# FEED THE FUTURE ILSSI – GHANA

## RESEARCH DESIGN

### BACKGROUND AND JUSTIFICATION

The continuous agricultural expansion in Ghana stimulates the country`s economic development, but the majority of the agricultural crops produced throughout the year remains rainfed. Only 0.26% (11,000 ha) of Ghana`s cultivated land is under irrigation since 1996 and this has hardly expanded throughout the last decades (Agyei Agyare *et al.*, 2008). According to Namara *et al.* (2010), the current irrigated area in the country is much larger than the official country statistics. The estimated area (including inland valleys) having irrigation potential range between 0.36 and 2.9 million ha. Efforts have been made, in various regions throughout Ghana, to develop large and small reservoirs with appropriate irrigation schemes. In the White Volta basin, small reservoirs have been constructed since the 1950-60s, followed by larger reservoirs with associated irrigation schemes in the 70-80`s (Agyei Agyare *et al.*, 2008; Ofosu *et al.*, 2010). Currently 22 irrigation schemes are managed by the Ghana Irrigation Development Authority. These water control structures are mainly initiated and developed by the Government of Ghana, NGOs and to a smaller extent communities, where irrigation schemes are serving a large number of households at once. Although, various advantages are associated with large irrigation schemes, water consumers might face challenges due to a lack of maintenance, institutional water conveyance arrangements and overall water availability when irrigation demand increases. These systems together with flood recession agriculture (Ofosu 2014), shallow groundwater irrigation (coastal areas of south-eastern Ghana) using traditional lifting technologies and residual moisture irrigation are categorized as conventional systems (Namara *et al.*, 2010).

With the growing water demand for agricultural practices, several so called `emerging systems' have been developed by entrepreneurs and farmers, which include: groundwater irrigation systems (with manual or motorized pumping technologies), river or stream pumping or lifting, lowland/inland valley rice water capture systems and private small reservoirs or dugouts (Namara *et al.*, 2010; Tekuni Nakuja *et al.*, 2012). The pumping technologies used in these emerging systems have to meet the `mobile and flexibility' demand, using various energy sources (e.g. diesel, solar, electricity etc.) (Namara *et al.*, 2010). Due to the high variability and seasonality of the erratic rainfall events, access to emerging systems for supplementary irrigation or dry season irrigation can alleviate farmers' dependency on rainfall as well as enhance livelihood through additional agricultural production outside of the rainy season. However, the promotion of these technologies are highly depending on the prevailing local field conditions as well as farmers' acceptance and willingness to invest in a certain technology, the investment and running costs of the technologies, the availability of spare parts and the existence of a market to sell the irrigated produce .

### RESEARCH DESIGN PRINCIPLES

Past research suggests that engaging farmers and other stakeholders in a research process often leads to greater use of research results and higher rates of change in practices by farmers. In addition, cases also suggest that distribution of technology often results in dis-adoption by farmers after a project is completed. Therefore, this project takes an action research approach in which the actual conditions and context are considered within the research design and process. Technologies and inputs are not provided for free to farmers by the project, but rather, the project partners act as brokers to link the farmers to inputs required for the intervention packages and facilitate the use of the technologies through training and mentoring.[1] Data is collected on the use of the technologies, the biophysical impact from the applications of the technologies, economic feasibility, and the socio-economic changes that occur because of the technologies/practice. The aim is to understand how the intervention would work under 'real world' conditions, rather than an experimental approach. The data collected is used to model where the same technologies would hold promise under the same 'real world' conditions. In addition, a PROCA framework (or similar) can be applied to assess in a participatory manner the potential for the technology packages.

Another principle of the project is that local stakeholders and farmers voluntarily participate in the project based on full information. Farmers are to be fully informed of the approach of the interventions, including what the project will provide and the risks that the farmers themselves must assume as part of their participation. The project also seeks to minimize risk to avoid any risk that is not experienced by farmers and other participants in their normal practices. The project also takes the approach of continuous stakeholder engagement, which extends to the field level where local government, customary authority and local institutions and organizations are consulted before the sites are finalized and throughout the research process.

## ILSSI OVERVIEW

At the ILSSI stakeholder workshop held in Ghana on 15th of April 2014, constraints and opportunities with regards to small scale irrigation (SSI) above the 8th Parallel were discussed. Based on these findings, this concept note aims to outline a relevant research framework for the implementation and assessment of small scale irrigation technologies for vegetable and irrigated fodder production.

ILSSI will pilot small scale irrigation technologies toward optimization for smallholder farmers. One type of technology that stakeholders noted demand for in the stakeholder consultation is small dugouts. Based on stakeholder observation, farmers are increasing the use of small reservoirs or dams and shallow wells to extend the use of rainwater into the dry season for vegetable production.[2] Dugouts in West Africa are described by Venot et al. (2012) as rainwater harvesting structures or ponds located in depressions with additional manual or mechanical excavation that often dry up during the dry season. These structures have multiple users and purposes, including

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[1] The project will attempt to identify a credit institution or cooperative to be a project partner to facilitate credit access as part of the package. Appropriate institutions, e.g. rural banks, should be engaged from the start. Economic data related to credit costs and economic feasibility should be part of the study.

[2] This was noted by participants of the ILSSI Stakeholder Consultation in Tamale, Ghana in April 2014. The local terminology for hand dug wells is 'dugouts', so care must be taken not to confuse shallow wells with small rainwater harvesting ponds.

domestic and livestock consumption. In some cases, dugouts fail to provide adequate water or rainwater cannot be effectively dammed, and farmers use shallow wells for irrigation. It is believed that the presence of dugouts or defunct reservoirs improves groundwater recharge, and therefore, shallow groundwater irrigation potential in the area. Stakeholders have noted the need to improve/rehabilitate rainwater harvesting ponds and shallow wells, and to understand the impact of increased use.

However, at present, little is known about the interaction between dugouts and shallow wells for irrigation purposes in the area. At farm level, rainwater harvesting ponds often experience large evaporation and percolation losses which, if practiced at small plot size might not yield enough water for one irrigated cropping season. This is more likely if the water application has a low efficiency; farmers in Ghana often practice flood bed or furrow irrigation that results in large water losses and further lowers the feasibility of dry season irrigation over the long term. Overall, the sustainability of shallow wells for irrigation purposes in many of the sites and the watershed generally is not known.

In addition, there are also socio-economic constraints to shallow groundwater and rainwater harvesting development for irrigation. Shallow wells and rainwater harvesting ponds are often situated on land with seasonal usufruct rights; shallow wells are dug by those with a dry season user right and then refilled before the land is handed over in the rainy season to the primary land right holder for rainfed farming of staple crops. This increases the costs to farmers to practice irrigation through increased labour requirements for annual digging then refilling of ponds or wells. The current season shifting of usufruct rights also further reduces the feasibility of fixed irrigation structures or technologies that reduce labour requirements for lifting and conveyance, and are more water efficient and productive in distribution at farm level.

This project aims to better understand the above constraints to sustainable intensification with small scale irrigation and to identify potential opportunities and business models to increase development of irrigation among smallholder farmers.

## KEY RESEARCH DESIGN ISSUES

1. Assess the occurrence of existing dugouts and their effects on groundwater recharge and shallow well sustainability;
2. Shallow groundwater use in conjunction with dugouts to optimize dry season irrigation. The shallow groundwater well inclusion links with assumption (d) and Biophysical Hypotheses (c), (d) and (e);
3. Improving water lifting, conveyance, storage, application and water use efficiency for dry season irrigation using shallow wells;
4. Explore the potential of roof water harvesting in combination with water efficient irrigation technologies such as drip for small homestead garden irrigation;
5. Balancing construction/maintenance costs and crop production benefits of irrigation technology;
6. Identifying the optimal land use arrangement to ensure a viable business case for investment by a community/farmer;

7. Identifying the potential interaction and measuring the trade-offs for different water lifting, conveyance and application technologies;
8. Identifying the potential for integrating fodder into irrigated plots;
9. Identifying the linkages between potential technologies, packages, practices and nutrition.

## OBJECTIVES OF PROJECT INTERVENTIONS

It is recognized that improved irrigation methods might not overweigh the actual investment costs in relation to the local rainfall/ groundwater recharge patterns, and even in cases where income is increased through irrigated methods, nutritional status does not always improve. As such, the project seeks to develop an appropriate system or model that combines technologies and practices, including crop selection, credit packages, and land use rights, toward improving livelihoods. The project outputs should include a 'plug and play' investment chart for farmers to facilitate technology decision-making based on their financial and geographical location (climate, water source, etc.) as well as their agricultural preference (vegetables, fodder, rice, or others).

**1.** Identify optimal irrigation technologies for shallow groundwater wells and rainwater harvesting with regards to **lifting, conveyance and application;**
**2.** Assess the potential and sustainability of shallow groundwater well extraction and roof water harvesting at watershed scale for various water saving scenarios;
**3.** Investigate shallow groundwater well capacity/recharge for vegetable and irrigated fodder production;
**4.** Reduce on-field water losses during irrigation through:
    **a.** Introducing water saving irrigation techniques
    **b.** Introducing simple soil moisture monitoring techniques to farmers to reduce excess-irrigation
**5.** Investigate the feasibility of technologies in relation to land use rights, labor, investment costs and maintenance at homestead level;
**6.** Identify farmer preferences (and cultural beliefs/customary rules) and incentive systems for use of various irrigation technologies and practices, including both men and women;
**7.** Develop suitable business models, including land lease arrangements and credit/insurance packages, to increase economic value of shallow wells, roof water harvesting and irrigation technologies;
**8.** Investigate impact of various technologies and practices **on nutrition** at household level.

## RESEARCH QUESTIONS, ASSUMPTIONS, HYPOTHESES

### OVERALL RESEARCH QUESTIONS

1. What is the optimum irrigated plot size, technology/practice package and land use arrangements to increase productivity, incomes and nutrition, considering both economic and environmental sustainability in specific locations in the study area?
2. What is the optimum combination of crops for market and for household nutritional needs that is both economically and environmentally feasible/sustainable and relationship to seasonal and annual market/price variations?

3. For all of the above: What are the constraints and opportunities for technology packages? (e.g. PROCA from AgWater Solutions; SWAT, APEX, FARMSIM to consider impact + scaling opportunities)?

## ASSUMPTIONS

1. Increased use of SSI will increase food production and improve livelihoods of small farmers
2. Dugouts present in the landscape feed downstream shallow wells and influence their sustainability for irrigated production
3. Increasing use/ extension of dugouts and/or shallow groundwater well extraction will influence the hydrological processes at watershed scale
4. Water is relatively scarce in the Sahelian regions of Ghana; efficiency of water use for food production needs to be improved to reduce water losses
5. Drip and other plant specific application technologies improve water and nutrient use efficiencies, potentially leading to higher yields compared to basin and furrow irrigation
6. Farmers will adopt technologies for optimized water lifting, storage, conveyance and application when technologies are accessible (markets, credit, affordability)
7. Limited land, labour and capital constrains farmers access to and use of SSI technologies
8. Access to technologies is gendered; female headed households and female farmers have higher constraints to SSI access

## HYPOTHESES

### BIOPHYSICAL

1. Specific aquifer characteristics will make shallow groundwater wells a suitable alternative to dugouts in places where dugouts are absent or non-operational;
2. Wells are shallower and more sustainable in areas where dugouts exist;
3. Roof water harvesting is a suitable alternative to improve nutrition through vegetable production at homestead level when shallow wells are not viable;
4. There will be trade-offs for ecosystem resilience with the use of dugouts and shallow wells;
5. Water use efficiency can be improved using drip, sprinkler and overhead[3] application technologies and irrigation scheduling tools combined with water harvesting and lifting devices;
6. Flexible and mobile water lifting technologies can be optimized making use of the available energy source (motorized vs. manual water lifting devices).

### SOCIO-ECONOMIC

[3] Overhead in this research design refers to watering of the plants using a hose. This study does not define overhead as exclusively watering can, as is sometimes used in Ghana.

1. Farmers will change behaviour and increase water use efficiency following increased knowledge of and use of basic soil moisture monitoring tools;
2. Appropriate land, credit and service provision models increase access to and use of SSI;
3. SSI development may adversely affect the nutritional intake of the poor when it leads to mono-cropping of cereals, especially rice around dugouts/small reservoirs;
4. Poverty incidence can be lowered among farmers that have access to SSI compared to purely rain-fed farmers;
5. Men and women are involved in different stages of the SSI value chain; access to a technology/practice package within the household will impact these two groups differently.

## SITES FOR INTERVENTIONS

### TARGET BENEFICIARIES

The project has identified a minimum of three communities/sites in Northern and Upper East Regions in which interventions will be piloted and data collected (biophysical and socio-economic). The project sites are in Feed the Future zones (above the 8th parallel) and one site is an existing Africa RISING site. The project will pilot three technologies/practices packages aimed to benefit at least 60 people during the project period ending in 2018, targeting women and where possible youth.

### SITE SELECTION CRITERIA

Partners of UDS, IWMI and ILRI selected three project sites during a joint field visit in the Feed the Future zone. Sites selection criteria considered geographical location, livelihood status and market access. The sites outlined below were selected based on four indicators: irrigation potential, livestock, gender and market access.

#### NORTHERN REGION – SAVELEGU/NANTON MANUCIPALITY: BIHINAAYILI

Bihinaayili ($9^{o}$ 36'12.1" N, $0^{o}$ 51'22.9" W, elevation 137 m a.s.l.) is a site near Tamale in the Northern Region of Ghana. Farmers depend on both rainfed and irrigated agriculture. A small group of farmers are already practicing irrigation using shallow wells and irrigation from a nearby dam. Water is lifted using buckets and motorized pumps, and farm plots irrigated with watering can and flood type surface irrigation methods. The main crops are tomatoes and leafy vegetables. Occasionally, women work on their husbands' plots to perform tasks such as weeding, and are actively involved in harvesting and usually responsible for the marketing of the produce. However, men have the primary user rights to the land, and women do not commonly take responsibility for irrigation activities. Farmers have experience with *Cajanus cajan* for livestock feed, suggesting potential for live fencing or other irrigated fodder crops. The nearest market is 3 to 5 km from the village.

#### UPPER EAST REGION – NABDAM DISTRICT: ZANLERIGU

Zanlerigu (10°48'11.94"N, 0°43'24.12"W, elevation 227 m a.s.l.) currently has a failed dugout within the community, but farmers dig multiple shallow wells within one plot for irrigation. It is believed that these shallow wells are partly fed by the seepage from the dugout. These wells are temporary and closed at the end of the dry season when the land is returned to the chief(s) or primary land holder. Famers mainly apply water by watering cans for onion, cabbage, tomato and hibiscus. Similarly to Bihinaayili, women are not involved in irrigated farming; women lack usufruct rights to land to develop irrigation and farmers state that irrigation requires too much labour for women. Women's main activities are related to small-scale quarrying, dawadawa and shea collection and extraction, and animal rearing. A few homesteads harvest water from roofs, but do not use it for irrigation due to the absence of appropriate water saving techniques to ensure sustained use throughout the dry season. The community has no experience with irrigated fodder, but occasionally buy fodder to overcome the shortage in the dry season for fattening animals and addressing animal health. Farmers are eager to try *Cajanus cajan* as a live fence as it serves a dual purpose. The nearest market is 3 km.

### UPPER EAST REGION – KASSENA NANKANA EAST DISTRICT: DIMBASINIA

Dimbasinia (10°54'23.57"N, 1° 2'8.31"W, elevation 189 m a.s.l.) has a larger reservoir or dugout (compared to Zanlerigu) used for multiple purposes, including domestic, livestock and irrigation. However, it is currently defunct because of siltation. The community has dug canals fed by the dugout to irrigate their fields during the dry season. In periods of insufficient water availability, they use shallow to deep wells presumably recharged by the dugout to irrigate their fields. Farmers tend to over-irrigate; they use motor pumps for water lifting in combination with furrow and flooded beds. The main irrigated crops are onion, pepper, garden egg, lettuce, tomato and cabbage. Some women grow vegetables within the plot for which their husband has usufruct rights; the majority of women work on plots managed by spouses to support agronomic practices such as weeding. Fodder cultivation is not practiced in the dry season, but is collected from the surrounding area. Farmers are interested to try fodder cultivation, especially dual purpose crops (Cajanus cajan, soy, pigeon pea, cowpea etc.). The nearest market is 5 km from the settlement with potential fodder markets in Bolgatanga and Navrongo.

## COMPLEMENTARY PROJECT SITES

Several irrigation projects have been or are earmarked for initiation in the region. The Africa RISING project, also part of the Feed the Future project, is working in the same regions as ILSSI with agricultural water management potential in some sites. The public-private partnership IWAD (Integrated Water & Agricultural Development) is active in the Sisili–Kulpawn Basin and introducing various irrigation technologies and practices. A Water, Land and Ecosystem research program project led by the Ghanaian Irrigation Development Authority, with UDS and IWMI, aims at comparing various large, medium and small scale reservoirs with regards to irrigation efficiency. The complementarity of these projects within the WLE framework may enhance data availability during the life of the project.

# RESEARCH APPROACH AND COMPONENTS

The project has adopted a modified action research method. Pilot interventions will be established with extensive consultation with farmers and local stakeholders. The project will have regular engagement with stakeholders and farmers, and will continually monitor issues, reflect on learning and adapt technologies and approaches as needed to achieve outcomes. The process of the research will be documented and lessons identified for best practices and business models for outscaling. Baseline data will be collected in the first year of the project (2015), and data from modified interventions collected in the following two to three years (2016, 2017 and 2018). The project understands the following components as inter-related; the separation of components in this document is for planning purposes.

## 1. SOCIO-ECONOMIC ASSESSMENT AND BUSINESS CASES FOR SHALLOW WELLS, ROOF WATER HARVESTING AND IRRIGATION TECHNOLOGIES

In order to design suitable technologies to improve water storage, conveyance and use, socio-economic research must be integrated with biophysical research. To begin, socio-economic research will aim at identifying: i) gender disaggregated farmer perception, preference and knowledge on dugouts, shallow in-field groundwater wells, roof water harvesting, water lifting and in field saving techniques, as well as land use rights (seasonal, gender-based, etc.), land rental agreements, and other institutional arrangements; ii) willingness to invest in potential technologies and practices (including shallow groundwater wells, roof water harvesting, water lifting and saving techniques); iii) feasibility of establishing small (2-5 homesteads) groups to invest in the defined technologies; and iv) farmers preference for specific irrigated vegetable and/or fodder production; v) feasibility of organizing farmers using shallow groundwater irrigation and other practices into commodity value chains to improve output marketing system..

Socio-economic interventions will include periodic assessment of farmers' perceptions of, responses to and incentives for acceptance of the various technologies and practices towards optimizing these throughout the project cycle. Biophysical and socio-economic analysis will contribute to development of suitable business models and strategies for upscaling suitable solutions in selected sites.

## 2. SHALLOW GROUNDWATER WELL POTENTIAL FOR IRRIGATION PRACTICES

The usage of in-field shallow groundwater wells for irrigation purposes might be restricted based on seasonal land user rights as well as access to appropriate water lifting technologies. Shallow groundwater wells are often dug in low-lying, high water table areas close to streams or wetlands/inland valleys and are de-silted in the dry season. Depth ranges between 3-6 m. the wells are usually covered using various methods prior to the rainy season when land is returned to the person with primary land use rights (Namara *et al.*, 2010). As such water lifting technologies associated with these wells need to be mobile and flexible to be removed during the rainy season. In addition, the continuous opening and closing of these wells creates soil instability and high preferential subsurface flows (due to lower soil compaction) and also requires high labour and investment costs of the land tenant in the dry season. Farmer training manuals will be developed (curriculum and materials) and implemented in the communities on best agronomic and irrigation practices using shallow wells as water sources.

This research component seeks to assess:

1. Cultural-social and economic context of in-field shallow groundwater wells including the value chains of inputs and produce;

2. Land user rights framework supporting a more sustainable management of these shallow wells. Options will be explored in which the person with the primary usufruct land right invests in upgrading shallow groundwater wells in a way that will be beneficial to both primary and dry season land users;
3. Spatial distribution of shallow in-field groundwater wells at the project sites using remote sensing to provide easy to comprehend groundwater maps for assessing the precise sitting of wells;
4. Suitable and flexible manual and motorized water lifting technologies;
5. Well recharge for irrigation potential and understand connectivity with existing reservoir/dugouts;
6. Sustainability throughout the dry season for irrigated vegetable production by assessing their water productivity, micro-nutrient uptake as well as the associated cost-benefit analysis;
7. Transition to a more permanent system for wells to decrease costs of investing in seasonal digging of wells, and more suitable water lifting devices, conveyance and application technologies;
8. Potential climate resilience for rainfed crops from permanent wells. The potential benefit and consequence for both women and men should be examined over the project period.

For all participating farmers, consensus is required on the chosen combination of irrigated vegetables/fodder during the duration of at least one dry season each year within one project site. This will facilitate the comparison of the various technologies as crop water requirements differ significantly and influence the water use efficiency, labor and cost involved for each of the technologies. In addition, there is both seasonal and annual fluctuation of market prices for crops.

An in-depth assessment of the constraints and potential of shallow in-field groundwater wells in relation to irrigated vegetable/fodder production and their effect on groundwater usage would allow for further suitability mapping of shallow in-field groundwater wells in inland valleys or adjacent to rivers. The basis for these suitability maps would be one of the outputs from the watershed modelling component, where the groundwater extraction sustainability, through various upscaling scenarios of shallow groundwater wells as well as respective water lifting technologies, can be assessed.

## 3. ROOF RAIN WATER HARVESTING

Zanlerigu will be a study case for roof water harvesting for homestead irrigation of nutritious crops. This will be done in combination with water saving techniques. Existing roof water harvesting systems (including local clay tanks) in Zanlerigu will be monitored in the first year on the amount of water stored within the rainy season and potential for a small homestead garden using water efficient technologies, such as drip irrigation (various options, including one UDS design). Investment costs and market availability of this system will be assessed. Recognizing that the water will be used for multiple purposes, water quality (e.g. microbial composition, micro-nutrient content, etc.) will also be assessed. Focus group discussions will be held by UDS in consultation and collaboration with IWMI on homestead gardening practices. Farmer training manuals will be developed (curriculum and materials) and implemented in the communities on best agronomic and irrigation practices for homestead gardens. Agronomic performance, micro-nutrient uptake and water productivity will be closely monitored throughout the season, as will farmer and household responses to the interventions and their water allocation preference (e.g. home gardens, domestic use, etc.). Based on the first year, an assessment will be made on water harvesting potential and need for improvement (e.g. size, placement, etc.).

This research component seeks to assess:

1. Potential for homestead gardening using rainwater harvesting and water saving techniques;
2. Strengths and weaknesses of different water application and saving technologies and practices;
3. Costs of homestead gardening using various water harvesting, storage and application options;
4. 'Best practices' for training on and sustaining optimal water management and agronomic practices on homestead gardens;
5. Potential for upscaling homestead gardening based on the pilot results;
6. Potential for improving household nutrition status.

For farmers who have no access to shallow wells or where groundwater potential is low, roof water harvesting might be a viable alternative to improving household food security and nutrition. The pilot will enable the project to define up-scaling potential and develop business models to use for other selected sites.

## 4. TESTING WATER SAVING TECHNIQUES

In the interventions reducing water losses in the water storage and lifting device component, there is another gap in the irrigated water cycle: reducing water losses during irrigation application. Low cost drip irrigation (385 USD) has been promoted by iDE, however, farmers' acceptance remains low; it still is considered to be a large investment (International Water Management Insitute, 2014). Additional issues have been identified related to adoption and frequent discontinued use of drip irrigation, including the belief by many farmers that crops need to be flooded in order to grow well. Furthermore, the technology faces a few technical issues. For example, drip irrigation systems are very susceptible to clogging depending on the sediment texture as well as quantity. In order to use drip irrigation systems as a function of the water source (riverine, dugouts, etc.), a solution needs to be developed to reduce pipe clogging.

This research component seeks to assess:

1. Potential for a low cost filter with the water lifting device before the water is lifted into the tank used for drip irrigation.
2. Potential for filtering the water prior to drip irrigation to reduce biofilm development in the tank and reduce maintenance costs.
3. Range of filter materials to improve current drip irrigation technologies based on sediment texture and structure observed
4. Market chains related to local materials to produce cheap drip irrigation kits.

5. Combination of drip with other lower cost water saving technologies like mulching (using soil coverage by rainfed residues reduces evapotranspiration and simultaneously improves nutrient cycling) will also be considered as part of the overall 'package' of interventions.
6. Trade-offs for farmers for using mulch for feed. This should be done prior to implementation of the component 5 as farmers may prefer plant residues for livestock feeding or other usage;
7. Irrigation scheduling options for optimizing water usage, notably wetting front detectors. Wetting front detectors signal the movement of the wetting front through the root zone and will give a signal once the wetting front has passed the root zone.
8. Costs related to labor, investment and maintenance in relation to income from irrigated crops.

The participating farmers will be trained by the project in irrigation scheduling using the various practices and technologies noted above. A group of farmers for each irrigation technology will be trained, and their irrigation knowledge, improvement and reduction in labour-costs can be assessed. Additional options may be added or adapted as the above technologies are assessed.

## 5. ASSESSING THE TECHNOLOGIES AT WATERSHED SCALE

The sustainability of upscaling the monitored interventions and their respective effects on hydrological/bio-geochemical processes and farmers livelihoods at watershed scale will be assessed through a modelling suite that provides decision support tools (SWAT, APEX, FARMSIM). Each of the above mentioned components will include the necessary data listed below, which shall be collected by UDS:

- Spatio-temporal variation of hydro-meteorological data in each of the project sites
- Seasonal variation of the water balance as affected by prevailing climatic conditions, crops irrigated and technology used
- Spatio-temporal recharge rates and overall groundwater potential within each of the sites with respect to the total irrigable land
- Assessment on water quality, micro-nutrients and health as many water sources are multi-purpose and contamination of groundwater or vector borne diseases (e.g. malaria) due to increased irrigation activities should be mitigated
- Agronomic crop performance indicators, crop micro and macro nutrient uptake, and water productivity for the various irrigated crops selected as affected by the **source, storage, conveyance and usage** aspects
- Water use and labour efficiency of the various irrigation and water saving technologies
- Water productivity for the water saving techniques monitored = water footprint of vegetable production in Ghana and its implication for irrigation expansion

## 6. IRRIGATION AND FODDER PRODUCTION

Opportunities for irrigated fodder production in Northern Ghana are limited; irrigated fodder production may not be attractive for farmers using dugouts or shallow groundwater. The use of small reservoirs for livestock watering in dry season has led to conflict in some cases. Therefore, the project will consider linking fodder to dugouts and shallow groundwater. This component of the research will be **led by ILRI and local partners including Animal Research Institute (ARI)**, in collaboration with IWMI and UDS. Potential interventions include the following:

a. Use of residues from irrigated crops and vegetable as animal feed. This would be to target market-oriented livestock enterprises, such as sheep fattening and peri-urban dairy production.
b. Demonstration plot around dugouts for fodder production using pilot or champion farmers. The objective is to demonstrate the economic potential for irrigated fodder production. This would be carried out in sites close to Tamale (Bihinaayili community) and Zanlerigu to facilitate sale of fodder at the market.
c. Use supplementary irrigation to grow dual purpose crops, particularly legumes such as cowpea and pigeon pea commonly grown in Northern Ghana.

The potential for forage production through irrigation in northern Ghana will be investigated through literature review and questionnaire surveys. It will cover the: 1) potential for adoption of forage irrigation by male and female farmers and 2) market opportunities for forage and the added value of forage irrigation to the livestock value chain during the dry season.

## PROPOSED TECHNOLOGIES/INTERVENTIONS BY SITE

The components will be implemented across the three sites to enable robust comparison, development of potential solutions into business models, and identification of opportunities and constraints to up- and out-scaling. In addition to the interventions/technologies and bio-physical data collection described below for each site, additional data at watershed scale will be collected at each of the sites. These data mainly include meteorological, discharge, stream quality, topography, land use, and overall physico-chemical soil information as well as GPS locations of the households, water sources, interventions, and irrigated plots. Additionally, detailed water level monitoring and recharge experiments will be conducted to determine the surface-water interaction and overall storage potential for irrigation for the sites where dugouts and shallow wells are available.

| District | Village | Coordinates | Water source | Intervention(s) biophysical |
|---|---|---|---|---|
| Savelugu | Bihinaayili | 9° 36'12.1N, 0° 51'22.9 W | Surface/streams, shallow wells | Surface/Stream, shallow wells, water can and tank-hose irrigation, irrigation scheduling tool |
| Savelugu | Bihinaayili | 9° 36'12.1N, 0° 51'22.9 W | Surface/streams, shallow wells | Irrigated fodder - agronomic assessment, nutritional quality and effect on animal performance |
| Nabdam | Zanlerigu | 10°48'11.94"N, 0°43'24.12"W | Shallow groundwater wells | Dry season vegetable irrigation using water can and tank-hose irrigation |
| Nabdam | Zanlerigu | 10°46'55.10"N, 0°43'50.30"W | Rainwater | Rainwater harvesting gardens, storage, bucket-drip and UDS drip irrigation |
| Nabdam | Zanlerigu | 10°48'11.94"N | Shallow wells | Irrigated fodder – agronomic |

| | | | | |
|---|---|---|---|---|
| | | , 0°43'24.12"W | and rainwater | assessment, nutritional quality and effect on animal performance |
| Kassena Nankana East | Dimbasinia | 10°54'23.57"N , 1° 2'8.31"W | Shallow groundwater; surface water | Wells + surface, bucket-drip and UDS drip, irrigation scheduling tool |

## 1. BIHINAAYILI COMMUNITY, SAVELEGU/NANTON MANUCIPALITY, NORTHERN REGION

### DRY-SEASON VEGETABLE IRRIGATION

Farmers will be organized into 2 clusters of 8 members each. In each cluster, one-half of the farmers will test the technology with an irrigation scheduling tool while the other half will use existing farmer practice (without irrigation scheduling tool).

There will be two irrigation technologies focusing on use of shallow wells: 1) water can irrigation and 2) overhead irrigation with a hose from a 150 L to 200 L tank. The vegetable Cochorus was selected in consultation with farmers for the on-farm demonstrations. The farmers using overhead irrigation will be provided with 2 pumps on loan, one for each group of 4 farmers. Water tanks will be provided free of charge. Two (2) watering cans will be provided to each of the farmers using water can irrigation, free of charge.

Thus, the suggested treatments will be as follows:

a) Water can + irrigation scheduling tool
b) Water can without irrigation scheduling tool
c) Overhead irrigation with tank and hose + irrigation scheduling tool
d) Overhead irrigation with tank and hose without irrigation scheduling tool

**Existing or farmer supplies equipment and technologies:**

- Weather data will be collected from an automated weather station nearby provided by the Africa RISING project.

**The biophysical data to be collected at Bihinaayili include:**

| Data for collection | Frequency |
|---|---|
| Climatic data for calculating daily crop and reference evapotranspiration | Daily |
| Rainfall data (placed randomly in the watershed) | Daily |
| Soil characterization each year (bulk density, texture, water holding capacity, pH, N, P, K, Ca, K, S, Mg, Na, organic matter, micro-nutrients (Fe, Zn, Se, etc.), electrical conductivity) | Twice: Before planting and at harvest |
| Measuring crop height | Every two weeks |
| Soil moisture content | Two times per week |

| | |
|---|---|
| Measuring root depth | Once a month |
| Sediment quality analyses | Monthly sampling in the dry season, weekly + few event sampling in the rainy season |
| Water sampling from wells for determining microbial populations, pH, As, Fe, Al and micro-nutrients (Zn, Se, etc.) | Every two weeks |
| Water sampling from roofs and tanks for determining microbial populations, pH, As, Fe, Al and micro-nutrients (Zn, Se, etc) | N/A |
| Monitoring groundwater table | One per week during the dry season, frequency in the wet season depends on catchment response |
| Plant density (at planting depending on plant and row spacing) | At planting |
| Amount of water applied at each irrigation (by recording number of buckets per irrigation or duration of irrigation by using the hose) | At each irrigation |
| Amount of water applied at each irrigation (recording duration of irrigation using each system and delivery rate); | |
| Fertilization rate | At application |
| Fruit yield and biomass | At harvest |
| Sample biomass for nutrient concentrations (N, P, K, Ca, K, S, Mg) and micro-nutrients (Fe, Zn, Se, etc.) | At harvest |
| Price for harvest biomass or fruit | At harvest |
| Amount of harvest that is marketed and the price | |
| Required labor involved from planting to harvesting and by gender and age | On going |
| Soil and land use maps for the district | Beginning of project |

## 2. ZANLERIGU, NABDAM DISTRICT, UPPER EAST REGION

### A. DRY-SEASON VEGETABLE IRRIGATION AT FARMS

Farmers will be organized into 2 clusters of 8 members each. In one cluster, one-half of the farmers will test the technology with an irrigation scheduling tool while the other half will use farmer practice (without irrigation scheduling tool). There will be two irrigation technologies focusing on use of shallow wells: 1) water can irrigation and 2) overhead irrigation with a hose from a 150 L to 200 L tank. Onion was selected in consultation with farmers for the on-farm demonstrations. The farmers using overhead irrigation will be provided with 2 pumps on loan, one for each group of 4 farmers. Water tanks will be provided free of charge. Two watering cans will be provided to each of the farmers using water can irrigation, free of charge. Treatments will be as follows:

a) Water can + irrigation scheduling tool
b) Water can without irrigation scheduling tool
c) Overhead irrigation with tank and hose + irrigation scheduling tool
d) Overhead irrigation with tank and hose without irrigation scheduling tool

**The biophysical data to be collected at Zanlerigu for intervention A include:**

| Data for collection | Frequency at Zanlerigu, A |
|---|---|
| Climatic data for calculating daily crop and reference evapotranspiration | Daily |
| Rainfall data (placed randomly in the watershed) | Daily |
| Soil characterization each year (bulk density, texture, water holding capacity, pH, N, P, K, Ca, K, S, Mg, Na, organic matter, micro-nutrients (Fe, Zn, Se, etc.), electrical conductivity) | Twice: Before planting and at harvest |
| Measuring crop height | Every two weeks |
| Soil moisture content | Two times per week |
| Measuring root depth | Once a month |
| Sediment quality analyses | Monthly sampling in the dry season, weekly + few event sampling in the rainy season |
| Water sampling from wells for determining microbial populations, pH, As, Fe, Al and micro-nutrients (Zn, Se, etc.) | Every two weeks |
| Water sampling from roofs and tanks for determining microbial populations, pH, As, Fe, Al and micro-nutrients (Zn, Se, etc) | N/A |
| Monitoring groundwater table | One per week during the dry season, frequency in the wet season depends on catchment response |
| Plant density (at planting depending on plant and row spacing) | At planting |
| Amount of water applied at each irrigation (by recording number of buckets per irrigation or duration of irrigation by using the hose) | At each irrigation |
| Amount of water applied at each irrigation (recording duration of irrigation using each system and delivery rate); | N/A |
| Fertilization rate | At application |
| Fruit yield and biomass | At harvest |
| Sample biomass for nutrient concentrations (N, P, K, Ca, K, S, Mg) and micro-nutrients (Fe, Zn, Se, etc.) | At harvest |
| Price for harvest biomass or fruit | At harvest |
| Amount of harvest that is marketed and the price | |
| Required labor involved from planting to harvesting and by gender and age | On going |
| Soil and land use maps for the district | Beginning of project |

## B. DRY-SEASON VEGETABLE IRRIGATION AT HOMESTEADS

Farmers will be organized into a group of 5 farmers. There will be two irrigation technologies focusing on use of roof-top rainwater harvesting: 1) UDS irrigation system and 2) bucket-drip irrigation. Each of these two technologies will be tested on homesteads of 2 farmers. One farmer will do the evaluation with farmer (traditional) practice. Local leafy vegetable was selected in consultation with farmers, for the demonstrations. The suggested treatments will be as follows:

a) Control without drip (1 farmer)
b) UDS drip irrigation system (2 farmers)
c) Bucket-drip irrigation (2 farmers)

**Existing or farmer supplies equipment and technologies:**

Rainwater harvesting structures and tanks already in place; land around homestead for gardens. Farmers using UDS and bucket-drip irrigation systems will be provided irrigation kits for free and 1000 L plastic tanks on loan.

**The biophysical data to be collected at Zanlerigu for intervention B include:**

| **Data for collection** | **Frequency at Zanlerigu, B** |
|---|---|
| Climatic data for calculating daily crop and reference evapotranspiration | Daily |
| Rainfall data (placed randomly in the watershed) | Daily |
| Soil characterization each year (bulk density, texture, water holding capacity, pH, N, P, K, Ca, K, S, Mg, Na, organic matter, micro-nutrients (Fe, Zn, Se, etc.), electrical conductivity) | Twice: Before planting and at harvest |
| Measuring crop height | Every two weeks |
| Soil moisture content | Two times per week |
| Measuring root depth | Once a month |
| Sediment quality analyses | |
| Water sampling from wells for determining microbial populations, pH, As, Fe, Al and micro-nutrients (Zn, Se, etc.) | Every two weeks |
| Water sampling from roofs and tanks for determining microbial populations, pH, As, Fe, Al and micro-nutrients (Zn, Se, etc) | Every two weeks |
| Monitoring groundwater table | |
| Plant density (at planting depending on plant and row spacing) | At planting |
| Amount of water applied at each irrigation (by recording number of buckets per irrigation or duration of irrigation by using the hose) | N/A |
| Amount of water applied at each irrigation (recording duration of irrigation using each system and delivery rate); | At each irrigation |
| Fertilization rate | At application |
| Fruit yield and biomass | At harvest |
| Sample biomass for nutrient concentrations (N, P, K, Ca, K, S, Mg) and micro-nutrients (Fe, Zn, Se, etc.) | At harvest |
| Price for harvest biomass or fruit | At harvest |
| Amount of harvest that is marketed and the price | At harvest |
| Required labor involved from planting to harvesting and by gender and age | On going |
| Soil and land use maps for the district | Beginning of project |

## 3. DIMBASINIA, KASSENA NANKANA EAST DISTRICT, UPPER EAST REGION

### DRY-SEASON VEGETABLE IRRIGATION USING WATER SAVING TECHNOLOGIES AND METHODS

Farmers will be organized into three clusters of 8 members each who are willing to own/manage motorized pumps. The groups testing bucket-drip and UDS drip irrigation systems will be provided with a water tank per farmer; a motorized pump on loan for each set of 4 farmers, implying 4 pumps for the 16 farmers; as well as drip kits which will also be supplied on loan basis. These farmers in the control group will be provided with 2 water cans each for free as a kind of motivation. In one cluster, one-half of the farmers will test the technology with an irrigation scheduling tool while the other half will not use irrigation scheduling tool. There will be three irrigation technologies focusing on use of pre-existing permanent wells and reservoirs: 1) Farmer practice (control), 2) Bucket-drip and 3) UDS drip irrigation system. Pepper was selected in consultation with farmers for the on-farm demonstrations. Treatments will be as follows:

a) Control group with no drip/sprinkler
b) Control group with irrigation scheduling tool
c) Bucket-drip + irrigation scheduling tool
d) Bucket-drip without irrigation scheduling tool
e) UDS drip irrigation + irrigation scheduling tool
f) UDS drip irrigation without irrigation scheduling tool

**Phases of intervention**

Based on the first year of interventions, surveys and focus group discussions, the project will identify potential for women to develop irrigated plots, assessing the opportunities and constraints for gender equitable irrigation development in the area. The project will facilitate after year one the entry of women into irrigated vegetable production based on development of a 'business model' that targets women. The project will also assess the age-related factors in entry into irrigation using motorized pumps to identify the potential need for packages to engage young farmers.

**The biophysical data to be collected at Dimbisinia include:**

| **Data for collection** | **Frequency at Dimbasinia** |
|---|---|
| Climatic data for calculating daily crop and reference evapotranspiration | Daily |
| Rainfall data (placed randomly in the watershed) | Daily |
| Soil characterization each year (bulk density, texture, water holding capacity, pH, N, P, K, Ca, K, S, Mg, Na, organic matter, micro-nutrients (Fe, Zn, Se, etc.), electrical conductivity) | Twice: Before planting and at harvest |
| Measuring crop height | Every two weeks |
| Soil moisture content | Two times per week |
| Measuring root depth | Once a month |
| Sediment quality analyses | Monthly sampling in the dry season, weekly + few event sampling in the rainy season |
| Water sampling from wells for determining microbial populations, pH, As, Fe, Al and micro-nutrients (Zn, Se, etc.) | Every two weeks |
| Water sampling from roofs and tanks for determining microbial populations, pH, As, Fe, Al and micro-nutrients (Zn, Se, etc) | N/A |
| Monitoring groundwater table | One per week during the dry season, frequency in the wet season depends on catchment response |
| Plant density (at planting depending on plant and row spacing) | At planting |
| Amount of water applied at each irrigation (by recording number of buckets per irrigation or duration of irrigation by using the hose) | N/A |
| Amount of water applied at each irrigation (recording duration of irrigation using each system and delivery rate); | At each irrigation |
| Fertilization rate | At application |
| Fruit yield and biomass | At harvest |
| Sample biomass for nutrient concentrations (N, P, K, Ca, K, S, Mg) and micro-nutrients (Fe, Zn, Se, etc.) | At harvest |
| Price for harvest biomass or fruit | At harvest |

| | |
|---|---|
| Amount of harvest that is marketed and the price | At harvest |
| Required labor involved from planting to harvesting and by gender and age | On going |
| Soil and land use maps for the district | Beginning of project |

## DETAILED DATA COLLECTION REQUIREMENTS

### BIOPHYSICAL DATA REQUIRED PER SITE/INTERVENTION

| Data for collection | Frequency at Bihinaayili | Frequency at Zanlerigu, A | Frequency at Zanlerigu, B | Frequency at Dimbasinia | Organisation responsible |
|---|---|---|---|---|---|
| Climatic data for calculating daily crop and reference evapotranspiration | Daily | Daily | Daily | Daily | IWMI |
| Rainfall data (placed randomly in the watershed) | Daily | Daily | | Daily | UDS/MOFA |
| Soil characterization each year (bulk density, texture, water holding capacity, pH, N, P, K, Ca, K, S, Mg, Na, organic matter, micro-nutrients (Fe, Zn, Se, etc.), electrical conductivity) | Twice: Before planting and at harvest | Twice: Before planting and at harvest | Twice: Before planting and at harvest | Twice: Before planting and at harvest | UDS/IWMI |
| Measuring crop height | Every two weeks | Every two weeks | Every two weeks | Every two weeks | UDS/MOFA |
| Soil moisture content | Two times per week | Two times per week | Two times per week | Two times per week | UDS/MOFA |
| Measuring root depth | Once a month | Once a month | Once a month | Once a month | Secondary Data/IWMI |
| Sediment quality analyses | Monthly sampling in the dry season, weekly + few event sampling in the rainy season | Monthly sampling in the dry season, weekly + few event sampling in the rainy season | | Monthly sampling in the dry season, weekly + few event sampling in the rainy season | IWMI |
| Water sampling from wells for determining | Every two weeks | Every two weeks | | Every two weeks | UDS |

| | | | | | |
|---|---|---|---|---|---|
| microbial populations, pH, As, Fe, Al and micro-nutrients (Zn, Se, etc.) | | | | | |
| Water sampling from roofs and tanks for determining microbial populations, pH, As, Fe, Al and micro-nutrients (Zn, Se, etc) | | | Every two weeks | | UDS/MOFA |
| Monitoring groundwater table | One per week during the dry season, frequency in the wet season depends on catchment response | One per week during the dry season, frequency in the wet season depends on catchment response | | One per week during the dry season, frequency in the wet season depends on catchment response | UDS |
| Plant density (at planting depending on plant and row spacing) | At planting | At planting | At planting | | UDS/MOFA |
| Amount of water applied at each irrigation (by recording number of buckets per irrigation or duration of irrigation by using the hose) | At each irrigation | At each irrigation | | | UDS/MOFA |
| Amount of water applied at each irrigation (recording duration of irrigation using each system and delivery rate); | | | At each irrigation | At each irrigation | UDS/MOFA/IWMI |
| Fertilization rate | At application | At application | At applicatio n | At application | IWMI |
| Fruit yield and biomass | At harvest | At harvest | At harvest | At harvest | UDS |
| Sample biomass for | At harvest | At harvest | At harvest | At harvest | IWMI |

| | | | | | |
|---|---|---|---|---|---|
| nutrient concentrations (N, P, K, Ca, K, S, Mg) and micro-nutrients (Fe, Zn, Se, etc.) | | | | | |
| Price for harvest biomass or fruit | At harvest | At harvest | | At harvest | UDS |
| Amount of harvest that is marketed and the price | | | At harvest | | UDS |
| Required labor involved from planting to harvesting and by gender and age | On going | On going | On going | On going | UDS |
| Soil and land use maps for the district | Beginning of project | Beginning of project | | Beginning of project | IWMI |

## BIOPHYSICAL DATA COMPREHENSIVE LIST: SITES AND WATERSHED/BASIN

| **Measurement** | **Method** | **Temporal resolution** | **Noted on data line in table above** | **Organisation responsible** |
|---|---|---|---|---|
| Climatic data | Weather station | Continuously (Daily) | Climatic data for calculating daily crop and reference evapotranspiration | UDS/IWMI |
| Potential evapotranspiration and actual crop evapotranspiration | Calculated according to Penman Monteith and FAO drainage paper 56 using CROPWAT 8.0 model | Continuously (Daily) | Climatic data for calculating daily crop and reference evapotranspiration | IWMI |
| DEM, soil and land use map | Sampling & governmental agencies/university data, GIS, Standard laboratory analysis | Once, start of the project | Soil and land use maps for the district | IWMI |
| Discharge | Pressure level sensor | 5-10 min interval | Measured at inlet/outlet of the watershed using pressure level sensors to be read out by UDS staff | IWMI |
| Sediment concentration/yield | Sampling | Event based & base flow in dry season | Sampling baseline every two weeks/event during rainfall based at selected watershed locations (where the | IWMI |

| | | | | |
|---|---|---|---|---|
| | | | pressure sensors are installed) to be taken by UDS project members/staff/students | |
| Sediment quality at selected watershed locations | Standard laboratory analysis | Event based & base flow in dry season | Using the collected sediment samples as identified in the previous row of this table | IWMI |
| Water quality of the water sources used by the technologies and streams (as well as the micro nutrients) | Standard laboratory analysis for microbial populations, pH, As, Fe, Al and micro-nutrients (Zn, Se, etc,) | Bi-monthly | Water sampling from wells, roofs and tanks on all sites for determining microbial populations, pH, As, Fe, Al and micro-nutrients (Zn, Se, etc.) | IWMI |
| Characterization of main irrigated and rainfed crops + crop calendar | Manual observation & GIS | Once, start of the project | To be captured during the household surveys during farmer interview, farm surveys and focus group discussions | IWMI/UDS |
| Groundwater table | Manual/Floating method | 2 X daily in rainy season; 1 X per week in dry season | Monitoring groundwater table in all sites | UDS |
| Irrigation scheduling and amount | Field book (at each irrigation record duration of irrigation for drip, sprinkler and hose; and number of buckets of known volume) | Continuous | Amount of water applied at each irrigation and number of irrigations per week | UDS |
| Moisture content | TDR | 2X per week | Soil moisture content | UDS |
| Crop development stages | Manual observation (will be recorded as days after planting) | At 3 crop development stages | Sample 3 plants per plot and do a leaf count and estimate leaf length and width for a total of 3 to 5 leaves and average. Estimate LAI. Stages are as follows: initial stage (<10%), crop development stage (10-80% ground cover), mid-season stage (from full groundcover to maturity), late season stage (from mid-stage to full maturity or harvest) according to | UDS |

| | | | | |
|---|---|---|---|---|
| | | | FAO 24 and FAO 56 Irrigation and Drainage papers. | |
| Crop height | Meter ruler | At 3 crop development stages | Measuring crop height | UDS |
| Planting density | Plant and row spacing | At planting stage | Plant density (at planting depending on plant and row spacing) | UDS |
| Crop yield + biomass | Scale (quantification) + economic evaluation (field books) | At harvest for the dry season | Fruit yield and biomass | UDS |
| Micro and macro nutrient status of the harvested product | Standard laboratory analysis for nutrient concentrations (N, P, K, Ca, K, S, Mg) and other micro nutrients (Fe, Zn, Se, etc) | At harvest | Sample biomass for nutrient concentrations (N, P, K, Ca, K, S, Mg) and micro-nutrients (Fe, Zn, Se, etc.) | IWMI |
| Fertilizer application | Type, quantity and quality through manual recording and laboratory analysis | At each application | Fertilization rate | UDS |
| Soil physiochemical and micro – nutrient properties of the plots | Standard laboratory methods for bulk density, texture, water holding capacity, pH, N, P, K, Ca, K, S, Mg, Na, micro-nutrients (Fe, Zn, Se, etc,), organic matter, electrical conductivity) | Before and after each cropping season | Soil characterization each year (bulk density, texture, pH, N, P, K, Ca, K, S, Mg, Na, organic matter, micro-nutrients (Fe, Zn, Se, etc.), electrical conductivity) | UDS |

## SOCIO-ECONOMIC DATA

| **Measurement** | **Method** | **Frequency** | **Organisation responsible** |
|---|---|---|---|
| Location and size of pilot plots marked with GPS | Field pilot inception report | At the beginning of the project | UDS |
| Farming system(s) to be simulated for each interventions site | Field pilot inception report | At the beginning of the project | TAMU |
| Type(s) of small-scale irrigation systems (including sources of water, lifting devices, | Field pilot inception report | At the beginning of the project | UDS |

| | | | |
|---|---|---|---|
| and application methods) to be piloted for each intervention site | | | |
| Descriptions of "typical" household gardens to be piloted for each intervention site | Field pilot inception report | At the beginning of the project | UDS |
| Any available farm survey information relevant to the intervention sites from previous studies | Baseline data report | At the beginning of the project | IFPRI |
| Crop management data (dates/amounts of tillage, planting, harvesting, fertilizer, irrigation, etc.) to be recorded for each interventions site as well as marketing | Follow up survey + household field book | Throughout every crop season | UDS |
| Livelihood activities and income, gender roles and risk aversion attitudes | Field pilot inception report | At the beginning of the project | IFPRI |
| For the intervention households: farm characteristics, farm family characteristics, including data from previous nearby studies | Follow up | At the beginning of the project | UDS/IWMI |
| Any cost (labor, input) and price data | Follow up + household field book | Throughout every crop season | UDS |
| Amount of family labor in man days or hours for crop + irrigation management | Follow up + household field book | Throughout every crop season | UDS |
| Amount of hired labor in man days or hours for crop + irrigation management | Follow up + household field book | Throughout every crop season | UDS |
| Daily wage rate during the same time | Follow up + household field book | Throughout every crop season | UDS |
| Amount and price of fertilizer, seed and other inputs (e.g. chemicals) | Follow up + household field book | Throughout every crop season | |
| Cost of credit related to technologies and input, if interest or fees | Follow up + household field book | Throughout every crop season | UDS |
| Total and composition of household food consumption | Follow up + household field book | Throughout every crop season | UDS nutrition |
| Total sales | Follow up + household field book | Throughout every crop season | UDS |
| Current market price of each product | Follow up + household field book | Throughout every crop season | UDS |

## INTEGRATED DECISION SUPPORT MODELS

### APEX AND SWAT: INPUT DATA

Most of the data required for APEX and SWAT models is listed in the tables above for required data to be collected under the project. APEX and SWAT share many of the same input data requirements, with APEX typically used for farm- or small watershed-scale applications with emphasis on crop management. SWAT is typically used for larger watershed- or river basin-scale simulations.

International sources of topography, weather, soils, and land use are available for most locations worldwide. In addition, IFPRI's SPAM model has processed crop area and yield data for most important crops from government statistical services for most of the world in five-year increments. As a result, it is often possible to conduct coarse-scale simulations of hydrology, soil erosion, and crop yields with little input of local data beyond expert knowledge of cropping systems. It is very useful if not imperative to obtain locally sourced information regarding crop management and natural resources. The following is a list of local data that can be very useful in simulating conditions and scenarios of interest for specific studies.

1. Cropping systems:
    a. Crop rotations in each study area (e.g. 1 year rotation of maize and winter wheat)
        i. Spatial distribution of different rotations (e. g., rotations on different soils or slopes)
    b. Annual crop yields
        i. Crop growth studies (detailed data on crop biomass accumulation)
        ii. Water use studies (water use efficiency data)
    c. Agricultural managements
        i. Timing of planting, tilling, and harvesting
        ii. Fertilizer application (annual total or kg/each application)
        iii. Sources of nutrients (organic and/or inorganic)
        iv. Irrigation timing, period, and amount (if not dryland)
        v. Source of irrigation water (surface or wells)
        vi. Typical ploughing depth
        vii. Any conservation tillage being practiced (such as contour till or reduced till)?
        viii. Local practices for tillage or irrigation
2. Weather data: kinds and duration
    a. Potential sources of climate data
    b. Measured daily weather data from the site
3. Historical land use data (or change in cropping systems with time), if available
    a. Availability of remotely sensed data
4. Soil properties
    a. Soil maps (spatial distribution of soil units)
    b. Soil properties by horizon (horizon depths, texture, bulk density, organic matter, pH, etc.)
    c. Other soil sampling data (soil tests)
5. Stream flows, sediment loads, and other water quality parameters at or near the site, if available
6. Topographic maps other than SRTM 90 m resolution, if they exist
7. Reservoirs used for irrigation, if they exist
    a. Physical properties such as storage volume, weir height
    b. Water storage volume over time
    c. Discharge volume: daily, weekly, or monthly
8. Wells used for irrigation, if they exist
    a. Actual or typical pumping rates: daily, weekly, monthly
    b. Areas irrigated
    c. Locations
9. Location and storage capacity of small ponds and wetlands used for irrigation or livestock water
10. Grazing, if available
    a. Livestock management practices
    b. Grazing period
    c. Grazing rotations

d. Animal kinds and average live weights
e. Stocking rates
f. Animal dry matter intake

## FARMSIM INPUT DATA

Much of the data is listed in the table above describing the socio-economic data to be collected. Input for FARMSIM consists of the information necessary to describe the assets and liabilities, as well as the production, costs, yields, prices, and use of crops and livestock **on the farm or village**. For each input variable the user must provide information for the current (base) farming system and for the alternative farming system (scenario). The following data requirements require consideration in developing the field books for farmers.

UDS students or research assistants will work with on the project to support data collection and periodically review field books for data quality and completion as agreed upon with IWMI.

| **Data required for FARMSIM** |
|---|
| **1. Crop information** |
| a) Primary and secondary crops raised on the farm |
| b) Hectares planted for each crop |
| c) Cash costs: fertilizers, seeds, and agricultural activities |
| d) Quantity of crop sold, consumed by the family, and fed to animals |
| e) Crop yield history |
| f) Market price history |
| **2. Livestock information** |
| a) Number of head by species |
| b) Fraction consumed by the family, die, and sold |
| c) Price history: live animals and animal products |
| d) Annual cash expenses: cost of production and veterinary |
| e) Offspring per animal per year |
| f) Animal products (milk, eggs, etc.) produced per year |
| **3. Purchased food by the family and quantity of food relief** |
| a) Animal products |
| b) Food crops: cereal, tubers, vegetables, etc. |
| c) Other items: salt, sugar, etc. |
| **4. Fixed costs for extended family** |
| a) Maintenance and repair costs |
| b) Insurance, Property taxes, School fees |
| **5. Assets** |
| a) Crop and pasture lands owned (Ha) |
| b) Value of owned crop and pasture lands |
| c) Value of machinery, tools and buildings |
| d) Cash on hand |
| **6. Liabilities** |
| a) Current loans and outstanding debts (regular and technology loans) |

b) Terms of debt: interest rates and length of loans

## LIST OF REQUIRED EQUIPMENT FOR DATA COLLECTION

| Item | Bihinaayili | Zanlerigu | Dimbisinia | TOTAL |
|---|---|---|---|---|
| Weather station | | 1 | | 1 |
| Time Domain Reflectometers (TDRs) | 1 | 1 | 1 | 3 |
| Wetting front detectors | 8 | 8 | 12 | 28 |
| Pressure level transducers for surface water monitoring (watershed) | 1 | 1 | 1 | 1 |
| Rain gauges | 5 | 5 | 5 | 15 |
| Water sampling vials | 500 | 500 | 800 | 1800 |
| Floaters for groundwater table monitoring | 1 | 1 | 1 | 3 |
| Digital scale | 1 | | | 1 |
| Cooler box for carrying samples | 1 | 1 | 1 | 3 |
| Soil/tissue sampling bags | 500 | 500 | 800 | 1800 |
| Fertilizer, pesticides and vegetable seed | As required | As required | As required | As required |

## LIST OF REQUIRED TECHNOLOGIES FOR PILOT INTERVENTIONS

| Item | Bihinaayili | Zanlerigu | Dimbisinia | TOTAL |
|---|---|---|---|---|
| Tanks (3000L) | | 4 | | 4 |
| Tanks (1000 L)[4] | | | 16 | 16 |
| Tanks (approx. 150-250 litres) | 8 | 8 | | 16 |
| Hoses (garden hoses as on local market) | 8 | 8 | | 16 |
| Motorized pump | 2 | 2 | 4 | 8 |
| Water can | 16 | 16 | 16 | 48 |
| Drip kits developed by UDS | | 2 | 8 | 10 |
| 500 $m^2$ bucket drip kits | | 2 | 8 | 10 |
| Fertilizer, pesticides and vegetable seed | As required | As required | As required | As required |

## SCHEDULE/KEY TARGET DATES:

<table>
<tr><th>Project agreement year</th><th>Primary focus</th></tr>
<tr><td>Year 1 –1 October 2014 to 30 September 2015</td><td>baseline surveys, establishing pilots, installing measurement equipment and technologies, training and data collection</td></tr>
<tr><td>Year 2 –1 October 2015 to 30 September 2016</td><td rowspan="2">data collection, reporting, adjusting/adapting as issues arise with pilots, and writing on interim results</td></tr>
<tr><td>Year 3 –1 October 2016 to 30 September 2017</td></tr>
<tr><td>Year 4 –1 October 2017 to 31 August 2018</td><td>preparing for project ‘exit’, final surveys, analysis and sharing results through broader stakeholder consultation, workshops</td></tr>
</table>

[4] The total number will depend on the UDS drip system. It is not clear the storage requirements for that system.

| | |
|---|---|
| | and preparation of knowledge products for up-scaling |

**Key dates: May to December 2015**:

- Socio-economic surveys (as needed, in addition to the baseline)
- Subject-based qualitative research (focus group discussions)
- Install measurement equipment; facilitate credit and inputs for farmers; install technologies; develop the training materials and implement trainings in communities.

## DELIVERABLES UNDER UNIVERSITY FOR DEVELOPMENT STUDIES AGREEMENT

**Deliverables for overall agreement (details to be confirmed in final work plan and budget)**

| Item | Type | Date due |
|---|---|---|
| Develop criteria for graduate student selection and identify/select students in collaboration with IWMI | Activity | May |
| Collection of baseline data for biophysical studies; report with data based on agreed upon format; repeated in rainy and dry season | Data, Report | May – July |
| Regular/routine collection of data – biophysical, agronomic, economic as listed in data requirements below | Data | On-going |
| Procurement of instruments for measurement | Activity | May - June |
| Instrumentation of measurement equipment on site | Activity | May-Aug |
| Research on/proposal for credit arrangement: proposed partners, protocol for facilitation of credit, budget for arrangement, timeline | Report | May-June |
| Installation of water lifting, storage, conveyance and application technologies for each intervention, as agreed with IWMI | Activity | Oct - Nov |
| Plan for capacity development of farmers and relevant local stakeholders (including curriculum, training materials and evaluation materials). | Report | May-July |
| Training of farmers implemented and completed | Activity | Aug – Sept |
| Capacity development report on training of farmers | Report | |
| Quarterly (fiscal) reports on progress based on work packages | Report | Quarterly |
| Quarterly finance reports and annual audited finance report | Report | Quarterly |
| Annual project meeting and meeting report | Activity, report | October |

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