of renewable and non-renewable energy sources (75%) in first determining market investments.

- Farm-based information is the second most important determinant of company market investment, including: farm specifications (e.g., size, location, crop, irrigation system). Farmer organization and social structures are ranked third: farmer cooperative, unions, and/or related.
- Market information has the biggest impact on company market expansion: local need and for irrigation products/services, client financial capacity, farming system type, capacity, and cash-flow.

Sub-Activity 1.1.3 Refining the suitability mapping framework for solar and SSI packages at national scale (Ethiopia and Ghana) and sub-national scale (Ethiopia); Sub-Activity 1.1.4 Validation of the suitability maps using available data from private sector piloting

IWMI introduced the interactive online tool (http://sip.africa.iwmi.org/) to private sector partners (EMICOM and ECOTECH) and other companies (Sonikara and Horonya) companies, to customize the map to the companies' distribution areas. The tool uses open-access geospatial drivers and constraints to map suitability based on water resources, location, and water lifting capacity. Company-based customization of maps integrates socio-economic and financial factors.


Botanga, Tamale. Establishment of demand-supply linkages for scaling of irrigation bundles. See videos at: https://www.youtube.com/watch?v=uLE-G-c63Zo&t=14s

Sub-Activity 1.1.7.a. Land suitability assessment for cocoa cultivation in Ghana using a GIS based Multi-Criteria Evaluation (MCE); Sub-Activity 1.1.7.b. Potential of small scale irrigation and improved soil management practices on cocoa production, income and nutrition in Ghana

Cocoa productivity has been declining in Ghana with climate change, especially related to lengthening dryspells; farm rehabilitation is hindered by the 40% loss of seedlings. As cocoa remains central to Ghana's exports, foreign exchange earnings, and direct and indirect employment and income, ILSSI conducted an initial suitability assessment for irrigated cocoa, using SWAT and APEX; an assessment was made on the optimal crop water requirement (CWR) for cocoa (Theobroma cacao) in Ghana, in order to provide information necessary for irrigation to enhance the growth and development of the crop, and for increased production in the face of the changing climate. The results suggest most current cocoa growing areas already lack sufficient rainfall to sustain production and supplemental irrigation will be necessary. See Annex 2 for interim results of studies.

In addition, two graduate students at national partner institution Kwame Nkrumah University of Science and Technology, conducted household surveys in two cocoa-producing regions (Ashanti, Western) to assess potential of SSI and improved soil management on cocoa production, household income/nutrition.

Activity 1.2: Identify constraints and assess impact of policy through analyses and dialogue

Sub-Activity 1.2.1. Constraints Analysis

IFPRI published on constraints to the adoption of SSI technologies (Hierarchical modelling of the constraints to irrigation adoption in Ghana, Ethiopia, and Tanzania). The key finding is that locale-specific targeting of small-scale irrigation technologies is essential. For example, there is a positive association between plot-level use of SSI and the intensity of agricultural labor and inorganic fertilizers applied on the plot as well as between type of land ownership and type of irrigation system.

Sub-Activity Activity 1.2.2: Role of credit constraints

IFPRI published "Are Smallholder Farmers Credit Constrained? Evidence on Demand and Supply Constraints of Credit in Ethiopia and Tanzania" and "Demand and supply constraints of credit in smallholder farming: Evidence from Ethiopia and Tanzania" (*World Development),* and presented results during Stockholm World Water Week. Results from Ethiopia and Tanzania – show:

- demand-side credit constraints are at least as important as supply-side factors in both countries
- women are more credit constrained than men (from both the supply and demand sides)
- two-pronged approach to address credit constraints:
- supply-side factors (e.g. asset-based financing rather than a land title for credit issuance; better understanding farmer risk perception/behavior); access to larger, initial credit for technology purchase and smaller credit for running costs
- demand side factors, focusing on human capital, strengthened farmer financial literacy, information, extension services, and risk mitigation (e.g., bundling irrigation technology with insurance)

Sub-Activity 1.2.3. Net-Mapping in Ethiopia and Ghana to understand private sector constraints

Two papers published. Policy note drafted.

Sub-Activity 1.2.6. Assess impact of change in cost of water lifting technologies related to reduction in tariff on producer revenue

In response to continued interest from Government of Ethiopia, IFPRI is conducting an in-depth study based on import data of irrigation pumps (Ethiopia Customs Commission) and importers' forms to request the duty-free provision (Ethiopian Ministry of Agriculture). However, customs data is based on pump weight, so IFPRI is exploring how to make meaningful analysis. This will add to the IDSS FARMSIM model ex-ante assessment: "Preliminary economic impacts assessment of tariff reduction on water lifting technologies in Ethiopia".

Sub-Activity 1.2.7. Facilitating dialogue between key stakeholders to strengthen SSI scaling

Multi-stakeholder dialogues are convened and facilitated by ILSSI to bridge information gaps and strengthen irrigation equipment/input markets in project countries.

Ghana:

- 'Sustainability of cocoa systems: Exploring segmentation, water management and small scale irrigation suitability' (October 2021; 40 individuals; 25 organizations). Co-convened with IWMI and International Institute of Tropical Agriculture (IITA). Highlights: various stakeholders are initiating irrigation in cocoa with different approaches; knowledge sharing will be needed for sustainable development and monitoring of irrigation in the sector.
- 'Market and value chain approaches to farmer-led irrigation development' (April 2022; 51 individuals; 28 stakeholder organizations). Highlights: Participants perceive the potential for

private sector investment in FLI and the irrigated agricultural value chain to be high. Opportunities include: some local manufacture of irrigation equipment; growing awareness; use of water-saving technologies; bundling technologies with financing; interventions to process horticultural outputs for local and international markets; high market demand for irrigated products. Constraints include: dominance of public/donor technology transfer models that undermine market growth; lack of inclusion of women farmers; limited tailor-made product and service packages for irrigation; poor synergy among the interventions; donor approaches that reduce farmer investments.

- 'Innovations for improving irrigation water use efficiency in farmers' fields' (July 2022; 51 individuals; 23 organizations), convened with and funded by Ghana Agricultural Sector Investment Programme (GASIP). Highlights: Irrigation sector in Ghana is still in a niche stage; offers opportunities for both government and private sector investment. Surface water and groundwater irrigation have advantages and disadvantages that may complement each other if developed conjunctively.

Ethiopia:

- 'The role of offtake markets in unlocking small scale irrigation investments' (14 October 2021; 48 individuals; 28 stakeholder organizations). Co-convened by IWMI, World Bank Water Resources Group 2030 and Agriculture Water Management – Task Force, Ministry of Agriculture. Highlights: offtake market actors and other stakeholders have multiple roles in unlocking SSI investment, but are constrained by informal processes, high risk and price fluctuation, low transparency, and unbalanced decision-making power between actors.
- 'Scaling Sustainable and Inclusive Farmer-Led Irrigation' (May 2022; 41 individuals/18% women; 20 organizations), co-convened with the Agriculture Water Management Task Force at the Ministry of Agriculture (MoA), and the 2030 Water Resources Group (2030WRG). Highlights: constraints include lack of access to water resources, low quality of available technologies, underdeveloped aftersales and financial services, inadequate support for local manufacture. In the policy environment, inefficient management/regulatory framework for shallow groundwater development, poor tax exemption policy implementation, limited access to forex, and significant gaps in awareness, coordination, and collaboration among users, implementing institutions, and technology importers. Participants suggested digitization and stakeholder sensitization to improve tax exemption implementation while prioritizing forex allocation for the irrigation sub-sector.

Activity 1.3: Identify entry points to reduce supply constraints on irrigation technology markets

Sub-Activity 1.3.1 Determination of marketing margin along different points of SSI chain of actors

Ghana:

Irrigation supply chain net market margins are estimated to be between 5%-30%. Market margin is heavily dependent on import prices, port charges, and the business operating environment, there are challenges in the business operating environment across the irrigation equipment supply chains that influence the margin. Services and fees are not calculated per unit as part of determining margins. Market margins may change significantly with new tax policies and fluctuations in the Ghana Cedi.

Irrigation equipment actors in Ghana appear to price primarily on tangible costs (e.g. import, transportation, storage costs and services (warranty), demurrage, waiver filing fees, and additional illegal charges). Intangible costs include bureaucracy, non-adaptation, politics, and poor collaboration costs.

Policy changes in tax and port charges: Government of Ghana reduced the benchmark from the 50% discount on port charges to 30%; irrigation equipment importers now pay an additional 20% on port charges. In addition, Value Added Tax for small- to medium-scale enterprises (annual revenue above 500,000 GHC) changed whereby the previous rate of 4% VAT/levies on their products increased to 19.25% under the Value Added Tax (Amendment) Act, 2021 (Act 1072). This has increased the cost of irrigation equipment.

Structure of market: Lack of synergy in the industry results in poor bargaining power to influence government policy and interventions as well as the minimal development of the supply chains. The market is currently not supported by a range of services, such as research, input supply, communication, transportation, local administration, market information, and financial services.

Ethiopia:

The estimated marketing margin for solar, diesel, or petrol motor pump, and rope pumps range between 12-48% (60% for Grundfos), 23-50%, and greater than 70% respectively. The estimated marketing margin is greater than the anticipated marketing profit of about 20%; high risk perception may influence margins.

Supply chain for solar, motor pump and rope pumps are short, i.e., the importer or supplier of the locally manufactured irrigation technologies and wholesaler and retailer is the same company, sometimes using middlemen as the final link to end-users by charging an additional commission of 10-15 % of the sale price. The marketing structure is characterized as a segmented monopolist, with farmers having a limited role in determining the market price of these irrigation technologies.

Import/manufacturing cost, duty tax, and marketing (including storage and logistic) costs are important factors influencing the sales price. Solar and diesel/petrol pumps are not low-cost for smallholder farmers and there are no financial products, either from microfinance institutions or suppliers, to address the farmers' borrowing needs as the current burrowing ceiling is very low. Suppliers do not keep stocks of pumps and accessories because of the shortage of hard currency.

Policy changes on tax breaks are not effectively implemented, characterized by unclear import duties, a lack of clarity on which accessories (e.g., solar pump vs panel) are tax exempted, and problems of long import procedures. The lack of political commitment in not giving priority to the importation of irrigation equipment (agriculture in general) is contributing to the slow market growth for irrigation technology, contrary to the intent of policy.

Enhancing competitiveness by developing the supply chain and improving policy-related implementation issues to importation taxes and hard currency is critical for a better business environment and diffusion of irrigation technologies to smallholder farmers.

Sub-Activity 1.3.2 Identification and piloting of SSI scaling pathways with private entities

IWMI leads collaboration on scaling with private partners. In Ghana, IWMI's activities were co-funded by ILSSI and Africa RISING, while PumpTech covers all their own costs (zero funding from ILSSI/USAID); this follows the closure of the PEG Africa water pump business in Ghana.

Ghana:

Research shows high demand and potential for SPIS in Upper East, Upper West, and Savannah. Market segments in Upper East, Upper West, and North East Region: 1) resource-limited farmers, 2) mobile farmers, 3) farmer groups, 4) resource-rich farmers, 5) institutional clients (government organizations, development partners, and projects and businesses that promote solar-powered irrigation by introducing and supporting farmers to use the technologies, e.g., GIZ, USAID, SNV, and World Vision). Segments also vary by water sources, e.g. resource-rich farmers tend to use boreholes.

IWMI is supporting Pumptech in customizing business models and financial services, including:

- Direct payment by installment for resource-rich farmers
- Pre-paid pump services (PAYGO) for mobile farmers who use mainly surface water sources to farm during dry season and can afford a movable SPIS.
- Pay-as-you-own and/or blended financing for the resource-limited farmers who usually have permanent access to cultivated lands with water from dugouts and wells as their main sources
- Market development and linkages for the farmer groups who can raise funds from monthly or seasonal use paid by members in village savings and loan schemes and gradually accumulate capital to invest in SPIS.
- Training on solar irrigation knowledge and labor-force development for the institutional partners (government agencies, research and development partners) who promote SPIS.

To support public and private stakeholders to operationalize the establishment of a SPIS supply chain, IWMI, Pumptech, GIZ-Market Oriented Agriculture Programme, and Tech2 reached around 1,480 farmers and other value chain actors through:

- 3 demand-supply linkage workshops in Upper West Region, Ghana (October 2021; 238 participants being 86% male and 14% female; Agricultural Extension Agents, farmers, irrigation equipment and service companies, NGOs/development organizations, value chain actors).
- 3 Pumptech field demonstrations for PS2 solar-powered irrigation pumps in Upper West Region (83 farmers; 53% male; 47% female).
- 9 demand-supply linkage workshops co-funded with GIZ-Market Oriented Agriculture Programme (GIZ-MOAP) in Upper West (Wa, Jirapa, and Tumu), Northeast (Yagaba, Walewale, and Bunkprugu), and Savannah Region (Sawla, Daboya, and Buipe).
- 7 workshops n the Northeast, Northern, and Savannah Region, including TECH2 to introduce different irrigation systems/equipment to participants.
- 10 field demonstrations to connect farmers and the relevant value chain actors with SPIS bundles.

Pumptech brought the GIZ Ghana Green Energy to the knowledge partnership through a de-risking investment in Pumptech's distribution of pay-go SPIS. Specifically, Pumptech will give male farmer and female farmer clients 40% and 50% discounts, respectively when they buy Lorentz solar pumps. GIZ Ghana Green Energy will reimburse the discounts to Pumptech upon the installment.

Lorentz Foundation and Shell Foundation are joining the knowledge partnership as accelerators and impact investors to de-risk Pumptech's investment in the resource-limited/smallholder farmer segment. Furthermore, addressing the most critical challenge to farmers' investment in solar-based irrigation, Pumptech and Tech2 will introduce new product lines and packages that better target the resource-limited farmer segment (PS2 150W and 200W for 2 – 4 acres, PS2 300 for 6 acres, and PS2 600W for 8-10 acres; bundled PS2 with sprinkler and spray tube irrigation system).

Ethiopia:

IWMI and Rensys co-organized demand-supply linkage workshops and demonstrations for solar-based irrigation bundles (Hossana, Lemo: 31 March - 2 April 2022; 284 farmers and other value chain actors) and two demonstrations in Hosanna town and Jawe kebele.

IWMI and Rensys conducted market segmentation based on multiple methods for solar-based irrigation bundles in the Oromia region and Amhara region (September 2022; 96 women and 334 men); 5 field demonstrations (Lorentz PS2-100 solar pump) and 2 stakeholder consultation workshops were held.

Sub-Activity 1.3.3. Assess blocking and enabling mechanisms and develop systematic scaling approaches for Ghana and Ethiopia

IWMI has begun to develop a performance and impact assessment framework to monitor and assess investment partnerships for sustainability. The framework is tested with the private sector scaling partnership with Pumptech and Tech2 in Ghana. The framework has been developed to assess whether the partnership for sustainability is relevant, coherent, efficient, and effective in achieving sustainability impacts. The effective investment partnership for sustainability is formed by businesses, governmental or civil society actors that invest their own resources with the aim of catalyzing their investment to increase the scale and impact of sustainable development, minimizing negative and maximizing positive impacts on people and the planet partnerships. In addition, IWMI is consolidating the systemic, adaptive scaling toolkit in an online interactive form. The toolkit includes: *(i) Tools to facilitate scaling partnership, (ii) Diagnostic tools for decision making, and (iii) Scaling and impact assessment tools*.

Objective 2: Identify and test approaches to scale SSI to be sustainable and support resilience

Activity 2.1.: Assess tradeoffs between environmental and human resilience to climate shocks and stressors

Sub-Activity 2.1.2. Irrigation and water pollution analysis

IFPRI is drafting a paper analyzing the extent to which returns from irrigation can be affected by sub-optimal uses of complementary inputs is currently under development. The descriptive analysis shows that fertilizer use is more likely to be combined with purchased seed. Although the share of plots that use only fertilizer (without purchased seed, agrochemicals, and hired labor) is about the same for irrigated and non-irrigated plots at about 32%, the share of plots with both fertilizer and purchased seed is higher in irrigated plots by about 12% than plots without irrigation. The econometric analysis is identifying more concrete relationships on the impact of irrigation on input complementarity.

Sub-Activity 2.1.5 Assess potential trade-offs in irrigated fodder production; Sub-Activity 2.1.6 Validate alternative irrigated forage options for different contexts

ILRI is evaluating and screening ten forage genotypes suitable for SSI to identify the forage genotypes or varieties that perform well under minimal irrigation and nutrient input, which can in turn reduce risks of crop failure for smallholders. Preliminary analysis showed large variability in biomass yield and quality among forages; promising varieties are being recommended to national development partners for further scaling.

ILRI analysis of the tradeoff of irrigated fodder production vis-a viz crop cultivation have been analyzed considering three business case scenarios: 1) Irrigated fodder, 2) irrigated vegetables and other crops, 3) irrigated khat. Results show that:

- Adoption of irrigated fodder induces competition for land, labor and water between crop and khat cultivation.
- Irrigated fodder requires less water and chemicals (fertilizer, pesticide applications) resulting in environmental advantages compared with khat and vegetable production.
- Marginal rate of return indicates that shifting from vegetable production to irrigated fodder increases farm income by approximately 17%. However, going from khat production to irrigated fodder production significantly decreases farm income (more than 200%).
- Despite the economic tradeoffs, adopters of irrigated fodder are keen to expand their fodder plots, partly due to the strong connections farmers have to their livestock and unaccounted benefits in terms of improved household nutrition and manure from livestock.

Activity 2.2: Assess approaches to reducing risks associated with irrigation investments

Sub-Activity 2.2.1: Climate risk assessment; Sub-Activity 2.2.2: ENSO assessment, Ethiopia

IFPRI paper on "The role of small-scale irrigation for climate resilience: Insights from the 2015 ENSO event in Ethiopia" shows that irrigating households had higher resilience to extreme weather events than non-irrigating households. The paper is submitted to *Climatic Change*.

Sub-Activity 2.2.3. Identifying cropping systems (including legume crops, fodder, etc.) that provide the best productivity under different climatic scenarios

Vegetables in Inner Niger Delta and Mali: Identifying suitable land for vegetable and other crop production is important to ensuring the sustainability of the water resources and agricultural sectors to support the effort toward alleviating malnutrition in Mali. TAMU's IDSS team assessed the impact assessment of land use change and irrigation expansion on water balance components and inflow to the Inner Niger Delta. The result in this study revealed the impacts of the land use change on the water balance components, particularly in the central and southern parts; increased surface runoff increase and drainage water with expansion in irrigation. These results highlight the need for an integral approach to develop well-planned land use managed practices in the basin. As such, an ex-ante analysis was modeled, introducing conservation practices in the SWAT model (i.e., contour farming, strip cropping, and grasses waterway), to under potential for improvement at subbasin scale. The analysis showed no significant change on the water balance components at the basin scale analysis, but potential improvement in reducing the soil erosion and enhanced water availability for the vegetable production. Notably, water use efficiency would improve if large water consuming crops (especially rice) were replaced by vegetables.

Results of the Crop Water Requirement (CWR) and Irrigation Water Requirement (IR) analysis show that for optimal yield, supplementary irrigation is necessary for vegetable production in Mopti region. Water requirement for melon was the highest (900 mm/season) followed by shallot (866 mm/season) and then tomatoes (839 mm/season). Okra had the least water requirement (390 mm/season). In addition to the rainfall, all the five vegetables require irrigation if optimal yield is desired. Tomato, shallot, chili and melon require over 500 mm of irrigation based on the planting dates indicated by farmers in Mali. Okra, on the other hand, requires about 120 mm of irrigation per season. See Annex 5 for more results.

Legumes: ILSSI studied gaps and constraints of vegetable and fodder production under SSI systems using field data collected from multiple sites across Ethiopia and Ghana. Although diverse agroecosystems help with pest and disease suppression and serve as a buffer to climate variability, most farmers in sub-Saharan Africa cultivate a few staple crops, e.g. teff, wheat, and maize covers about 75% of agricultural land in Ethiopia. Legumes can grow with a relatively minimal amount of soil moisture, improve soil fertility and enhance nutrition, but are not extensively cultivated. ILSSI has expanded the evaluation of farming systems to include legume cropping in Ethiopia and Ghana with scenarios that use both only legume and intercropped legume to study the impacts of such cropping systems on agricultural production, environmental sustainability, and household income and nutrition; legumes include common bean (Phaseolus vulgaris L.), cowpea (Vigna unguiculata (L.), and vetch (Vicia villosa). More legume crops may be added based on partners and stakeholder feedback. The FARMSIM model will assess the household income and nutritional impacts of legume cropping systems. In collaboration with International Center for Tropical Agriculture (CIAT) field data of the legume cropping system in Ghana and biophysical data has been collected.

Ghana/Maize: ILSSI provided a rapid analysis of the potential for irrigated maize production in targeted Zones of Influence in Ghana. The work was done for the West Africa Rice Company, which has funding from USAID West Africa to sustainably expand maize production within the poultry feed value chain. While the company had considered supplemental irrigation to increase the number of production seasons, a water resource assessment of the targeted districts suggested low access to suitable water resources. The project has paused activities to introduce irrigation, given the risk to water resources.

Faso Kaba Seed Enterprise. Adoption of solar-powered irrigation pumps in combination with efficient irrigation methods by a seed company in Mali. The adoption by seed companies stimulates the adoption by vegetable farmers. (Photo: World Vegetable Center)

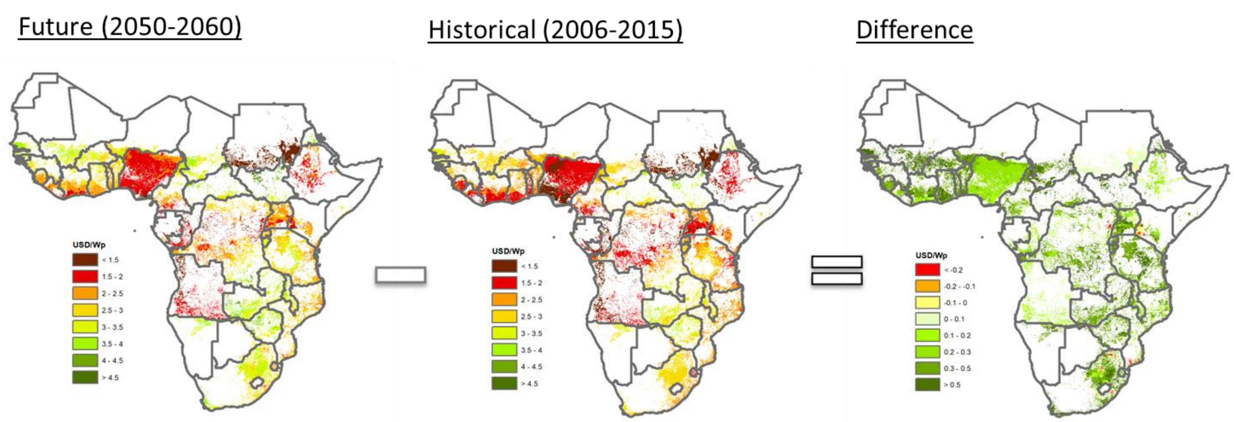
Sub-Activity 2.2.5. Yield-Index insurance and farmers' resilience: premiums and indemnity schedule

The IDSS team developed an integrated yield-based index insurance modeling approach that assesses the economic impacts of different insurance schemes or coverages. Crop insurance is an effective strategy to prevent smallholder farmers from falling deeper into poverty and is an important factor in encouraging farmers to invest in risky businesses. The main drawback of crop index insurance is the basis risk that a farmer might experience a yield loss and receive no insurance payment because the loss is not captured in the index. To improve the quality of the index insurance, this study applies an integrated approach that uses a plant growth model: Agricultural Policy/Environmental eXtender Model (APEX), and a farm simulation model (FARMSIM) to build yield-based index insurance. The first part of the study on developing the yield index insurance and estimating premiums and indemnity schedule was completed and manuscript drafted.

Activity 2.3.: Assess the potential for innovative technology and scheduling tools to contribute to social-ecological resilience

Sub-Activity 2.3.2. Estimating the potential of solar pumps in improving irrigation access vis a vis energy intensity

IFPRI completed new work on the impact of climate change on the cost-effectiveness of solar irrigation relative to diesel irrigation using a recent CMIP6 scenario. The analysis shows that climate change supports further adoption of solar as compared to diesel as water scarcity grows the need for lifting groundwater from greater depths and also increases crop water demands. Climate change improves on the cost-effectiveness of solar irrigation relative to diesel irrigation. the competitive edge of solar irrigation is growing further with climate change, as a result of complex interactions across higher solar irradiation levels, increased crop water demands and higher temperatures (the latter of which can negatively affect solar system performance). This higher economic viability of solar over diesel pumps is irrespective of the food-security enhancing climate mitigation benefits of these systems.



IFPRI presented the results on the relative benefits of solar versus diesel irrigation at the African Water and Sanitation Week, Stockholm World Water Week ("Solar irrigation in Africa: Bright future or broken promise?") and in the March 2022 ILSSI-USAID World Water Day virtual event.

Activity 2.4.: Identify pathways from water access and management to improved water and food security, and sustainable resilience (Mali)

Sub-Activity 2.4.1. Irrigation-nutrition linkages assessment Mali

Increased availability of affordable vegetables is important to food and nutrition security in Mali. The World Vegetable Center research has described the context of how small scale irrigation can contribute increased production of quality vegetable seed and fresh vegetables. WorldVeg is combining results into a strategy to inform policy making.

Challenges: Security issues in Mali have negatively affected progress.

Activity 2.5.: Approaches to catalyze scaling of SSI within market system

Sub-Activity 2.5.1. Identify scaling pathways within market and food system for irrigation

IMWI analyzed the market for solar-powered irrigation system (SPIS) equipment and services in Mali, finding the dynamics of solar-based irrigation equipment supply chain and market characterized by:

- High popularity/availability of solar home products can increase awareness/uptake of SPIS.
- Prices for solar panels and SPIS are falling. On average, a secondhand, 250-Watt panel costs between 40,000 - 50,000 CFA (~ USD$70-85) [1-3 panels of are needed for the desired water flow]. Locally produced panels cost around 90,000 CFA; quality is comparable.
- Grundfos (Denmark) and Lorentz (Germany) dominate high-quality pump market (fossil fuel and electric), while Chinese brands dominate other segments. Grundfos and Lorentz pumps cost around 1 million CFA and last 10+ years. Chinese pumps are half or quarter of the price, but many farmers replace every 2 years.
- Local assembly of pumps is done by local technicians from used parts from imported pumps.
- In Mali's long supply chains, local technicians link pump suppliers and farmers. However, advice is intended to maximize the technicians' profit, and not provide farmers with suitable equipment.
- With a limited number of their own technicians on staff, companies rely on independent technicians, to send potential customers their way.
- Some farmers have lost money on low quality irrigation equipment or misuse with low level of technical knowledge and experience. This discourages other farmers from investing.

Sub-Activity 2.5.2. Identify entry points for the improved diffusion of small scale irrigation; 2.5.5. Multi-stakeholder dialogue process

IFPRI published "Smallholder irrigation technology diffusion in Mali: Insights from stakeholder mapping" as a working paper, based on two workshops in 2021 at the national and regional levels. Key constraints identified: lack of linkages between intermediary organizations in the small-scale irrigation diffusion process, such as commodity associations, financial institutions and technology vendors with government agencies in charge of irrigation, limiting the sharing of consistent and effective information across entities; the lack of a clear policy framework and long-term guidance for private individual irrigation; an associated lack of targeted technology development including limited adaptation to different local contexts, missing financial products linked to irrigation technology, and inadequate capacity building of farmers through extension services and demonstration sites. Workshop participants suggested a dedicated platform for more effective information exchange, improved capacity on private-led irrigation, and a supportive policy and financial environment to ensure growth with sustainability.

In Mali, IWMI initiated the MSD process; 'Multi-Stakeholder Platforms and Processes: The Case for Inclusive and Sustainable Agricultural Water Management in Mali' shows little engagement between public and private sector. The barriers to scaling agricultural water management and SSI include: finance, connectivity among MSPs and stakeholders, deeper private sector engagement. Creating space for engagement in the MSPs is needed to sustainably scale agricultural water management, as noted above.

Sub-Activity 2.5.4. Business model and finance/credit modalities for scaling inclusively

IWMI organized the workshop 'Solutions supporting partnership to scaling small scale irrigation in Sub-Saharan Africa' (December 2021; 15 participants) with EMICOM, ECOTECH, and technical staff from the Ministry of Agriculture; co-organized demand-supply linkage workshops in Sikasso.

Objective 3: Identifying and testing approaches to maximize inclusivity, effective governance, women's empowerment, and involvement of youth for nutrition-sensitive irrigated production

Activity 3.1: Institutional and policy analysis & strengthening of governance

Sub-Activity 3.1.1. Design and pilot governance studies using different methods

Ethiopia: Local partners finalized activities in 15 treatment and 15 control communities; IFPRI is finalizing analysis and drafting a paper. The team presented the project intervention and preliminary quantitative and qualitative results in various events, including the African Water Week, the Swiss Development Corporation conference, and USAID's recent Climate Adaptation and Resilience webinar (March). A video about the groundwater game intervention in Ethiopia was produced and disseminated.

Ghana: Local partners completed the baseline FGD, local level games, follow up surveys and community debriefings in 15 treatment and 15 control communities. Further, as a result of the African Water Week session on groundwater governance, University of Ghana (UG) expressed interest in expanding the work in Ghana in more areas; ILSSI added UG as a sub-awardee to extend the games to the Volta Region where there are risks to groundwater. IFPRI added an activity of groundwater monitoring and 3 stakeholder workshops; a South-to-South exchange event in Ghana between Ethiopian and Ghanaian experts was initiated.

Sub-Activity 3.1.3. Conduct cost-benefit analysis of irrigated fodder production

ILRI analyzed the economic viability of irrigated fodder in the Bahir Dar milk shed. ILRI surveyed 30 smallholder dairy producers (adopters of irrigated fodder technologies) and interviewed 30 key stakeholders along the dairy supply chain. Findings suggest improved forage production and quality feed supply are key for smallholder dairy transformation in the region. Economic analysis results identified three classes of variable costs: labor inputs, farm inputs, and animal inputs; the largest share (61%) is labor. The analysis showed that irrigated fodder production is a viable agribusiness for smallholder dairy producers. On average, dairy producers obtained a net economic return of ETB 20,000 from the production of irrigated fodder per household per year - higher than that of fresh fruits and vegetable cultivation, but lower than khat.

Activity 3.2: Analysis of approaches for equity (along value chains), focused on women and youth

ILRI completed analysis on irrigated fodder and women empowerment. The Women Empowerment in Livestock Index (WELI) tool was applied to evaluate the levels of empowerment among farmers in the study. The research showed men view an empowered woman as a renegade who is going against the grain of the community's culture, norms, and social relations, and some women agreed that women's empowerment is disruptive to the community's 'order'. However, a few women were interview who aim for their own empowerment in rural areas and in livestock product marketplaces. Two of the three dairy cooperatives in partnership with ILSSI are led by women and perceived as innovative.

A journal article has been submitted for peer review; a blog report has been published.

Sub-Activity. 3.2.2. Gender and inclusivity

3.2.2a. Understanding the linkages between SSI and women's empowerment

IFPRI published "Understanding Women's Empowerment in Northern Ghana and the Relationship with Small-Scale Irrigation" in *Agriculture and Human Values*, which innovates a framework on the linkages between small-scale irrigation and three dimensions of women's empowerment: resources, agency, and achievements. This shows that many women face serious constraints to participating in and benefitting from small-scale irrigation, including difficulties accessing land and water and gender norms that limit women's ability to control farm assets. Despite these constraints, many women do benefit from participating in irrigated farming activities leading to an increase in their agency and well-being achievements. For some women, these benefits are indirect—these women allocate their time to more preferred activities when the household gains access to modern irrigation technology. The paper offers a new understanding women's empowerment in relation to irrigation technology.

IFPRI is drafting a paper "Small-scale irrigation and women's time allocation—Evidence from Ethiopia" analyzing two research questions: 1) How does small-scale irrigation influence women's time allocation? And 2) Does women's time use differ by type of irrigation? The paper follows two hypotheses: H1: If modern irrigation technologies are adopted, women's time allocation may shift among different livelihood activities, creating more opportunities for income-generating activities; H2: If women switch from non-irrigating to using irrigation, it may lead to a change in women's time use dynamics.

3.2.2b. Gender sensitive business models and scaling, aligned with private partners

ILSSI private partnerships generated lessons across Ethiopia and Ghana related to aims at inclusive market access to SPIS. Despite the co-development of a gender-responsive credit/customer assessment scorecard with the private companies, sales agents work on commission and only target individuals they perceive to be likely clients. Sales agents act on bias in client acquisition: agents perceive women as unlikely to qualify for credit, and therefore do not pursue pre-sales assessments. Company reluctance to share client data has also hindered deeper analysis.

Leveraging the WLE program, IWMI completed an analysis on 'Gender mainstreaming from an institutional perspective: Cases of small and micro irrigation projects in Ethiopia', which highlights that despite the 'rule-based' strategies adopted by small, scheme-based irrigation projects, social structures continue to present barriers. The paper reiterates a call for gender-responsive policies and institutions.

Activity 3.3: Assess approaches for more nutrition- and health-sensitive SSI

IFPRI paper "Seasonal variation in maternal dietary diversity is reduced by small-scale irrigation practices: A longitudinal study" was published in December 2021 in *Journal of Maternal and Child Nutrition*. Using three rounds of data by season, results showed irrigators were more likely to meet the MDDW than women from non-irrigating households ($p< 0.05$). The main finding from the study is that high seasonal variation of diets can be offset, at least in part, by irrigation.

A second paper "Irrigation improves weight-for-height z-scores of children under five, and women's and household dietary diversity scores in Ethiopia and Tanzania" was published in June 2022 in *Journal of Maternal and Child Nutrition*, showing that among Ethiopian households who reported having faced drought, women in irrigating households had higher Women's Dietary Diversity Score (WDDS) compared to women in non-irrigating households. In Tanzania, women in irrigating households had higher WDDS compared to non-irrigators and the impact of irrigation on WDDS more than doubles among households facing drought. In addition, among Tanzanian households who reported having faced a drought shock, irrigating households have higher Household Dietary Diversity Score compared to non-irrigators. Children in irrigating households in Ethiopia had weight-for-height z-scores (WHZ) that were 0.87 SDs higher, on average, than WHZ of children in non-irrigating households. In Tanzania, irrigation lead to higher WHZ-scores in children under-five among households who reported having experienced a drought in the 5 years preceding the survey. The study showed that small-scale irrigation has a strong effect on households' economic access to food and on nutritional outcomes of women and children. The policy conclusion is that small-scale irrigation should be promoted as a nutrition intervention.

Sub-Activity 3.3.1a. Assessment of WASH-irrigation interlinkages

The paper on WASH-irrigation linkages points to irrigators being more likely to have sufficient water available for domestic use and better access to improved sanitation facilities, but the source of water is the key determinant for a household's hygiene practices. Groundwater likely is an overall better-quality source for domestic purposes than surface water; multiple uses of irrigation water for WASH are more promising for households using groundwater. Moreover, our results show that hygiene practices are independent from the water source; behavioral change communication will be important. For small-scale irrigation to effectively support WASH and, thus, to strengthen nutrition and health outcomes, systems would need to be co-designed by irrigation and health specialists, and women farmers who are largely responsible for providing WASH would need to participate in the design and management of dual-purpose systems.

Sub-Activity 3.3.2. Examining the impact of production systems that include improved irrigated fodder on livestock productivity (milk and meat production), household nutrition and economic improvement

Using the FARMSIM model, researchers began to assess the contribution of irrigated fodder to household nutrition and diet diversification, simulating short and long-term production and use of irrigated fodder as a feed through improved small-scale irrigation technologies, agricultural land and input use. Four scenarios were analyzed that include a scenario under climate change impacts and two scenarios under no climate change impacts and purchase options. Profitability varied across the scenarios, though climate change reduced likely income. In addition, the use of improved livestock production technologies (feeds) increased livestock production in terms of milk and meat at the household level. The consumption of more milk and beef due to production and purchase led to more available nutrient intakes and improved nutrition at the household level significantly under a food purchase alternative. Results show that the increase in animal products availability and purchase can potentially lead to higher consumption of animal products at the household level and increase nutrient intake for better nutrition. However, choosing among the income or production paths to improve nutrition can be a difficult choice to make for households.

Objective 5: Assessment of watershed and SSI interventions on nutrition and resilience under PSNP in Ethiopia

A draft final report, as well as two policy notes were developed to address all three research questions jointly. Results specifically focused on the implementation of PSNP found that BHA-supported interventions strengthened institutional infrastructures and built up the technical and managerial capacity of communities, government experts, and local governments; it also contributed to developing a sense of ownership and to the sustainability of positive outcomes.

Activity 5.1: Assessment of the implementation of the PSNP watershed rehabilitation approach; identification of limitations to the approach and role of upstream watershed rehabilitation on irrigation sustainability

Remote sensing analysis and biophysical modeling showed that implementation of interventions improved greenness in intervention areas in dry season, including in years dominated by drought. Soil erosion was lower after the implementation of the interventions. Biophysical modeling using the SWAT model generally showed positive impacts of watershed interventions on soil erosion, surface runoff generation, groundwater recharge and soil moisture. See Annex 6.

Activity 5.2: Qualitative assessment of watershed rehabilitation and small scale irrigation

Qualitative data were collected from project beneficiaries in Amhara and Oromia regions and in-depth information on program implementation was collected from experts. Recommendations include:

- Modalities should be revised. PSNP participants do not own land in rehabilitated areas or irrigation schemes. Farmers need to build resilience based on their own farming practices, which is a key component of graduating from the PSNP program. Groundwater irrigation using pumps could help to resolve this issue, but land ownership needs to be considered in business models for pump ownership or irrigation service provision.
- Reductions in the time spent by farmers on public works activities could increase the time available to affected beneficiaries for engagement on their own land (even if small) and for income generating activities.
- Increased emphasis needs to be placed on the functionality and maintenance of constructed irrigation and watershed infrastructure, as the current focus is primarily on construction.
- Monitoring and evaluation approaches should be revisited in order to help realize positive outcomes from the interventions; priority needs to be given specifically to revising indicators and georeferencing rehabilitated watersheds and irrigation works.
- Long-term rehabilitation practices should be coupled with immediate income generating activities as a potential solution to ensuring sustainability.

Based on analysis, the research highlights 12 suggestions to enhance the nutrition and resilience benefits of the PSNP public works program.

Challenges: During the implementation of the fieldwork, a number of field sites had to be changed due to the civil conflict in Ethiopia. As a result, the qualitative and biophysical analyses did not take place in the same sites. This limited the quality of the analysis considerably.

Activity 5.3: Quantitative assessment of watershed rehabilitation and small scale irrigation investments

Quantitative analyses were completed, but no additional data (specifically endline data directly collected by BHA) could be accessed as the endline was not collected. Selected findings include: PSNP has rehabilitated degraded lands and increased water availability for multiple uses, thus benefiting local livelihoods including PSNP beneficiaries and non-beneficiaries. Some beneficiaries, however, and in particular female headed households (FHHs), remained highly vulnerable to shocks. Prior to PSNP, intervention sites experienced high vulnerability and low resilience to shocks due to erratic rains and poor soil fertility. PSNP investment in SWC through the implementation of public works projects helped improve soil fertility and increase availability of food and livestock feed. The expansion of irrigation practices was key to improving food and feed availability. These results were seen from the biophysical analysis, but also from the socioeconomic assessments.

Annual Challenges: USAID BHA in Ethiopia had confirmed that if a woreda was included in PSNP all administrative subunits were part of PSNP. More recently we were informed that this was not always the case. This change could distort the findings and require someone to re-collect and analyze the data. Moreover, there is now a new round of PSNP population survey data; while not directly applicable to the BHA sites, there is overlap that could strengthen the quality of the analysis. The BHA baseline data could also be assessed (it does not include control sites, however).

3. Objective 4 - Achieve impact through uptake of ILSSI research results and/or methods

Activity 4.2. Short-Term and Long-Term Training on subject matter

Sub-Activity 4.2.4. Short-term trainings targeted at producers, technical experts, other local and national stakeholders and private sector

Producer trainings:

- ILRI organized forage seed threshing cleaning and packaging training, Ethiopia: six cooperative members across three sites.
- ILRI provided two-day training on hygienic milk handling, and processing, Ethiopia: staff of cooperatives (5 hired workers)

Integrated Decision Support System Trainings:

- Hosted by International Center for Research in Agroforestry (ICRAF), Cote d'Ivoire (February 21- 25, 2022): 69 participants [62 men, 7 women], four West African countries. Participants came from research institutes, academia, and non-governmental organizations with diverse backgrounds (e.g., hydrology, economics, and climate sciences).
- Hosted by Department of Environment, Water, and Waste Engineering, University for Development Studies, Ghana (February 28 - March 4, 2022): 71 participants (14 women, 57 men). Trainees included lecturers, graduate students, and researchers with backgrounds in agricultural economics, engineering, agricultural sciences, and hydrology.

Private sector capacity development:

- IWMI co-organized (Ghana, Ethiopia and Mali) 13 demand-supply linkages workshops, and 13 field demonstrations for solar-based irrigation bundles, benefiting 2,682 individuals from different sectors. IWMI has engaged with broader stakeholders of 10 outreach/communication events to share, for example, an adaptive scaling approach and toolkit, scaling partnerships for solar-based irrigation, and scaling inclusive business models to support SSI FLI.

Research methods trainings:

- Research methods training, Wachamo and Bahir Dar Universities, Ethiopia. Training focused on quantitative household data collection procedures and field data collection.
- Experiential water governance games and methods (January 2022) training, Ghana.
- Quantitative data collection methods training for 12 young researchers from national universities on using the ODK platform and WELI tool.

Table 1. Summary of short-term trainees

Short-term Training Module - EG.3.2-1: Number of individuals who have received USG-supported short-term agricultural sector productivity or food security training		
Total trainees	**Target**	**Actual**
Non-disaggregated total trainees	**108**	**2719**
EG.3.2-1 Producers: Number of producers who received USG-supported short-term agricultural sector productivity or food security training	**2021 (Current)**	
	Target	**Actual**
Male	50	1182

Female	12	643
Disaggregation not available	0	0
Sub-Totals	**62**	**1825**
EG.3.2-1 Government: Number of individuals in government who received USG-supported short-term agricultural sector productivity or food security training	**2021 (Current)**	
	Target	**Actual**
Male	6	376
Female	6	57
Disaggregation not available	2	0
Sub-Totals	**14**	**433**
EG.3.2-1 Private Sector: Number of individuals in private sector firms who received USG-supported short-term agricultural sector productivity or food security training	**2021 (Current)**	
	Target	**Actual**
Male	0	107
Female	0	12
Disaggregation not available	10	0
Sub-Totals	**30**	**119**
EG.3.2-1 Civil Society: Number of individuals in civil society who received USG-supported short-term agricultural sector productivity or food security training	**2021 (Current)**	
	Target	**Actual**
Male	1	15
Female	1	4
Disaggregation not available	0	0
Sub-Totals	**2**	**19**
EG.3.2-1 Other: Number of other individuals who have received USG-supported short-term agricultural sector productivity or food security training	**2021 (Current)**	
	Target	**Actual**
Male	0	263
Female	0	60
Disaggregation not available	0	0
Sub-Totals	**0**	**323**

Sub-activity 4.2.5. Post-graduate research training/mentoring

Candidates are expected to complete all field work before the end of the ILSSI project in August 2023. Continuing graduate students and post-docs supported by ILSSI are listed in Table 2.

Table 2. Long-term Trainees

M/F	University	Degree	Major	Program End Date	Home Country
Male	Arba Minchi University	Ph.D.	Biotechnology	January 2023	Ethiopia
Male	Bahir Dar University	Ph.D.	Water resources engineering and management	May 2023	Ethiopia

M/F	University	Degree	Major	Program End Date	Home Country
Female	Texas A & M	Master's	Geography	May 2022	U.S.
Male	Texas A & M	PhD	Water Program (inter-disciplinary)	May 2023	U.S.
Female	Hohenheim University	PhD	Agricultural Economics	Completed	U.S.
Male	Bahir Dar University	MSc	Agricultural Sciences	Completed	Ethiopia
Male	Bahir Dar University	MSc	Agricultural Sciences	May 2023	Ethiopia
Male	Bahir Dar University	MSc	Agricultural Sciences	May 2023	Ethiopia
Male	Bahir Dar University	MSc	Agricultural Sciences	May 2023	Ethiopia
Male	Bahir Dar University	MSc	Agricultural Sciences	May 2023	Ethiopia
Male	Bahir Dar University	MSc	Agricultural Sciences	May 2023	Ethiopia
NA	Bahir Dar University	MSc	Water resources engineering and management	May 2023	Ethiopia
NA	Bahir Dar University	MSc	Water resources engineering and management	May 2023	Ethiopia
NA	Bahir Dar University	MSc	Water resources engineering and management	May 2023	Ethiopia
Female	University of Ghana	MSc	Social science	May 2023	Ghana
Male	University of Ghana	PhD	Geological/hydrological science	NA	Ghana

Sub-Activity 4.2.7. Innovation Scholarships and Internships

Ghana: IWMI co-supervised four interns working with PEG and Pumptech in Ghana. Two interns with PEG completed by June 2022; one is now a consultant with IWMI. Two interns with Pumptech finished their internship in May-Aug 2022. Both interns are working with Pumptech as permanent staff.

Ethiopia: In Ethiopia, the first six interns from the first Agri-hackathon from Bahir Dar Institute of Technology (BiT)/Bahir Dar University finished their internships with Rensys. One student group formed a tech start-up that is being contracted by other companies for software development.
The second Agri-hackathon and Innovation Grant selected 8 students in two teams to address:

- Solar cold room app (SCR app) to enhance output market linkages for perishable produce
- Digital marketing and sale app (DMS app) for solar products
- Maintenance management app (MM app) for solar products

Mali: One intern worked with EMICOM to develop Digital Paygo Credit Assessment App, which is expected to be used by financial institutions in their partnerships with EMICOM to roll out the PAYGO solar pump.

Activity 4.3. Engage with stakeholders and other potential end users of research

Sub-activity 4.3.2.-4.3.3. Sub-national and national events, platforms/dialogues, and other convenings

- Multi-stakeholder Dialogue Platform Meetings: 5 completed in Ethiopia, Ghana and Mali

- IWMI, together with Pumptech, TECH2, GIZ, and MOFA, organized 11 demand-supply linkages workshops and 10 field demonstrations in the Upper west, Northern, Northeast, and Savanah Region, Ghana from October 2021 – June 2022 (see activity 1.3.2).
- IWMI, together with EcoTech, EMICOM, Horonya Solar, and Sonikara Solar Electro companies in Mali, IWMI co-organized one demand-supply linkage workshop and two demonstrations of a solar-based irrigation bundle in Sikasso in May 2022 (see activity 2.5.1).IWMI, together with EcoTech, EMICOM, Horonya Solar, and Sonikara Solar Electro companies in Mali, IWMI co-organized one demand-supply linkage workshop and two demonstrations of a solar-based irrigation bundle in Sikasso in May 2022 (see activity 2.5.1).

Sub-activity 4.3.4. Regional and global events, platforms/dialogues, and other convenings

ILSSI targeted global, regional and national events to share research and engage potential end users. (See Annex 3, *Outreach/Engagement*.) Notable events include:

- 'Scaling innovation: adaptability and agility for climate smart agriculture in COP 26 Webinar on 'Managing water for climate adaptation and mitigation—what does it entail and how to implement it'? Hosted by CGIAR Research Program on Water, Land and Ecosystems (WLE). [19 October 2021, Virtual]
- International Solar Alliance and IWMI webinar, 'Institutionalisation of Backward & Forward Linkages of Solar Irrigation': Presented ILSSI results in 'Data-driven tools to facilitate scaling solar-based irrigation' [27 January, 2022; 400 registered participants;150 attendants globally].
- IWMI-ECOWAS Webinar, 'Promoting sustainable groundwater irrigation for building climate resilience in West Africa': Presented ILSSI results in 'Systemic, adaptive approach for scaling groundwater irrigation in West Africa' [18 March, 2022, Virtual]
- ILSSI convened webinar, Achieving climate adaptation and resilience for all: Role of small scale irrigation [22 March, 2022, Virtual]
- USAID webinar, 'Achieving climate adaptation and resilience for all: Role of small scale irrigation, contributed lessons learned and knowledge gaps on scaling inclusive business models to support small scale and farmer-led irrigation [22 March 2022; Virtual]
- IWMI 9th World Water Week event, 'Scaling Ecological Sustainable Agricultural Water Management for small-holder farmers in Sahel', presented 'Water for agricultural climate resilience: ILSSI experiences' [23 March 2022, Dakar, Senegal]
- IFPRI Policy Seminar, 'Irrigation Investment Policy: Does scale matter?' Insights for small-scale irrigation derived from ILSSI. [May 2022, Virtual]
- 'Systemic, adaptive scaling approach to solar-based irrigation bundle', Regional Workshop on Solar Irrigation opportunities and solutions for the Sahel region', co-organized by IWMI, FAO, and GIZ [13-16 June 2022, Ouagadougou, Burkina Faso]
- 'Evidence-based partnership strategies to accelerate innovation scaling in irrigated agricultural value chains', AFRICA CLIMATE WEEK webinar 'Climate crisis is a water crisis: water management approaches to strengthening climate resilience in Africa', co-organized by IWMI, Zambia Met Department, Zambia Water Resources Management Authority [10 August 2022, Libreville, Gabon]
- SWWW2022 webinar 'Solar irrigation in Africa: Bright future or broken promise?' [25 August 2022, Virtual]
- SWWW2022 webinar 'On the money'': Innovating finance to enable farmer-led irrigation' [23rd August 2022, Virtual]

Activity 4.4. Outreach and communications

Sub-Activity 4.4.3-4.4.5. Outreach knowledge products and communications

- **Website**: 9,110 page views have been recorded for the ILSSI website during this period.
- **Social media presence**: On social media, tweets from the ILSSI profile gained more than 24,000 impressions, and Facebook posts reached more than 2,200 readers during this period.
- **Newsletter**: Inclusive small scale irrigation for climate resilience [November 2021] (open rate 38.6%, click rate 12.6%); Celebrating science as we embark on 2022 [January 2022] (open rate 45.5%, click rate 11.5%); Small scale irrigation as a climate-adaptation investment [March 2022] (open rate 59.8%, click rate 14.0%); Compounding Crises: the Role of Water in Building Resilience [July 2022] (open rate 54.2%, click rate 16.7%). The number of newsletter subscribers grew by 16 during the past 12 months with a current total of 228 subscribers.
- **News stories**: 13 news stories were produced and published on the ILSSI website, including SSI forage production: Abate Wale's pathway out of poverty and malnutrition, Coping with climate change: Could irrigation bring relief to Ghana's parched cocoa sector?, as well as Making solar irrigation accessible for women and youth farmers, and Making irrigation financing solutions work for everyone. Details on an upcoming study on the impact of solar-powered pumps in vegetable production in Mali along with ILSSI's research on how New business models bring solar irrigation to Malian farmers(English and French) were also published.
- The program has also been featured elsewhere, including by the Africa Energy Portal, Agrilinks.org, Farmers Review Africa, LEAP4FNSSA and local newspapers in Mali.
- **Briefs**: 6 (See Annex 3, *Briefs*)
- **Webinars**: 1 convened by the project; participated in others (See Annex 3, *Outreach/Engagement*)

Sub-Activity 4.4.7. Scientific conferences and invited scientific presentations

ILSSI partners contributed nearly 30 presentations to conferences and events at the global, regional and national scale. See Annex 3. Data and Publications for the full list of Conference papers, posters, and presentations.

Sub-Activity 4.4.8. Publications and data

ILSSI continued to see strong collaboration across research partner institutions on both publications and outreach materials. The figures for each type of publication are summarized in Table 3 below, while the full list of publications with links to web access can be found in Annex 3. Data and Publications.

Table 3. ILSSI Publications (October 1, 2021 – September 30, 2022)

Category of publication and/or knowledge product	Total Number (all partners)
Peer-reviewed publication	24
Discussion/Working paper	6
Briefs	6
Technical report	7
Conference paper, poster, and/or presentation	28
Outreach and social media (e.g., blogs)	15
Capacity development material or product	2
Submitted and under review, and/or accepted with revisions	18

4. Technology transfer and scaling partnerships

ILSSI was able to co-produce various outputs with partners, such as the USAID Gender, Climate Change and Nutrition Integration Initiative to identify contributions that ILSSI and other innovation labs have made to address growing inequities linked to multiple, interlocking crises, as well as progress on a second paper for which data were originally collected under the Sustainable Intensification Innovation Lab (SIIL). The World Bank asked to partner on a video produced with CGIAR Water, Land and Research Ecosystem funds showcasing ILSSI research, summarized in a World Bank supported guidance.

A highlighted outreach was the *Nature* Comment "To ease the world food crisis, focus resources on women and girls" was published in August, 2022 as a joint engagement by IFPRI and Texas A&M and as a co-investment between the USAID GCAN project and ILSSI. The comment reflects some of ILSSI's contributions to addressing the food price crisis, reflecting on measures by ILSSI to grow women farmers' access to solar pumps by reducing the collateral and down payments and by building women's creditworthiness and capacity for financial documentation. This was the result of a technical roundtable and the key lessons shared at a public webinar.

Institutional Capacity Development (examples)

- Multi-stakeholder dialogues and sub-national workshops build company capacities, enhance partnerships and knowledge sharing, and contribute to increased sales of irrigation equipment; now co-convened with World Bank in Ethiopia.
- IDSS training requested by the International Center for Research in Agroforestry (ICRAF) in Ivory Coast, aimed to support modeling capacity of the cocoa sector in West Africa toward planning for irrigated cocoa under climate change. (February 2022).
- IDSS training requested by Department of Environment, Water and Waste Engineering at the University for Development Studies (UDS) in Nyankpala, Ghana (February 2022).
- ILRI's performance-based sub-sub-awards with dairy cooperatives led World Bank to give technical and financial support to these and more cooperatives.
- Technical and material support provided to dairy cooperatives enabled cooperatives to serve as a source of forage seeds, planting materials, compound feeds, and milk and milk products. Cooperatives reportedly earned over USD 2000 from planting material sales.
- ILSSI & PEG Africa produced farmer materials on safe agri-chemical use (French, English); private companies and implementing partners are using (Ghana - MSR activity; Mali - Sene Yiriwa).
- South-South knowledge exchange (Ethiopia, Ghana, India) on community-scale groundwater governance, based on demand from national stakeholders in Ghana.

5. Issues, Concerns, and Lessons from the reporting period

5.1. Project Management Issues, Concerns and Lessons

Issues and concerns

Current market conditions are extreme test of the business models for SPIS. Company ability to partially or fully meet sales targets suggests the high potential market. Increased barriers to fertilizer inputs, high fuel prices, limited access to fuel (Ethiopia), economic sanctions (Mali) and conflict (Ethiopia, local in Mali) negatively affected smallholder irrigators. Barriers to foreign exchange worsened. Farmer willingness and ability to invest in irrigation technologies reduced, while companies became more risk averse and restrictive with asset-based finance.

Monitoring and evaluation of the private sector partnerships are challenged by limited data sharing and lack of data recording. At the same time, the multiple global and national crises and conflicts altered prices and complicated on-going market margin and tax analysis.

Ethiopia: Conflict and security issues continued to negatively affected project activities; private partner (Rensys) was negatively affected by supply chain issues and restricted travel areas.

Mali: Political crisis limited researchers from travel to and within Mali, which delayed project implementation; consultants are being used to address the constraints. In addition, pump importation for one private partner was blocked due to sanctions and the company had to re-order and ship the pumps.

5.2. Research-related issues, concerns and lessons

Research can stimulate uptake by farmers and lead to investments by implementing partners and development partners. This has occurred in Ghana with the SPIS market activities (investment by GIZ and private companies) and in Ethiopia with dairy and fodder cooperatives partners (World Bank, Dutch development agency). However, implementing partners often do not attribute knowledge inputs from the Innovation Lab, even in cases where the reports and briefs name the source.

More opportunities could be developed in Mali and Ethiopia through CGIAR programs for scaling, as well as impact assessment and planning, but security concerns significantly hinder activity.

Involvement of diverse private sector entities in the irrigation equipment supply chain in the demand-supply linkage interventions is key to meeting the real demands for pumps as well as to capitalizing the supply chain actors' investments. In this regard, co-convened sub-national workshops and multi-stakeholder dialogues have been critical to increase market information sharing and joint action.

Skilled, human resource pipeline for private and public sectors will be critical to the expansion of the market in irrigated agriculture and in sustainability (regulatory and planning). At present, lack of skilled staff and high staff turnover constrain private company market growth, while private companies will likely be expected to self-regulate in water resource management until public sector capacity increases.

Various online tools have potential to speed up access to knowledge and therefore scaling, but apps are not a broad 'fix' and ICT is unlikely to create much impact until: 1) internet access is affordable and widespread, 2) apps are context adapted, and 3) other constraints to use of irrigation are addressed.

6. Future work

Objective 1. Identify and Test Approaches to Sustainably Scale SSI through Reducing Constraints and Strengthening Opportunities for Access

- Close out scaling partnerships with private sector partners
- Validate the suitability maps using available data from the private sector piloting
- Close out partnerships with dairy cooperatives; support exit to be operational in forage seed market
- Complete the systemic, adaptive scaling toolkit® in an online interactive form
- Papers: role of changes in tariffs on the importation of solar pumps into Ethiopia; approaches for equity (along value chains), focused on women and youth

Objective 2. Identify and test approaches to scale SSI to be sustainable and support resilience

- Complete analysis of the potential of irrigated cocoa production on income and nutrition
- Complete assessment of climatic risk on water availability and crop production; Identify cropping systems (legume crops, fodder, etc.) that provide best productivity under different climatic scenarios
- Complete evaluation of the performance of different forage varieties under irrigation (Ethiopia)
- Complete guidance on implementing nutrition-sensitive irrigation (Mali)
- Papers: Irrigated fodder and packaging of technologies for scaling by development partners; complementary technologies and extent to which returns from irrigation can be affected by sub-optimal uses of complementary inputs; performance of small-scale irrigation system powered by

solar PV under variable and changing climate conditions; solar potential in Sub-Saharan Africa; vegetable and vegetable seed farm systems under irrigation (Mali)

Objective 3. Identifying and testing approaches to maximize inclusivity, effective governance, women's empowerment, and involvement of youth for nutrition-sensitive irrigated production

- Complete analysis on the linkages between SSI and multiple uses systems
- Complete community-level water governance approaches, scaling and South-South initiative
- Complete analysis on irrigated fodder, empowerment, household nutrition, climate resilience
- Papers: irrigation technology and women's time burden (Ethiopia); nutrition-sensitive irrigation with a focus on Mali; small-scale irrigation and nutrition in areas favorable to irrigation in Mali; irrigation and WASH interlinkages; groundwater governance in Ghana; linkage between irrigation and diets in northern Ghana; children and women's diets and small-scale irrigation in Ethiopia

Objective 4. Achieve impact through uptake of ILSSI research results and methods

Short-term and long-term trainings

- Dairy and irrigated fodder partner cooperative trainings
- Producer and public agency trainings on solar irrigation (IWMI with Rensys, EMICOM, Ecotech Pumptech, Tech2)
- Mentor/support graduate students and field assistants; Complete Innovation Grants, Internships
- IDSS trainings in Ethiopia, Ghana and Prairie View A & M University (Texas, USA)

Outreach

National/Subnational

- 3 MSD dialogues in Ghana, Ethiopia, and Mali; connect the grassroots scaling ecosystems to the national dialogues
- Workshop in Mali on vegetable seed sector, strategy for irrigated vegetable production, nutrition responsive irrigation
- Irrigated fodder workshops to engage national and international partners (Ethiopia)

Global

- ILSSI Symposium (March 1, 2023) and Congressional Reception (February 28, 2023)
- HBCU Student and Young Scientist conference (March 8-9, 2023, Prairie View A & M University)
- Water for Food Conference at University of Nebraska (May 8-9)

Knowledge products and publications

- Technical/policy briefs published (March-May 2023)
- Flagship research results summary booklet (May 2023)
- Policy guidance and briefs on the role of watershed rehabilitation and small-scale irrigation in selected PSNP areas (Ethiopia)
- IFPRI policy briefs on solar irrigation assessments, sub-national, for Ghana and Mali
- Publish quarterly newsletters through July 2023

Annex 1. Private sector partnerships: Progress toward milestones and key lessons

PEG Africa (Ghana)

Observations and lessons:

PEG Africa has halted sales of solar pumps in Ghana, though they continue sales in other countries in the region. PEG's recent private equity investors sought quicker and higher returns than what was being achieved in the water business in Ghana; adapted approaches to marketing achieved about 1/3 less than the targeted sales monthly. Notably, the recent Tax Act was expected to substantially increase PEG's business income tax and lead to higher pump prices, which PEG assessed as beyond the reach of resource poor farmers. PEG completed the milestones agreed and provided an additional report on lessons learned, particularly related to constraining policies (e.g. tax and energy) and finance ecosystem.

Rensys Engineering (Ethiopia)

Observations and lessons

TAMU ME revised the sub-award with Rensys in February 2022 to address the delays related to COVID, the conflict in Ethiopia, and supply chain/shipping constraints that delayed delivery of pumps. Pumps were delivered around May and sales began. However, Ethiopia continues to be a challenging context for private companies in the irrigation equipment supply chain to operate. Rensys has faced substantial constraints on accessing land for cold stores and distribution hubs, on accessing foreign exchange and therefore letters of credit to import, and on establishing solid business relationships (e.g. the mobile money system that had partnered for two years closed suddenly and the solar cold store supplier locally withdrew their sales offer unexpectedly). Given the importance of small scale irrigation in Ethiopia, the ILSSI project makes extra efforts to retain Rensys as a partner, including through support from IWMI and SunCulture (pump manufacturer).

Milestones

Rensys made progress toward:

- Milestone 5. Distribution hubs established in 4 sites (Amhara, SNNPR, Oromia); Marketing activities begin
- Milestone 7A. Sales records (pumps)

Activities

- Imported 390 pumps after extensive supply chain delays; SunCulture (manufacturer/supply) conducted quality control and provided training for Rensys staff
- Held demonstrations in targeted areas
- Participated in IWMI-facilitated demand- supply linkage workshop at Hosanna; created app-based platform to network with potential clients.
- Created a mobile app (market linkage between producers and off takers) through the Hack-a-thon with Bahir Dar University.
- While Rensys identified a solar powered cold room supplier, localized conflicts thwarted all attempts to acquire land for solar powered cold room installation

Ecotech Mali (ETM)

Observations and lessons

ETM's approach to social marketing and strong investment in capacity development on farmer financial management, irrigated agronomy and pump use/management will be central to addressing concerns in the market related to pump quality and after sales service. ETM's participation in the market may help to offset some of the problems identified in ILSSI's market analysis. In addition, ETM is now connected with the Sene Yiriwa project in Mali, in part through introduction by the ILSSI ME.

While ETM has taken over 15 orders for the ENNOS Sunlight pump, the actual pumps were refused entry at the Mali border in relation to recent trade restrictions (i.e. sanctions). The pumps were reshipped to Mali after months of delay.

Milestones completed in FY2022 October to March

- Milestone 1: Social marketing strategy and plan completed
- Milestone 2: Social marketing materials completed (videos and other materials)
- Milestone 3: Strategy and agreement in place with financial institution; Credit assessment or scorecard tool for potential clients completed
- Milestone 4: Demonstration fields prepared (one per target commune/Zone of Influence)

Activities

ETM engaged farmers in demonstrations and met initial focal points (i.e. local, embedded agents).

- Koulikoro/Bamako:
  - Market gardening perimeters of Samanko (farmers and cooperative meetings on use of pumps)
  - Field test site in Fana (Demonstration field for video content and technical tests)
- Koutiala (Sikasso):
  - Fagui (Zenia) (Meeting and Training Focal Points)
  - Kolonigue (Molobala) (Meeting and Training Focal Points)
  - Sinkolo (Meeting and Training Focal Points)
  - Zangasso (Meeting and Training Focal Points)
- Mopti:
  - Sene Yiriwa's[1] Fair in Mopti (Awareness and client prospection)

EMICOM

Observations and lessons

A primary challenge has been establishment of the PAYGO system with the FuturePump SF2 related to the poor cellular network coverage that prevents remote payment, text reminders for the repayment, and pump deactivation in case of nonpayment. EMICOM is now targeting the use of PAYGO in areas with good network coverage, but this excludes some of the poorer farmers who want to irrigate. In addition, the agreement with BNDA did not yield any loans to farmers and BNDA increased the interest rate from 5% to 8%.

[1] Sene Yiriwa is supported by USAID in Mali and implemented by DevWorks and other implementing partners.

In addition, EMICOM has found it difficult to reach the youth with pumps. Multiple youth as potential clients expressed interest, but the final decision must be made by head of household; in some cases, the household head refused purchase of pumps.

The economic sanctions have also negatively impacted pump sales. While EMICOM was able to import pumps, they learned that many vegetable producers finance activities through income from other crops, notably cotton in the Sikasso region. The trade sanctions delayed cotton exports, leaving farmers without financial resources; farmer pre-orders for SF2 pumps can only proceed once cotton is sold.

Milestones completed:

- Milestone 5. Finance (Credit assessment tool for PAYGO finance)
- Milestone 6. WP2: Marketing and promotion: Marketing and promotion plan initiated and active.
- Milestone 7. WP4. Sales and distribution between 1 October and 31 December: 37 pumps
- Milestone 8. WP3: Distribution network and demonstration: Showroom and 9 sub distribution points were established in Mopti, Koutiala, Kati, Ségou, Bamako, Sikasso, Bougouni, Kita, San
- Milestone 9. WP4. WP4. Sales and distribution between 1 January and 10 March: 61 pumps over 24.4 hectares; USD $11,621 was provided as credit to 9 farmers on test PAYGO finance product.

Activities

- EMICOM set up the sub-distribution network in target Zones of Influence and additional areas; this includes training of distributors.
- Promotion of FuturePump SF2 through demonstrations, and agricultural fairs, festivals and farmer days.
- To find better options to reach youth and women, a socio-economic study was carried out in the circles of Sikasso, Yorosso and Kadiolo in the Sikasso region from January to February 2022. This study was carried out by the local NGO, ADH (Association for the Harmonious and Sustainable Development of Mali), which is a partner of EMICOM for integrating irrigation into value chains in the Sikasso.
- In addition, the Centre d'Appui à la Micro Finance et au Développement (CAMIDE)/Association Benso Jamanun is partnering with EMICOM to raise awareness on the SF2 particularly among a group of about 4000 women. An agreement is being drawn up between EMICOM and CAMIDE to assess the capacity of the women in the group to pay in instalments for SF2 kits for their market gardening activities.

Annex 2. Optimal crop water requirement (ETc) for cocoa (Theobroma cacao) production in Ghana

1.0 Background

The production and export of cocoa (Theobroma cacao) contribute directly to Ghana's socio-economic development. Cocoa beans and products contribute substantially to export earnings in the country, second only to the export of gold and well beyond other agricultural products (Teye and Nikoi 2021). In addition, 800,000 households derive most of their income from the crop and over six million people rely on it for their livelihoods (Asamoah and Owusu-Ansah, 2017). Performance and output of the cocoa sector since its establishment in the late 19th century has been highly variable with periods when the sector nearly collapsed (Amanor, Yaro and Teye, 2020). While some studies outline the socio-political and economic causes of the fluctuations in total output (see for example Kalovalli and Vigneri, 2017 and Amanor, Yaro, and Teye, 2020), production-related causes for changes in yield have been attributed to outbreaks of pests and disease on cocoa farms, inadequate access to farmer finance for inputs, depletion of soil nutrients, and various impacts of climate change (Ntiamoah and Afrane, 2008; Läderach et al. 2013; Kumi and Daymond 2015; Ali et al., 2018).

Studies (e.g., Läderach et al., 2011, Laderach et al., 2013 and Schroth et al., 2016) suggest that production suitability will decline in large parts of current cocoa producing areas in West Africa. The projected decline is associated particularly with changing climate, such as higher temperatures, increased rainfall variability, and long dryspell or drought periods that are expected to increase by 2050 (Läderach et al., 2013, Schroth et al., 2016). Cocoa plays the main role in Ghana's economic stability and the livelihoods of millions of people, but risks to production (e.g. climate) in the sector could undermine progress toward Sustainable Development Goals (SDG) 1 (No Poverty) and 2 (Zero Hunger). To meet the water demands of cocoa and for optimal production, the adoption of the right quantity of water as well as the timing of application is very necessary. As a first step, we assessed the crop water requirement (CWR) for cocoa in order to provide information necessary for irrigation to enhance the growth and development of the crop, and for increased production in the face of the changing climate. This study is part of a bigger study aimed at increasing cocoa productivity and enhancing the livelihood of smallholder cocoa farmers in Ghana.

2.0 Methodology and dataset

The water requirement for cocoa production in Ghana's cocoa producing regions was estimated using one of the most widely used methods – multiplying crop coefficient (Kc) values with reference evapotranspiration (ETo) (Doorenbos and Pruitt 1975). Based on the availability of weather data, various methods (e.g. Priestly-Taylor 1972; Hargreaves-Samani 1985; FAO Penman-Monteith method: Allen et al. 1998) have been suggested for calculating the Eto of crops. In this study, we used the Penman-Monteith method (Allen et al. 1998) due to reports showing the method as yielding consistently more accurate reference evapotranspiration (ETo) estimates across a wide range of climate conditions (e.g. Irmak et al. 2003). The estimation of the ETo was done using an excel spreadsheet developed specifically for the purpose. The water requirement for cocoa was calculated on daily basis by subtracting monthly water need from the effective monthly rainfall (Pe) for each of the stations. The data set used for the calculation included daily maximum and minimum temperature of six stations (Table 1) located in the six cocoa growing regions of Ghana, obtained from the Ghana Meteorological Agency. The data set spanned a period from 2006 to 2016. Additional datasets also for the same locations, included solar radiation, relative humidity, sunshine hours, and wind speed (obtained from Climate-Data.org).

The PM equation given in FAO-56 (Allen et al. 1998), used for computing the ETo is as follows:

(Equation 1)

Where: ETo is reference evapotranspiration (mm day-1), Rn is net radiation at the crop surface (MJ m-2 day-1), G is soil heat flux density (MJ m-2 day-1), T is mean daily air temperature (°C), u2 is wind speed at 2 m height (m s-1), es is saturation vapor pressure (kPa), ea is actual vapor pressure (kPa), Δ is slope of saturation vapor pressure curve (kPa oC-1), γ is psychrometric constant (kPa oC-1) and es-ea is saturated vapour pressure deficit (kPa).

The equations for calculating the ETc and CWR for cocoa are shown in equations 2 and 3, respectively:

$$Etc = Kc * ETo \quad \text{(Equation 2)}$$

Where,

ETc = daily crop evapotranspiration (mm), Kc = daily crop coefficient, ETo = reference evapotranspiration (mm). The Kc used to estimate the ETc of cocoa was set at 1.05 (Allen et al., 1998) for the growth stages.

$$CWR = ETc + losses \quad \text{(Equation 3)}$$

Table 1. Details of climate stations used in the study

No.	Station name	Region	Latitude	Longitude	Elevation
1	Axim	Western	4.87	-2.23	37.8
2	Ho	Volta	6.60	0.47	157.6
3	Koforidua	Eastern	6.08	-0.25	166.5
4	Kumasi	Ashanti	6.72	-1.60	286.3
5	Saltpond	Central	5.20	-1.07	439
6	Sunyani	Brong Ahafo	7.33	-2.33	308.8

3. Results

3.1. Reference Evapotranspiration (ETo)

The daily reference evapotranspiration (ETo) values for cocoa varies from 3.2 and 5.8 mm/day across the six cocoa producing regions of Ghana. The highest values were recorded in February, March and April at Ho, and the lowest in August (Kumasi and Sunyani) and July (Koforidua) as shown in Table 2. The maximum and minimum average daily ETo recorded were 4.9 and 3.9 mm/day at Ho and Axim, respectively.

Table 2: Reference Crop Evapotranspiration (mm/day)

Month	**Eto mm/day**					
	Kumasi	Axim	Ho	Koforidua	Saltpond	Sunyani
January	4.6	4.1	5.1	4.2	4.6	4.9
February	5.1	4.4	5.8	4.6	5.0	5.4
March	4.9	4.6	5.8	4.6	5.1	5.1
April	4.5	4.5	5.8	4.5	5.6	4.9
May	4.0	4.0	5.4	4.2	5.2	4.5

June	3.5	3.5	4.5	3.5	4.3	3.8
July	3.3	3.5	4.2	3.2	3.8	3.3
August	3.2	3.4	4.1	3.3	3.9	3.2
September	3.6	3.5	4.0	3.5	4.1	3.5
October	3.7	3.8	4.5	4.0	4.4	3.9
November	3.7	3.9	4.7	4.2	4.6	4.0
December	4.2	3.9	4.5	4.0	4.2	4.1
Mean	**4.0**	**3.9**	**4.9**	**4.0**	**4.6**	**4.2**
STDEV	**0.62**	**0.42**	**0.69**	**0.51**	**0.56**	**0.72**

3.2. Crop Water requirement for cocoa

As Table 3 depicts, the monthly CWR of cocoa ranges between 130 mm (Kumasi, in August) and 235 mm (Ho, March). Axim recorded the lowest mean CWR (125 mm/month) with the main rainfall months (June, July, August, and September) showing the least values. Ho, on the other hand, had the maximum mean CWR (155 mm/month). The water deficit graphs (mm/month) for each station in the cocoa growing regions, calculated by subtracting the monthly water need from the effective monthly rainfall (Pe) is presented in Figure 1. According to the results, Axim has water available for plant use during the months of May (95 mm), June (297 mm) July (10 mm) and October (26 mm), with the remaining months showing a deficit (Figure 1a). In Ho and Koforidua, all but the months of June and September show the need for supplementary irrigation (Figures 1b and c). In Kumasi, only the months of June, September and October showed the availability of water for plant use. The highest water availability in Kumasi is recorded in June (78 mm) while the lowest (3 mm) is recorded in October. In Saltpond and Sunyani only about 45 and 44 mm of water, respectively, is available for plant use during the month of June (Figures 1e and f). As shown in the combined water deficit graph (Figure 2), all the six stations show water deficit during critical months such as from February to April when cocoa plants need a lot of water to distribute photosynthates to plant parts such as the stem, leaves, and fruits. In general, the monthly water deficit results obtained for all the stations indicate that in order to maintain or increase cocoa production in Ghana, supplemental irrigation is necessary.

Table 3: Crop Water Requirement (mm/month)

Month	**Etc mm/month**					
	Kumasi	Axim	Ho	Koforidua	Saltpond	Sunyani
January	149.3	134.0	167.1	135.8	149.5	160.3
February	149.8	129.2	170.1	134.9	147.0	158.5
March	159.8	149.3	188.4	150.1	166.7	165.9
April	141.4	142.0	183.5	142.2	175.0	152.9
May	130.9	129.3	175.9	137.6	168.7	145.0
June	111.8	109.4	141.1	109.5	134.9	119.7
July	108.7	113.3	135.2	103.0	122.9	109.0
August	104.2	109.7	133.5	106.2	125.8	105.6
September	112.7	111.1	127.2	111.4	129.4	109.0
October	121.3	125.3	146.0	131.2	144.0	126.5
November	117.8	124.1	149.0	130.8	143.4	126.8
December	135.6	128.4	146.8	128.8	136.5	132.6
Mean	**128.6**	**125.4**	**155.3**	**126.8**	**145.3**	**134.3**
STDEV	**18.53**	**12.85**	**20.77**	**15.40**	**17.14**	**21.65**

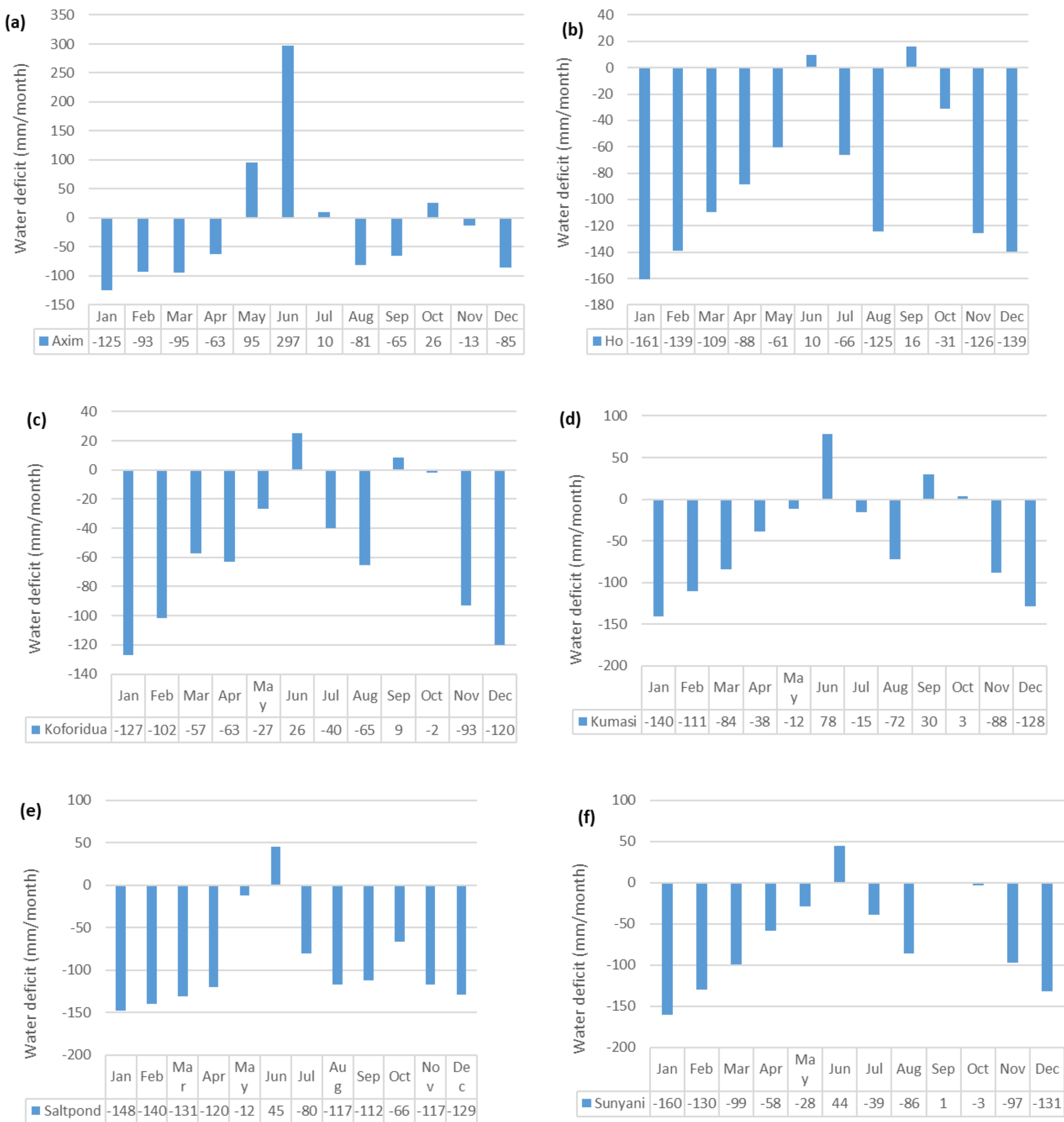


Fig. 1. Water deficit graph for cocoa in Ghana's cocoa growing regions (2006 – 2016)

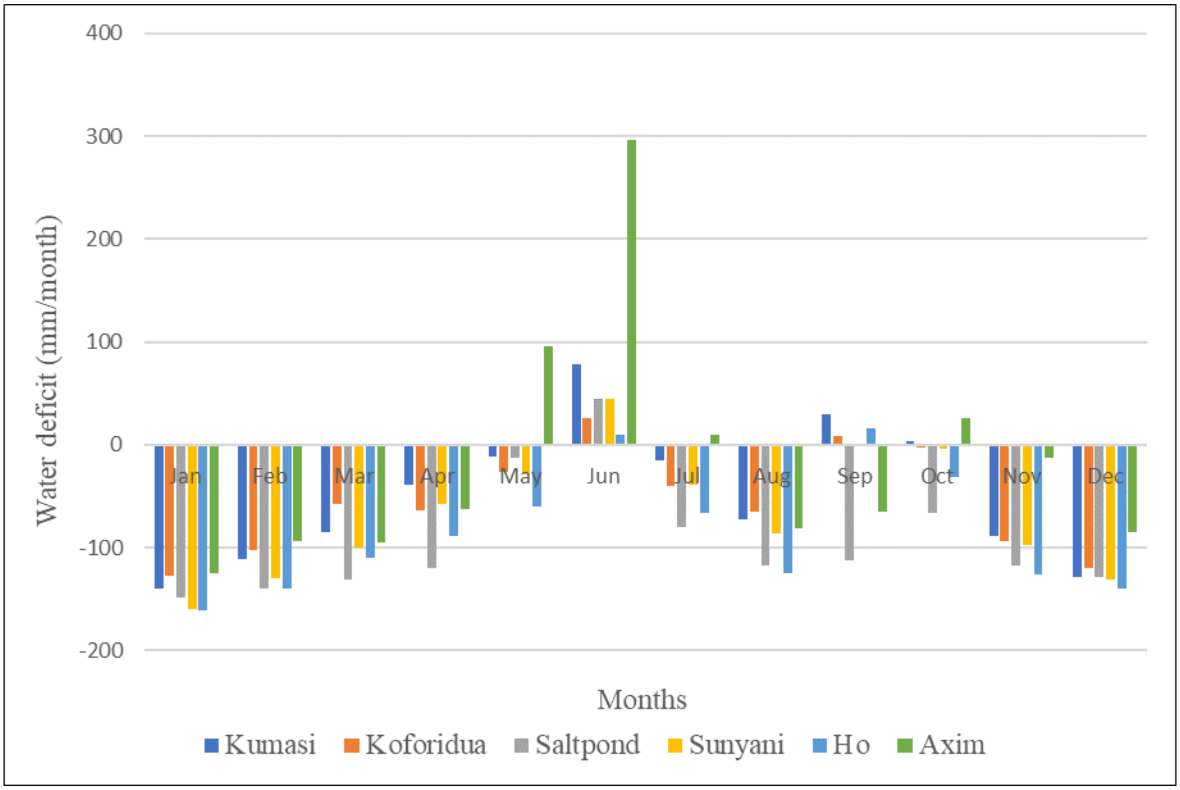


Fig. 2. Combined water deficit graph for cocoa production in Ghana (reference period 2006 – 2016)

4. Conclusion

Based on the research results, the daily reference evapotranspiration (ETo) values for cocoa vary from 3.2 and 5.8 mm/day across the six cocoa-producing regions of Ghana. The monthly CWR for cocoa for the regions ranges from130 mm to 235 mm. The water deficit analysis suggests that to maintain/increase cocoa productivity in Ghana, supplemental irrigation is necessary. The results of this study will be beneficial for developing a supplemental irrigation schedule for cocoa cultivation in Ghana.

Annex 3. Data and publications

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Annex 4. Success Stories

Collaboration between ILSSI and Word Bank funded livestock and fisheries sector development (LFSD) in Bahirdar zuria district

In Bahirdar zuria district, the ILSSI project has been collaborating with the livestock and fisheries sector development (LFSD) project, which is a World Bank funded project and implemented by the Ministry of Agriculture of Ethiopia. In this district, the LFSD project has partnered with the ILSSI to promote some of the fodder technologies that have been evaluated and recommended by the ILSSI. Recently the project has announced that it would provide material support/donation to one competitive dairy cooperatives from across the fifteen kebeles they are operating. In the selection process, the dairy cooperative which has been working with the ILSSI, Genet Lerobit, was nominated to receive the in-kind award amounting to 1.3 million ETB. The in-kind donation include cream separator, churn, milking cans and a vehicle. The selection of this cooperative was a direct result of ILSSI's investment in terms basic infrastructure development and human capacity building. As a result the cooperative was found to be in a much better position to utilize the new resources and hence was nominated for the award. This is a good success story how the ILSSI support have helped to strengthen local institutions to serve their communities at a higher capacity.

The training was organized to capacitate enumerators who participate in the ILSSI gender analysis study to determine the gender dynamics around irrigated fodder production

Group photo of participants of enumerators training workshop, held in the ILRI Addis Ababa campus from 25 February to 1 March

Participatory forage variety evaluation field day in SNNP region, Ethiopia

Farmers invited to visit the ILSSI irrigated fodder demonstration and research site for participatory variety evaluation to promote irrigated fodder cultivation among livestock farmers

Dairy cooperatives earning income from sale of forage seeds

In Ethiopia the majority of farmers have no access to affordable forage seeds/planting materials. When the ILSSI phase II was launched, it was planned to support local institutions to engage in forage seed business. Dairy cooperatives were chosen for this purpose as private companies were not available in the project sites. The cooperatives were supported technically and financially to establish forage seeds/planting material multiplication, storage and sales shop facilities. The support started to bear fruit in the reporting physical year as the cooperatives were able to multiply and sale forage seeds of oat, vetch, lablab, and cuttings/root splits of Napier grass. The records showed that the cooperatives sold forage seed worth more than two-thousand dollars. This was considered a good beginning to strengthen the local forage system and position the cooperatives as important input suppliers. Such activities are also expected to diversify the income of farmers and increase the adoption of irrigated fodder by dairy producers.

Annex 5. Impacts of land use change and irrigation expansions land suitability analysis for Upper Niger River Basin

The Upper Niger River (UNR) basin covers 276,000 sq km upstream of the Inland Niger Delta (IND). The Niger and Bani are the two main rivers contributing the total inflow to the IND and the downstream parts. These two rivers confluence at Mopti, just upstream of the inlet of IND. Anthropogenic activities and other natural drivers have an immense impact on water management and use, affecting the ecosystem and wetland hydrology. Population growth increased water demand, and there are increased efforts and interest to achieve food security through employing water resources development programs upstream of the IND. A tradeoff between water resource development and water use is crucial to mitigate water shortages and impacts on the downstream ecosystems. Unless an equitable water use approach is adopted, conflicts between the upstream and downstream water users will be inevitable. In addition, an integrated approach between the development and utilization of water resources and environmental flow release can trigger more efficient water use to minimize the vulnerability of the wetland and risks to its ecosystem. The available evidence indicates that the flood inundation area of the IND has reduced due to several interplaying factors, mainly land use and climate change, poor water management, and expansion of upstream mega irrigation development (Rebelo et al., 2013). The impacts are becoming more intense due to climate change and will continue to do so with projected population increase. Proper water management practices and knowledge of water resources are crucial for the sustainability of water resources and wetland ecosystems.

According to the U.S Geological Survey (USGS) report, cropland has predominately increased by 3.5% annually across the south, especially in Haut Bani Niger, Koutiala Plateau, and Kaarta ecoregions. The expansion of the cropland was attributed to the need to feed the fast-growing population and to grant food self-sufficiency. In addition, the irrigation land has increased by 400% in the southwest and along the Niger River and its tributaries in the southern part of the IND. Despite the considerable year-to-year variation of the flood extent in the IND, no significant land use change has occurred except for irrigation interventions in some parts. Conversely, there is a 23% decrease in the gallery forest due to agricultural expansion driven by an increase in population and other factors, which induced the destruction of the natural habitat, which is one of the core issues in Mali. The reduction in forestland instigates severe erosion of the topsoil, which adversely reduces soil fertility and land productivity. The eroded soil eventually deposited upstream reservoir area. This potentially reduces the overall efficiency and lifetime of the hydraulic structures unless extensive soil water conservation interventions are implemented to minimize soil erosion. More studies are required to assess the land use dynamics and irrigation expansion to quantify the subsequent impacts on the water balance. Therefore, evaluating the impacts of land use and irrigation expansions upstream of the IND is crucial for better management and sustainability of the water resources and the ecosystems in the IND and the basin at large.

Since there is pronounced expansion in agricultural land across the basin, identifying suitable land for vegetable and other crop production is paramount to ensuring the sustainability of the water resources and agricultural sectors to support the effort toward alleviating malnutrition in Mali. The available statistics indicate that 29 percent of Mali's population is already malnourished. Biophysical and socio-economic variables such as climate, soil, land use and topography, population density, and market proximity are key indicators and inputs for land suitability analysis. Integrating expert opinion and farmers' feedback is also essential to enhance the accuracy in identifying suitable land for better production. Augmenting traditional agricultural practices, commonly used in Mali, with climate-smart and conservation agriculture can benefit farmers and pastoralists by boosting agricultural productivity and household-level income, eventually helping the growth of the Gross Domestic Product (GDP) of Mali. The climate-smart agricultural practices include systems that conserve soil moisture, reduce greenhouse gas emissions, sequester carbon, and enhance ecosystem productivity (Lipper et al., 2014; McCarthy et al., 2011; Steenwerth et al., 2014; Zerssa et al., 2021; Zougmoré et al., 2016). Therefore, identifying potential environmentally and economically sustainable climate-smart agricultural management is crucial to enhance nutrition-sensitive irrigated production.

This study assessed the impact assessment of land use change and irrigation expansions on the different water balance components and inflow to the IND. It also included land suitability analysis for vegetable (okra, chili, tomato, shallot and melon) production across the Malian part of basin, as well as crop water requirement and irrigation water requirement of the selected vegetables in Mopti region. The land suitability assessment was conducted using a GIS-based Multi-Criteria (MCE) technique. Selected biophysical (climate, soil, land-use and slope) and socioeconomic (proximity to road and population density) factors were weighted by experts using a pair-wise comparison matrix, reclassified and overlaid to identify the suitable areas for vegetable cultivation. The crop water requirements and irrigation water requirements of the vegetables were assessed using the CROPWAT 8 computer model. The impact assessment of land use change and irrigation expansion (biophysical modeling approach) was implemented to simulate crucial hydrological fluxes for the baseline periods from 1982 to 2020. The SWAT model was used to develop the baseline model. This model requires several hydroclimatic and biophysical input variables acquired from different sources, mainly from satellite products, given the high purchasing cost of the observed climate data from the National Meteorological Agency (MALI-METEO) of Mali. After developing the baseline model, impacts of land use change and irrigation expansions were integrated into the model. Then, changes in the water balance components were quantified to assess the overall impacts on the IND and other parts of the basin. In addition, scenarios of climate-smart agricultural interventions were implemented in highly suitable areas, and their biophysical impact was estimated using the calibrated and validated SWAT model. This component is also valid for identifying environmentally sustainable approaches for improved nutrition and women empowerment through small-scale irrigation interventions to enhance high-nutrition crop and fodder production locally in the IND.

After obtaining the optimal model simulation through calibrating the sensitive model parameters, a separate model simulation was carried out using the 2020, 2010, and 2000 land use maps by keeping all other parameters constant. Thus, the changes in different water balance components are due to the change in land use. The subbasin level model outputs of actual ET, soil water, water yield, and sediment yield were generated, and the change in these water balance components was investigated under the three land use inputs. Since there was no significant change in land use in 2020 and 2010, the changes in the water balance components were not pronounced as well, and the result obtained due to land use change in 2020 and 2000 is presented in this section. Figure A.1 below, illustrates the spatial distributions of change in actual ET, soil water, water yield, and sediment yield simulated using different land use as the main input. A reduction in actual ET up to 54mm has been observed in subbasins mainly located in the central and southern parts of the watershed due to land use change in the past two decades. Croplands are the dominant land use types in these subbasins. Except for some subbasins in the southwest parts, there is no significant change observed in the soil moisture due to land use change. Similarly, the subbasins in the central and southern areas depict an increase in water yield from 11-35mm, except one subbasin in the southeast that revealed a decline in the water yield by 10 to 20mm. The water yield accounts for both surface and groundwater, and its enhancement might be due to land use change induced surface runoff increase and also an increase in drainage water because of the expansion in irrigation. The change in sediment yield to the range of ±20t.ha^{-1}yr^{-1} has been observed in the majority of the subbasins across the watershed. Pronounced decline and enhancement in sediment yield has been identified in the subbasin in the central parts of the basin. The results from this study revealed the impacts of the land use change on the water balance components particularly in the central and southern parts. This may highlight the need for an integral approach to develop well-planned land use managed practices in the basin.

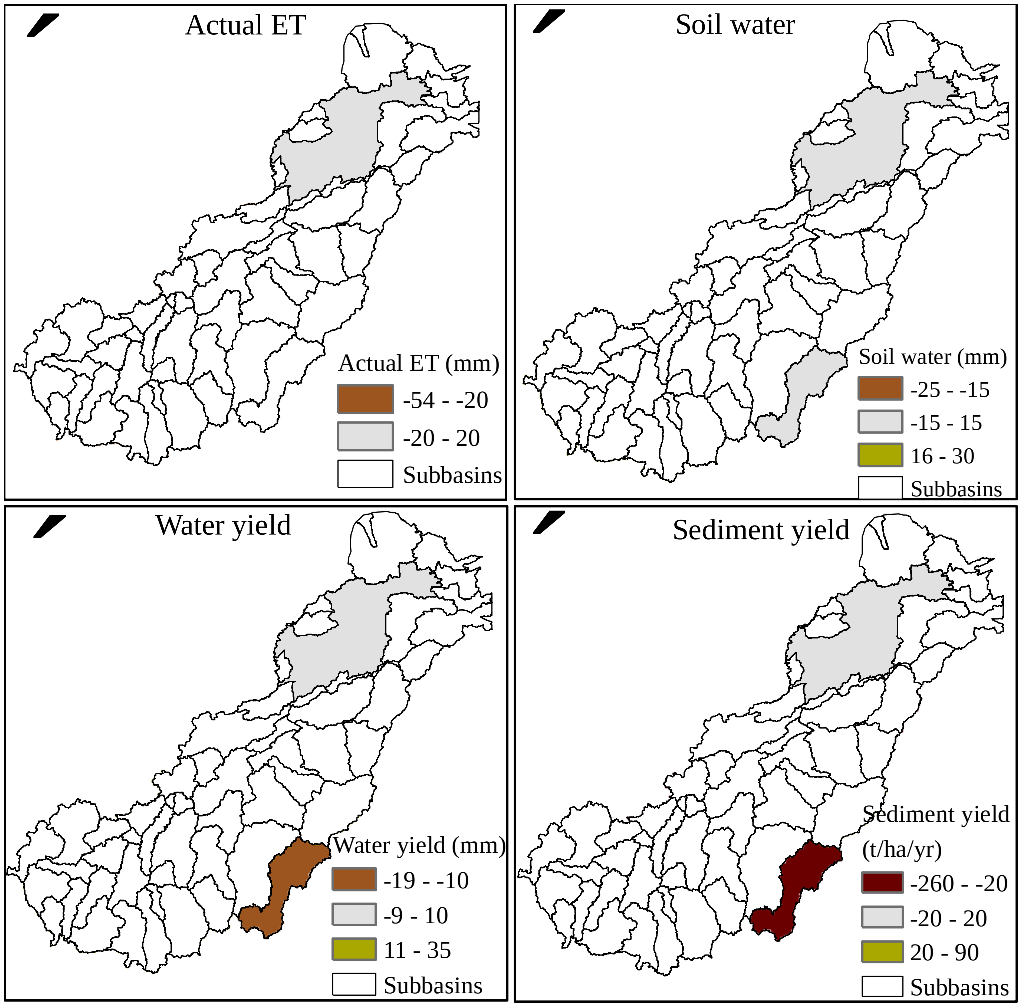

Figure A.1: Biophysical model simulation of the different water balance components under the three land use change scenarios.

The land suitability assessment for vegetable production, extracted at a threshold level greater than 80 % and excluding all restricted areas indicate that ~38 % of the study areas are highly suitable for producing melon, followed by okra and chili (29 %), tomato (20 %), and shallot (10 %) (Figure A.2. a, b, c, d, and e).

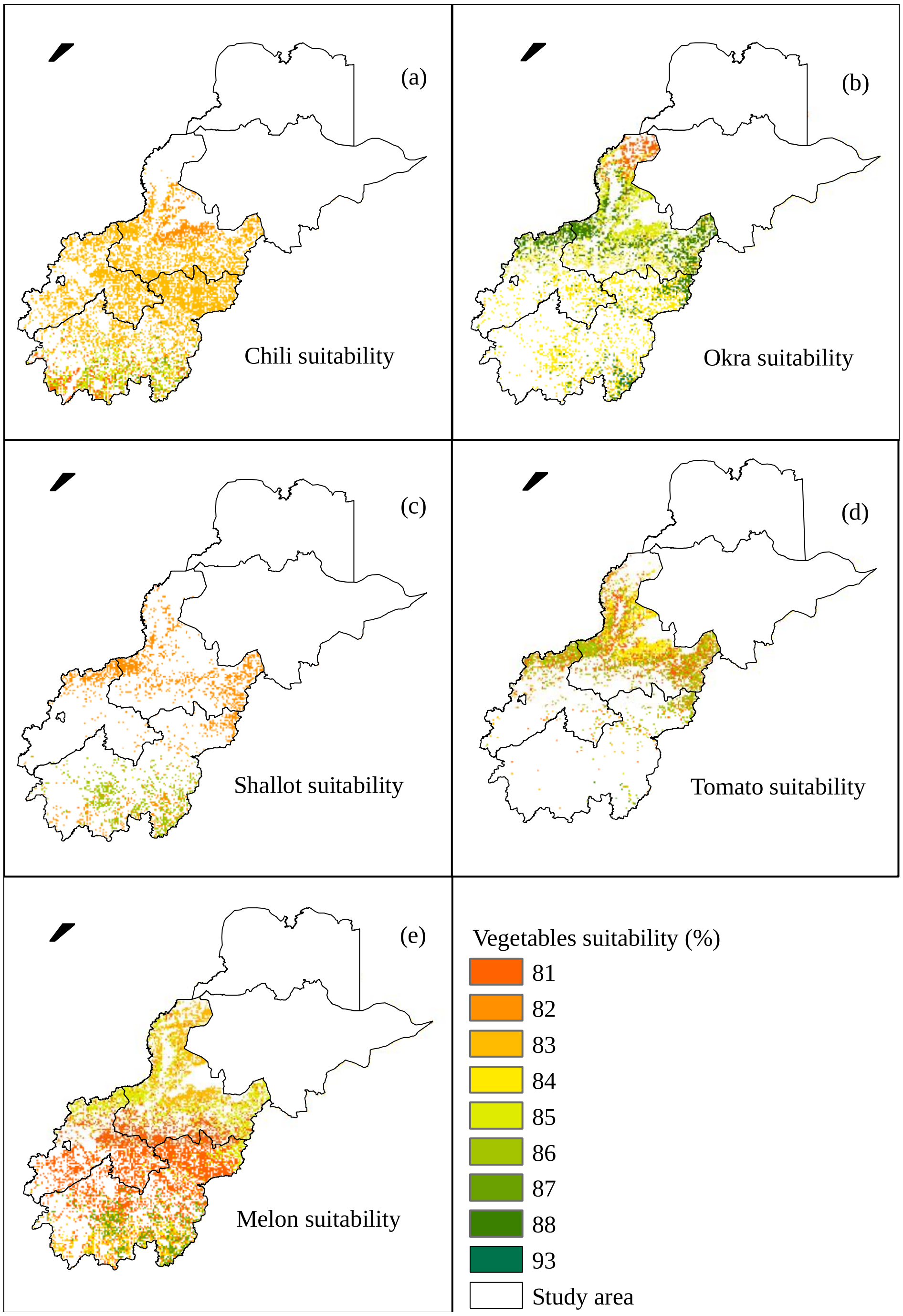

Figure A.2: Potential suitability maps for vegetable production in Mali: optimal suitable land (greater than 80 %) for Chili (a), Okra (b), Shallot (c), Tomato (d), Melon (e) productions.

Following the aggregation of the different vegetables at a suitability level greater than 85%, (Figure A.3) watershed discretization using the SWAT model indicted that the suitable lands for vegetable production are mainly located in the central parts of the basin (i.e., subbasins 34, 41, 45 and 46) and close to the IND (subbasins: 9, 16, 17, 19, 20, 22, 23, and 26). To identify the suitable areas that all the vegetables cover in the basin, the individual suitable maps wer aggregated at a suitability level greater than 85% (Figure A.3). Based on the resulting watershed discretization using SWAT model, the suitable lands are mainly located in the central parts (i.e., subbasins 34, 41, 45 and 46) and close to the IND (subbasins: 9, 16, 17, 19, 20, 22, 23, and 26).

Regardless of the current agricultural conservation practices that are existing on the ground, the conservation practices introduced into the SWAT model (i.e., contour farming, strip cropping, and grasses waterway) illustrate that there is potential for some improvement at subbasin scale. There is no significant change on the water balance components at the basin scale analysis. The analyzed conservation practices suggest this could be effective in reducing the soil erosion and enhanced water availability for the vegetable production. The water use efficiency would improve if large water consuming crops (e.g., rice) were replaced by vegetables.

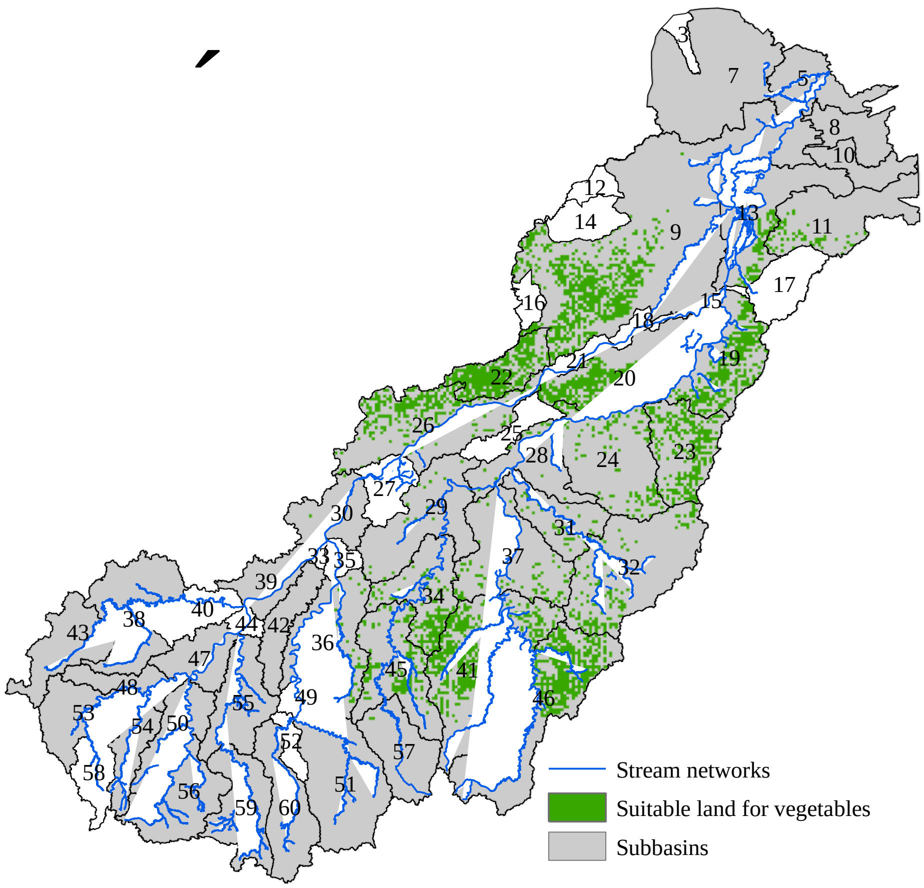

Figure A.3: Suitable land for vegetables (i.e., Chili, Melon, Okra, Shallot and tomato) in the central and downstream sparts of the basin.

Results of the CWR and Irrigation Water Requirement (IR) analysis shows that for optimal yield, supplementary irrigation is necessary for vegetable production in Mopti region (Figure A.4). Water requirement for melon was the highest (900 mm/season) followed by shallot (866 mm/season) and then tomatoes (839 mm/season). Okra had the least water requirement (390 mm/season). In addition to the rainfall, all the five vegetables require irrigation if optimal yield is desired. Tomato, shallot, chili and melon require over 500 mm of irrigation based on the planting dates indicated by farmers in Mali. Okra, on the other hand, requires about 120 mm of irrigation per season.

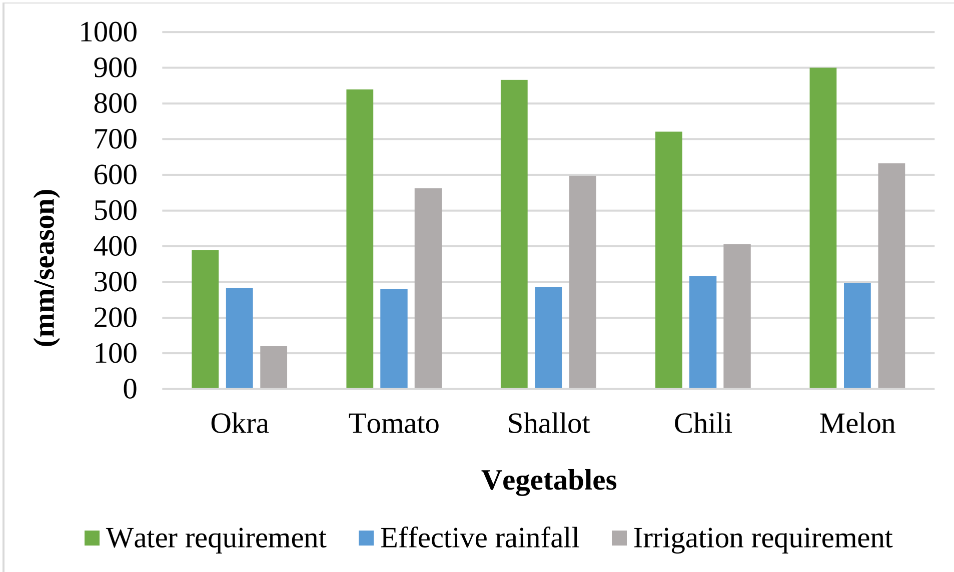

Figure A.4: Water requirement, effective rainfall and irrigation requirement of the vegetables in Mpoti

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Annex 6. Impacts of the PSNP watershed rehabilitation and irrigation interventions

The impacts of the watershed rehabilitation and irrigation interventions implemented in Productive Safety net Program (PSNP) woredas of Ethiopia were evaluated to explore their benefits in terms of improving the livelihood of the society, granting food security and environmental sustainability at large. These investments were financially supported by the USAID Bureau of Humanitarian Assistance (BHA) in collaboration with other international organizations that include World Vision (WV), Food for Hungry (FH), Relief Society of Tigray (REST) and Catholic Relief Services (CRS). These international organizations have an indispensable role in implementing the watershed rehabilitation and irrigation intervention mainly in Amhara, Oromia, and Tigray regions, and Dire Dawa administration in Ethiopia.

There were 75 watershed outlets primary identified in Productive Safety Net Programme (PSNP) woredas and a total of 17 watersheds were initially selected for the deep dive analysis with a joint effort with IFPRI partner using the selection criteria that include mainly the availability of development map, availability of different types of interventions, area of the watershed, and the availability of Feed the Future (FtF V02) secondary data. Percentage coverage of the interventions varies from one watershed to another. The interventions cover upto 100% of the total area of smaller watersheds as compared to the bigger watersheds. Equal weights were assigned for each criterion and then watersheds that scored relatively the higher value were identified and used for the deep dive analysis. The implementers also forwarded their feedback on the selected watersheds and suggested to drop out some of the watersheds from the deep dive analysis due to the age of the interventions and accuracy of the development maps. For example, the implementers confirmed that the watershed treatments in Ija Bowa and Didimtu watersheds were commenced since 2020 and there is short record length of data length to pursue the evaluation before and after intervention. In addition, there is also accuracy issues on the development map obtained from WV watersheds. More accurate and representative development maps were reproduced later by WV through conducting the field survey for Lawber, Abriko and Kolaye watersheds. Therefore, a total of nine watersheds were finally selected for further use in this study. These watersheds include Feresmay (REST), Zergawido, Ganwuha, Tilikwenz (FH), Bereka, Garalakole (CRS), Lawber, Qedelit, and Qolaye (WV).

This section summarizes largely the findings of the remote sensing and biophysical modeling-based analyses performed to evaluate the impacts of the watershed rehabilitation and irrigation interventions in terms of enhancement in vegetation greenness, actual ET, soil water availability, groundwater recharge, and reduction in soil erosion, and runoff generation. The evaluation process, in general, requires the utilization of several input variables, including the development map, weather, biophysical (i.e., land use, soil, dem and NDVI) and other data acquired from governmental and non-governmental organizations and other sources. The development maps which show the location, types and extents of the interventions implemented on the ground in each study watershed were acquired from the implementing organizations. In the remote sensing-based analysis, long-term Landsat based Normalized Difference Vegetation Index (NDVI) was used to contemplate the change in vegetation greenness due to the implementation of watershed rehabilitation and small-scale irrigation interventions. The time series NDVI data was clustered into "*before*" and *"after"* the intervention's periods using the threshold years (2008 and 2017) for the evaluation process. Majority of the interventions were implemented, and extensive rehabilitation and maintenance activities were commenced since these threshold years. The improvement in vegetation greenness was also assessed during the dry and wet seasons to explore the enhancement in vegetation greenness under different weather conditions. Due to improved soil moisture holding capacity and soil fertility in the rehabilitated watersheds, better vegetation may be observed in the rehabilitated watersheds during the dry and wet seasons. In addition, the analysis was expanded to explore the drought resilience of the vegetation greenness as a result of the interventions. Historic drought years before and after the intervention periods were identified and used to explore the benefits of the interventions to enhance the greenness during shock years. Besides the remote sensing analysis, the biophysical modeling approach was also applied in this study to explore and quantify the outcomes of the interventions in terms of changes in actual ET, surface runoff generation, sediment yield, soil water availability, and groundwater recharge.

Remote sensing and biophysical based results indicated an overall improvement in vegetation greenness and water budget components in the watersheds due to the interventions although the change varies per type of interventions, and from one watershed into the other. Water availability has improved since there is enhancement in actual ET, soil water content and groundwater recharge in most of the watersheds. While soil erosion and surface runoff have reduced with a magnitude that varies from one watershed into another. Since most of the interventions are implemented with the financial support from the international donors including USAID, the finding of this study supports the positive impacts of those investments and an indirect benefit on improving the livelihood and household level income in the watershed. Pronounced improvement in vegetation greenness has been observed during dry season compared to the wet season in the majority of the watersheds. In addition, the vegetation greenness has improved during dry season after the interventions compared to before the intervention period. The interventions have the potential to enhance the soil fertility and water holding capacity of the soil to retain more soil moisture during the dry season somehow to enhance vegetation greenness. There is no consistent improvement in vegetation observed during the rainy season due to perhaps sufficient rainfall amount to satisfy the water requirement of the plants before and after the interventions. The interventions further helped to improve drought resilience due to an increase in water availability during drought years to mitigate/reduce drought impacts on vegetation greenness although the level of vegetation greenness largely depends on drought severity at the local scale. This might allude an indirect benefit of the interventions to grant food security in the watersheds. Area closure enriched with plantation and other soil conservation activities, and irrigation interventions are more effective in terms of enhancing the vegetation greenness and soil erosion. While other soil water conservation structures (i.e., bunds, check dams, terraces have also contributed towards improving the vegetation greenness and water budget components. Despite the fact that the analysis of this study is good enough to support the positive impacts of the investment, follow-up research using an integrative approach between the remote sensing-based vegetation indices and biophysical modeling with the field level measurement and qualitative household level data will certainly offer an opportunity for better understanding of the biophysical changes linked to the soil and water conservation investments. Remote sensing is also able to provide collaborative evidence to complement with the biophysical modeling, however biophysical model provides more detailed sub-component output such as water budget components, biomass, crop yield etc. Moving forward, biophysical modeling-based analysis can be expanded further to conduct econometric and other types of analyses, which satellite based assessment limited to address.

The analysis in this study is fully based on the existing interventions on the ground. Future study may require to identifying the potential sites for further implementation to culminate the net benefits at watershed to basin scale. The biophysical modeling analysis can be upscaled and expanded to the basin and country scale to assess the overall benefits of the BMPs to the downstream hydraulic structures such as dams. Although the biophysical modeling is capable to show the benefits of the BMPs, integrating ground observation and field data may further improve the finding of this study. The accuracy and number of observations of the remote sensing largely depends on the availability clear sky imageries which is difficult to get particularly during the wet season due to cloud cover. Therefore, the biophysical model can complement this limitation and can be extensively used for future study. The age of the interventions is one of the limiting factors that significantly affects the effectiveness of each intervention particularly if there is no routine maintenance activity. Future studies through addressing the limiting factors are paramount to support further the finding of this study.