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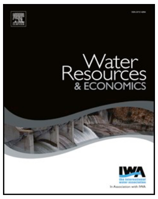

Economic and food security effects of small-scale irrigation technologies in northern Ghana

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ABSTRACT

Small-scale irrigation (SSI) technologies can be useful not only to increase crop productivity and income but also as a viable adaptation practice to climate variability. A farm simulation model (FARMSIM) and data from selected SSI technologies piloted in northern Ghana under the 'Feed the Future-Innovation Lab for Small Scale Irrigation' (ILSSI) project were used to assess the economic feasibility of the SSI technologies and their potential to improve income and nutrition of smallholder farm households. Three dry season irrigated crops (onion, corchorus, amaranthus) grown under three agricultural water management regimes were analysed. Results show that adoption of the SSI technologies could increase the net farm profit by 154%–608% against the baseline depending on the 'crop type - SSI technology' combination. Nutrition levels also improved significantly as a result of the improvements in crop yields due to irrigation and use of complementary inputs. However, the results further reveal that the options that utilize capital-intensive SSI technologies such as solar-powered water pumps to grow high value cash crops are constrained by the high investment cost. Currently, farmers tend to choose low-cost SSI technologies such as a traditional watering-cans, which generate low economic returns. Improving access to credit or alternative financing schemes could mitigate the capital constraints and enable smallholders to gain more benefits from participating in market-oriented high-value irrigated production.

1. Introduction

Limited or no access to appropriate agricultural technologies has led to low productivity and persistent food insecurity in developing countries [1]. National governments and several development organizations have attempted to make agriculture more productive and profitable by introducing agricultural technologies but with modest results [2]. Several factors such as lack of credit access, farmers' risk behaviour, lack of technical know-how, high investment and operational costs and supply chain constraints (e.g.

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high transaction costs) have contributed to low rate or lack of adoption of new agricultural technologies in developing countries [3–8]. Even where these technologies have been adopted at pilot communities, the dissemination to a larger segment of the population has failed in many cases [3].

The Ministry of Food and Agriculture (MoFA) of Ghana promotes irrigation as a climate variability adaptation measure in response to the declining rainfall and increasing intermittent dry spells during the rainy season cropping period [9]. Informal irrigation includes small scale irrigation (SSI) within one of three principal irrigation systems recognized in the National Irrigation Development Policy[2] in Ghana. According to this policy, SSI is practised by individuals, who cultivate a land area of up to about 0.5 ha or more, using simple structures and irrigation equipment such as buckets, fuel-powered motorized pumps, hose pipes, and watering cans. Water sources can include small reservoirs, shallow groundwater, rivers and wastewater. Often referred to as farmer-led irrigation, SSI is an irrigation system practiced on small plots using a level of technology that an individual farmer can effectively control, operate and maintain [10,11].

SSI continues to expand despite limited technical support or extension services to farmers in Ghana [8,11,12]. It employs 45 times more people and covers 20 times more land area than large-scale public irrigation schemes. As of 2010, an estimated 185,000 ha were under SSI, benefiting 500,000 smallholder farmers [13]. [14] projected that the use of motorized pumps in SSI could benefit from 564,000 to 730,000 households and irrigate up to 584,000 ha in the country. Similar projections suggest that the use of small reservoirs could benefit up to 163,000 households and irrigate from 74,000 to 163,000 ha. The main SSI technologies currently in use include watering cans, handheld hose pipes, and diesel or petrol-powered motorized pumps. Drip and sprinkler irrigation are also being adopted, albeit very slowly [15,16]. Potential also exists for the use of shallow groundwater using various water lifting, conveyance and application technologies, in addition to improved utilization of multi-purpose small reservoirs [8,17].

The rate of adoption of SSI is likely to increase. Demand for vegetables and fruits is growing with increases in income and changing diets of the growing middle-income consumers in urban areas [18]. This could provide business opportunities for producers and others engaged in small-scale irrigation. Various out-grower models are feasible for more small-scale irrigators to get involved in market-oriented production. However, sustainable adoption and scaling of various SSI technologies depend on the biophysical conditions and economic feasibility along the value chains, among other factors. At present, there is lack of evidence on socio-economic and technical factors that could promote or impede adoption of SSI in northern Ghana. Understanding these factors could provide decision support evidence to improve the scaling pathway for SSI and the livelihoods of smallholder farmers. These factors include: (i) identification of ways to improve water use and management for farmers adopting SSI technologies; (ii) provision of evidence for informed investment decisions by farmers and other actors in irrigated value chains; (iii) identification of promising technologies and crop types with high financial returns that improve livelihoods and food security for smallholder farmers; and (iv) understanding household economic and other benefits of scaling up of the SSI technologies. To understand these factors in Ghana, the Innovation Laboratory for Small Scale Irrigation (ILSSI[3]) project field tested selected SSI technologies in a few communities in northern Ghana.

This paper seeks to contribute to filling the knowledge gap on the economic return on investment, food security effects and potential risk factors of SSI technology adoption by smallholder farm households. The study aims to assess profitable and economically feasible '*crop type–SSI technology*' combinations in northern Ghana. Primary farm level data on selected SSI technologies piloted in the study communities and secondary data from government agencies were used in the analysis. A farm simulation model (FARMSIM) was applied to assess the economic potential and nutritional effects of farmer investments in SSI technologies.

This paper is structured as follows: Section 2 briefly presents a review of previous studies on water resources, climate change and the income and food security effects of SSI in the study area. The methods, including descriptions of the farm simulation (FARMSIM) modelling approach and SSI technology scenarios, are then presented in Sections 3 and 4. Results are presented in Section 5, while the last two sections contain discussions, conclusion and recommendations.

2. Previous studies in the study area

2.1. Water sources for SSI in northern Ghana

Northern Ghana is drained by the Volta River system that consists of the White and Black Volta Rivers, and the Oti and Darka Rivers. In the Volta Basin, water for irrigation is sourced from rivers, groundwater, and stored water in natural and built infrastructure or reservoirs [19,20]. In northern Ghana, there are large and medium reservoirs for public sector managed irrigation schemes at Tono, Vea, Golinga, Bontanga and Libga with storage capacities ranging from 5.9 to 93 cubic megametre (Mm^3). Additionally, there are more than 500 small reservoirs and over 6280 boreholes managed by communities and smallholder farmers [19]. Water is also stored on-farm in ponds and wetlands [21]. In many areas in northern Ghana, shallow groundwater is the farmers'

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[2] www.mofa.gov.gh/site/wp.../07/GHANA-IRRIGATION-DEVELOPMENT-POLICY1.pdf. The other two irrigation categories comprise of *formal irrigation* (one that is reliant on some form of permanent irrigation infrastructure funded by the public sector and *large scale commercial* irrigation system.

[3] ILSSI is an action-oriented, farmer-centered research project supported by the Feed the Future (FtF) program through USAID and implemented in Ghana, Ethiopia, and Tanzania. It aims to investigate and understand the technical and socio-economic factors, constraints and opportunities of SSI technologies towards achieving sustainability and efficiency in resource utilization (water, land and other resources) and enhance the livelihoods of smallholder farmers.

preferred water source [22,23]. Permanent shallow wells are widespread in several communities [20], though many more are reconstructed each year in the dry season. Small reservoirs and dugouts are in high demand because they support multiple livelihood strategies, including irrigation, livestock production, fisheries and brick fabrication [24,25]. A number of multi-purpose small reservoirs have been constructed in northern Ghana over the past few decades (Appendix A), though could be better managed and utilized for small-scale irrigation [13,14].

Several studies assessed the potential for shallow groundwater development for SSI in Northern Ghana [17,26]; Drechsel and Keraita, 2014; [8]. Some of these studies showed high groundwater potential in northern Ghana; 70% of the area was found to have moderate to high groundwater availability, and 83% has medium to high groundwater accessibility [26,27].

The Volta River system furthermore provides a perennial source of water that could be used for year-round irrigated agricultural production by smallholder farmers. Large floodplains created by the Volta River and several of its tributaries provides a good opportunity for flood recession agriculture[4] in the floodplains. These floodplains are suitable for cultivation of high value crops such as tomatoes, onions, pepper, and cowpea [28,63,29].

2.2. Effects of climate change on water availability

Using the Soil and Water Assessment Tool (SWAT), Williams et al. [18] [5] assessed the impacts of climate change on water resources and water availability for irrigation in the three regions of northern Ghana. The climate change scenarios were generated using global circulation model and downscaled to regional scales. For the SWAT model simulations, water yield in two-time snap shots (2030 and 2050) were used. The baseline simulation (1990–2010) showed that annual water yield in study area was about 29,079 Mm^3, while at the sub-watershed level water yield ranged from less than 100 Mm^3 to more than 1450 Mm^3.

Simulations were conducted to estimate the spatial distribution of water yield in 2030 and 2050. Fig. 1 shows the water yield for the study area under four Representative Concentration Pathways (RCPs) simulation[6] under various climate change scenarios Williams et al. [18]. All the four RCPs show annual fluctuations in water yield during the simulation period.

Simulation results under various climate change scenarios show less than 5% changes (-5% to $+5\%$)in water yields compared to baseline simulation in the region. That means the overall water availability for northern Ghana does not drastically change compared to the baseline under various scenarios. However, it should be noted that the study referred to here selected only two climate change downscaled projections, which may have biased the results.

In a large-scale study including the Volta River basin, Lacombe et al. [30] found no statistically significant trend in annual rainfall, but a reduction in the amount of light rainfall (< 20 mm/day) and a delay in the onset of rainy seasons. Studies on the effects of climate change on hydrology of the basin [31–34] found that river flows are sensitive to rainfall variability; but the studies focused on future developments of large numbers of reservoirs and did not investigate the effects of climate change on small scale irrigation. A study by Ref. [35] on the climatic and biophysical context of the study area provides an overview of the context for agricultural water management interventions. The results show no significant change in rainfall trends.

The present paper mainly focuses on the effects of SSI technology adoption on household economics over a short to intermediate time period. Moreover, the relationship between climate change and water availability for small scale irrigation has not been established in a robust manner in the existing literature in the study region. Thus, climate change scenarios and their effects on water resources for SSI were not explicitly modelled in our analysis.

2.3. The effects of SSI on household income and food security

Studies indicate that adoption of irrigation technologies can play an important role on poverty reduction, food and nutrition security and household income [3,36]. Irrigation can enable smallholders to engage in year-round production, increase yield and improve food and nutrition security. Smith et al. [37] found that in many rural areas of the dry tropics, households face chronic shortages of vegetables and fruits during the dry season and this has a direct effect on household's nutrition security. Access to irrigation could enable smallholder farmers produce high-value crops and tailor crop types and output supply in response to local demand [38]. The use of SSI technologies can help promote diversification and significantly increase returns to land and labour and reduce risk [3]. More current research identifies specific pathways that link irrigation and positive nutritional outcomes [39,40].

The study focused on northern Ghana generally, and included the Northern Region particularly, because it has the largest number of poor people in Ghana, being around 1.3 million people, as well as some of the greatest challenges on undernutrition [41]. The north also has the highest levels of inequality. Therefore, analyzing the potential for SSI in terms of income and nutrition is particularly important in the Northern Region of Ghana. In addition, a recent study in northern Ghana has shown that adoption of SSI has good potential to increase agricultural productivity and enhance food security [27,42]. In most cases, crops benefiting from irrigation expansion are high value vegetables grown during the dry season and their income and nutritional benefits are important for

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[4] This is an agricultural practice that uses residual soil moisture and nutrients left by receding flood water with or without supplementary irrigations to grow crops.

[5] The first author of this paper led field works, data analysis, draft writing and co-author in Ref. [18] report cited here.

[6] Simulations A and B use the projected climatic data of the Canadian Center for Climate Modelling and Analysis CCCma-CanRCM4 for RCP4.5 for 2030 and 2050 respectively, while simulation C and D used the projections derived through the same Regional Climate Model (RCM) for RCP8.5 for the same two time snap shots.

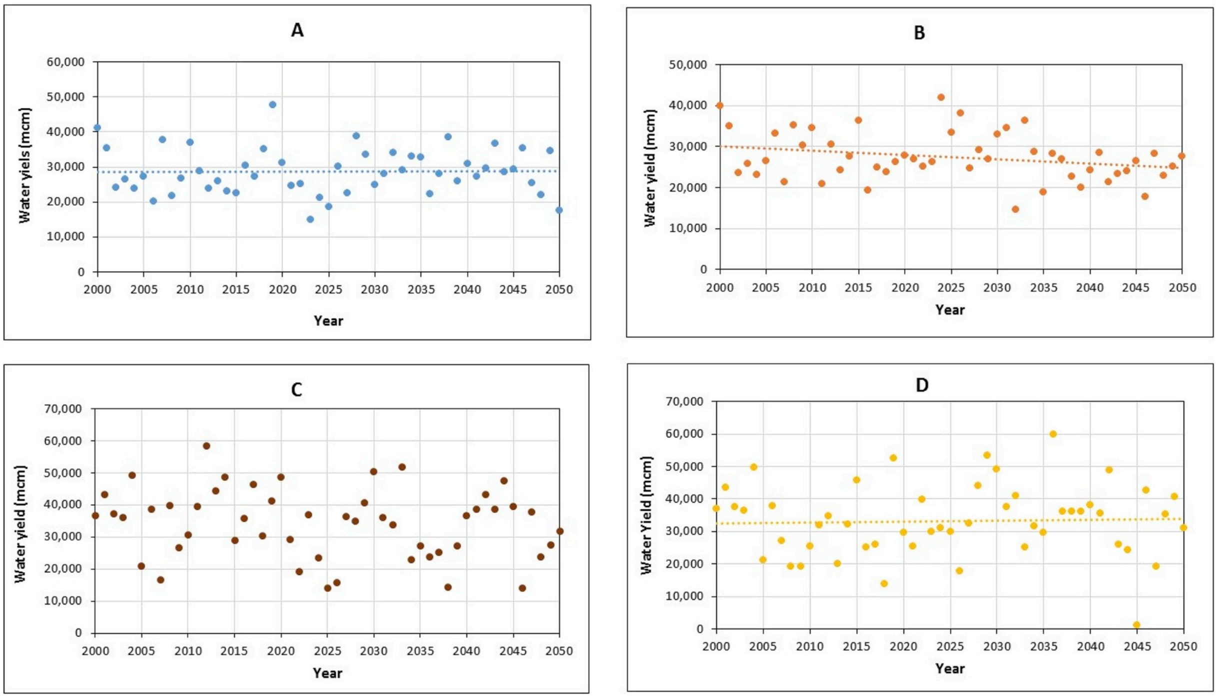

Fig. 1. Annual water yield from 2000 to 2050 under different RCPs (Source: [18].

improving household livelihoods [43]. A study in floodplains of the White Volta River in northern Ghana indicates that 60% smallholders practice dry-season irrigated farming and grow leafy vegetables such as cabbage (*Brassica oleracea var. capitata*), okra (*Abelmoschus esculentus*), corchorus (*Corchorus olitorius)*; amaranthus (*Amaranthus candatus*), and kenaf (*Hibiscus cannabinus*) [42]. Most of the crops grown in that area are produced by women farmers on small plots of land (< 0.1 ha) and used for home consumption.

In terms of household income, Balana et al. [42] showed that with gross margins ranging from about USD 1250 to USD 2625 per ha. Irrigated onion (*Allium cepa)*, tomato (*Solanum lycopersicum*), and pepper (*Capsicum annuum*) are the major cash crops and source of income for smallholder irrigators in northern Ghana. As the production of these crops is labour intensive (over 50% the cost of production of these crops is accounted for by cost of labour), SSI could provide employment opportunities for the youth and women and income for smallholder farmers to meet their cash demands, including direct purchase of household staples [42].

3. Materials and methods

3.1. Description of study areas

The study was conducted in two field sites under the ILSSI project in northern Ghana. Fig. 2 shows the two ILSSI field intervention sites (Bihinaayili and Zanlerigu). Zanlerigu and Bihinaayili are located in Upper East Region and Northern Region of Ghana respectively.[7] While both field sites are located in the Guinea Savannah agro-ecological zone, Zanlerigu (Upper East) is relatively closer to the Sudan and Sahel agro-ecological zones than Bihinaayili (Northern Region), and the former receives less rainfall than the latter. The SSI technologies and crop types piloted in selected farmers' fields in the two communities are summarized in Table 1. Northern Ghana is largely located within the White Volta Basin. Throughout northern Ghana small water storage structures are commonly constructed to access water during the long dry season. Rainfed crops such as maize, rice, millet and sorghum and groundnut dominate agricultural production in the study area. As noted above, the crops produced under irrigation are mainly vegetables including tomato, onion, pepper, okra and leafy vegetables such as lettuce, hibiscus (kenaf), bean leaves and cabbage. The two major types of land use in study sites are agricultural land (56%) and forestland (43%). The average annual rainfall is approximately 1,000 mm and the watershed received 75%–90% of annual rainfall between May and September. These weather patterns restrict rain-fed cropping to a single cropping season; therefore, irrigation may improve agricultural production.

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[7] The northern area of Ghana was recently rezoned into additional administrative Regions: Northern, Northeast, Savannah, Upper East, and Upper West. However, the case study sites remain within the regions noted in the paper.

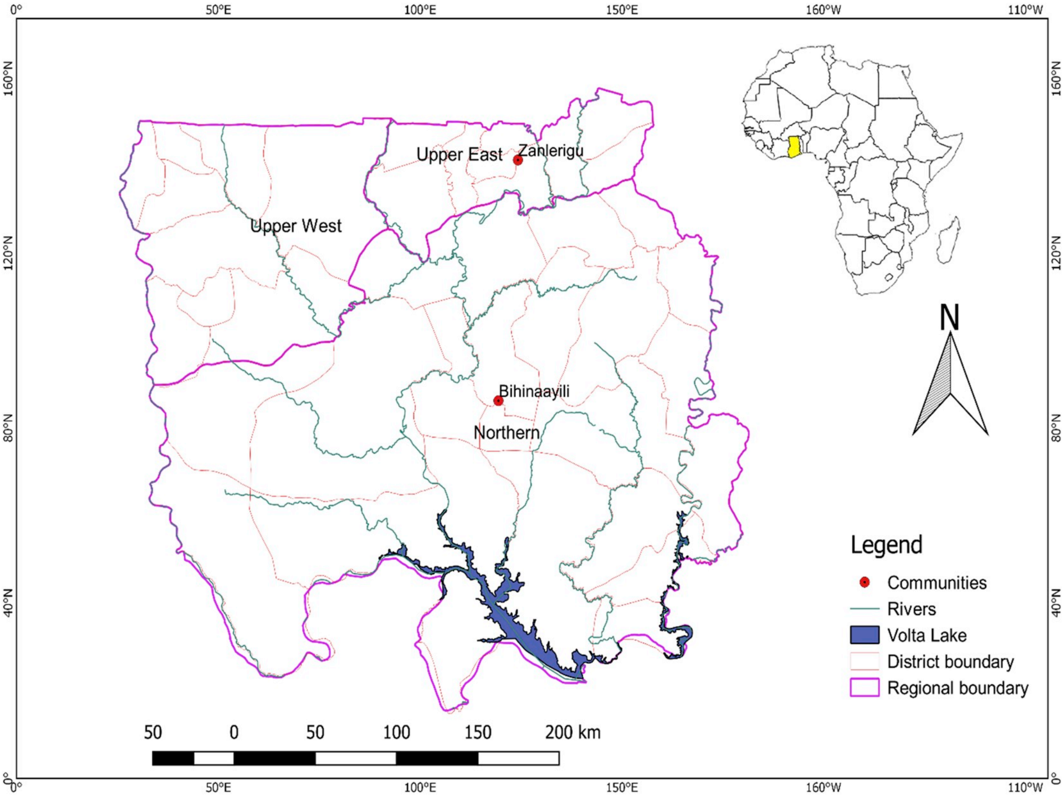

Fig. 2. Map of the study area in Northern Ghana.

Table 1
Description of baseline and alternative scenarios.

Bihinaayili Site	Zanleringu Site
Baseline: Current fertilizer + no or minimal irrigation	**Baseline:** Current fertilizer + no or minimal irrigation
Alternative Scenario 1 (Alt. 1): -Watering can for water lifting and application + irrigated corchorus (*Corchorus olitorius*) + recommended fertilizer	**Alternative Scenario 1 (Alt. 1):** -Watering can for water lifting and application + irrigated intercropping [onion (*Allium cepa*) and amaranth (*Amaranthus candatus)]* + recommended fertilizer
Alternative Scenario 2 (Alt. 2): Petrol powered motorized pump for water lifting + hose pipe for water application + irrigated corchorus (*Corchorus olitorius*)+ recommended fertilizer	**Alternative Scenario 2 (Alt. 2):** Petrol powered motorized pump for water lifting + hose pipe for water application + irrigated intercropping [onion (*Allium cepa*) and amaranth (*Amaranthus candatus)]*+ recommended fertilizer

3.2. Data

Data for FARMSIM (called 'input data') describe farm assets, liabilities, production costs, yields, out prices, and use of crops and livestock products. For each input data the user must provide information for the current (baseline) and for the alternative farming systems (scenarios). Household survey data were used to define the baseline scenario and field data collected on field site farms were used to define the inputs for the alternative farming technologies. The main datasets used in this study are listed below:

(i) Two household surveys on 400 farm households conducted in 2014 and 2015 by the International Food Policy Research Institute (IFPRI). The first survey was carried under the Ghana Africa RISING Baseline Evaluation Survey (ARBES) [44] [8] while the second was collected under the ILSSI project. These data were used to define the baseline scenario against which SSI technologies were evaluated.
(ii) Plot level production (inputs and outputs) data for ILSSI pilot crops (corchorus, onion, amaranth and cowpea) collected by the local project partner (University of Development Studies) over a dry cropping season in 2016–17.

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[8] https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/QUB9UT

(iii) Farm level inputs and outputs data collected by International Water Management Institute (IWMI) researchers through direct interviews of ILSSI pilot farmers in March 2017. Information on prices was obtained from local agricultural inputs dealers and commodity markets.

3.3. FARMSIM model description

The farm simulation model 'FARMSIM' is a Monte Carlo simulation model that simultaneously evaluates a baseline and alternative technologies for a farm. The model is programmed in Microsoft ® Excel and utilizes the Simetar© add-in program to estimate parameters for price and yield distributions, simulate random variables, estimate probability distributions for key output variables (KOVs) and rank technologies [45].[9] FARMSIM is programmed to recursively simulate a five-year planning horizon for a diversified crop and livestock farm and repeats the five-year planning horizon for 500 iterations[10]. A new sample of random values is drawn to simulate each iteration. After simulation, the resulting 500 values for each of the KOVs defines the empirical probability distributions for comparing the base and alternative farming technologies or interventions. By comparing the probability distributions for the base and alternative technologies, decision makers can quantitatively analyse the probable consequences of introducing alternative technologies. The FARMSIM model has four major components: crop, livestock, nutritional, and financial. The organizational and operational structure (flow chart) of FARMSIM is presented in Appendix C.

FARMSIM is programmed to simulate up to 15 crops as well as livestock (cattle, dairy, sheep, goats, chickens, and swine) annually for five years. The farm household is modelled as the first claimant for crop and livestock production with deficit food production met through food purchases using net cash income from selling surplus crops and livestock production. Standard accounting procedures are used to calculate receipts, expenses, net cash income, and annual cash flows. The KOVs for the model can include all endogenous variables in the model but most attention is focused on: annual net cash income, annual ending cash reserves, net present value (NPV), benefit-cost ratio (BCR), internal rate of return (IRR), and annual household nutrient consumption of protein, calories, fat, calcium, iron, and vitamin A. A detailed description of the FARMSIM model is presented in Refs. [6,46].

3.4. Economic feasibility assessment

The net present value (NPV), internal rate of return (IRR), and the benefit-cost ratio (BCR) are the key criteria used to assess the profitability of SSI technologies that involve capital investment in terms of water storage facility and pumping machines [47,48]. NPV is defined as the difference between the total sum of the present value of benefit streams and that of cost streams over the life of the project. Projects with positive NPV are accepted while projects with negative NPV are rejected. The IRR is the discount rate that generates a zero NPV value. If its IRR exceeds the cost of capital (i.e., the return from the capital if invested elsewhere) a project is accepted and if the IRR is less than the cost of capital the project is not recommended. The BCR is the ratio of the present value of the benefits to the present value of the costs. If this ratio is greater than one, the project is recommended.

In addition to the economic variables, FARMSIM simulates nutrition variables in terms of daily minimum requirements per adult equivalent, to determine excess or deficiency in nutrient intake. In the nutrition simulation, the total kilograms of each raised crop consumed by the family plus the kilograms of purchased foodstuffs are multiplied by their respective nutrient scores to calculate total calories, protein, fat, calcium, iron and vitamin A. Total nutrients consumed by the family from all sources, including donated food, are summed across plant and animal food stocks and compared with minimum daily recommended amounts for adults based on the FAO minimum requirements standards [49–51].

3.5. Stochastic simulation process

Simulation of the stochastic variables enables us to determine the level of risk and its mitigation, using price and yield risk information [6,52,53]. Stochastic annual output prices for crops and livestock are simulated using multivariate empirical (MVE) probability distributions estimated from historical data. In the absence of historical data, a GRKS probability distribution (developed by Gray-Richardson-Klose-Schuman) that uses three parameters (minimum, a mid-point, and a maximum) is elicited through expert consultation. Stochastic annual crop yields are simulated from MVE probability distributions estimated using 32 years of crop yields generated by APEX (Agricultural Policy/Environmental eXtender) (Williams et al., 1998). Selected SSI technologies piloted in the ILSSI project are simulated by APEX using the same historical weather data and plant growth parameters consistent with the assumed technologies so the only difference between the yield distributions is the technology package.

The baseline and alternative technology scenarios are simulated using the same equations so the only difference in the economic and nutrition outcomes are due to the technology differences. The random crop yields are simulated using the same stochastic uniform standard deviates to ensure that the weather risk for a crop under the base and alternative technology scenarios are identical. The same stochastic prices for crops are used for both scenarios, unless the alternative scenarios call for a different marketing program.

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[9] FARMSIM is a micro-computer, Excel/Simetar driven, enhanced version of FLIPSIM designed to simulate smallholder farms in developing countries. FLIPSIM has been used extensively for policy analysis and technology assessment for farms in the United States [62].

[10] Extensive testing with the Latin Hypercube sampling procedure in Simetar has shown that a sample size of 500 iterations is more than adequate to estimate a probability distribution for KOVs in a business model with more than 100 random variables.

4. Scenarios and technology ranking

4.1. Baseline and alternative farming scenarios

In FARMSIM modelling, the user must provide information for each input variable for the baseline and alternative farming scenario (Appendix C). Two case study sites/communities in northern Ghana (Bihinaayili and Zanlerigu) are discussed in this study.

The major rain-fed crops grown in Bihinaayili include maize, yam, rice, soybean and sorghum, while in Zanlerigu maize, millet, rice and groundnuts are the major rain-fed crops. Vegetables such as corchorus, amaranth and onion (Table 1) are grown on small plots either in a rain-fed system or with minimal irrigation. Agricultural inputs (fertilizer, irrigation, improved seeds) were used at a minimal level in both Bihinaayili and Zanlerigu. Most farm households use their own seeds from the previous harvest. Use of hired agricultural labor was also low; family members perform most of the agricultural tasks. However, cost of family labor was considered to take into account the opportunity cost of labor. To capture the effects of SSI technologies the model input data (yields, input costs, consumption, cropping area) for the rain-fed crops were kept constant for the baseline and alternative scenarios.

In alternative scenarios, farmer made to draw irrigation water from shallow wells, ponds and rivers and use different water lifting and application methods (watering can, hose pipes, and diesel/petrol powered motorized pumps) to grow three types of vegetables (corchorus, amaranth and onion) during the dry season (irrigated cropping twice per dry season on the same piece of land). Data on crop yields, area planted and costs of inputs for the study communities are summarized in Appendix D1 and Appendix D2. Three scenarios (a baseline and two alternative scenarios) are considered for both the Bihinaayili and Zanlerigu sites (Table 1). In Bihinaayili irrigation water was drawn from stream while the water source for Zanlerigu site is shallow ground water.

Two important assumptions underly the alternative farming scenarios. First, to show the full potential economic and nutrition effects of adopting new technologies, we assumed full adoption of the two scenarios described in Table 1. Although the data used for alternative scenarios were collected from farm households that participated in the SSI field studies, we assume adoption will spread across the entire village as a result of demonstration effect. Second, markets were assumed to be accessible to the smallholders. Accessibility to markets and competitive market prices depend mainly on the existence of road and market infrastructure. Survey data in Bihinaayili show that it takes on average about 30 min walking to get to a main local market center. This is a reasonably accessible market access point, compared to most African rural villages; only 34% of rural Africa has such road access [54]. The Zanlerigu community is located close (ca. 20 min drive) to the main regional marketing center of Bolgatanga town.

4.2. Technology scenario ranking

A utility-based approach is used to rank the different alternative scenarios. This is a preferred approach to compare alternative farming scenarios that help the decision maker in selecting among alternative farming systems based on producer risk preferences [6,55]. About four utility-based ranking functions are included in Simetar. They comprise of the Stochastic Dominance with Respect to a Function (SDRF), Certainty Equivalent (CE), Stochastic Efficiency with Respect to a Function (SERF) and Risk Premiums (RP). In this study, we used SERF to rank the risky alternatives. Hardaker et al. [55] merged the use of CE and Meyer's range of risk aversion coefficients to create the stochastic efficiency with respect to a function method for ranking risky alternatives. SERF assumes a utility function (in this case a negative exponential utility function) with absolute risk aversion range and evaluates the CEs over a range of absolute risk aversion coefficients (RAC) between a lower RAC and an upper RAC. The range can go from a lower RAC equals zero (risk neutral) to an upper RAC greater than zero (1/wealth) for a risk averse. The SERF approach compares the CE of all risky alternative scenarios for all RACs over the range and chooses the scenario with the highest CE at the decision maker's RAC as the most preferred and summarizes the CE results in a chart. Any key output variable (NPV, NCFI, and EC) distribution can be selected to rank alternative farming systems such as alternative irrigation technologies.

5. Results

A baseline and two alternative scenarios were simulated and forecasted for a five-year period in FARMSIM to evaluate SSI technologies in the two study communities. Cumulative distribution function (CDF) and probability density function (PDF) are presented to compare the scenarios in terms of their income and nutrition effects.

5.1. Economic returns

The simulation results show positive average net present values (NPV) for all the scenarios over the 5-year forecast period for the both study areas. Overall, the NPV results, as illustrated by the NPV cumulative distribution function (CDF) graph of NPV (Appendix E and F), indicate that investing in SSI technologies is economically profitable. In both study sites Alt.2 associated with the use of a diesel pump has the highest NPV value followed by Alt.1 that involves the use of a watering can (Tables 2 and 3). Notice that the two alternative scenarios have a higher NPV values than the baseline scenario.

The annual net cash farm income (NCFI), which represents the farm net profit, shows similar results as that of the NPV where the average profit under Alt.2 is five times higher than the profit under the baseline scenario in Bihinaayili and seven times higher in Zanlerigu sites (Tables 2 and 3). The probability distribution of the NCFI illustrated by the CDF also shows the superior performance of Alt.2 associated with the use of a diesel-powered motor pumps in both sites (Figs. 3 and 4). In Bihinaayili site, adoption of SSI increases profit by 154% under Alt.1 and by 395% under Alt.2 against the baseline respectively. The distribution of NCFI in

Table 2
Economic effects of SSI in Bihinaayili.[a]

	Baseline	Alt. 1—Watering Can	Alt. 2–Diesel-powered motorized pump
Average values are in GH₵/family			
Net present value	22,779	28,270	36,731
Avg. net profit (NCFI) in year 5	1,270	3,229	6,283
% change profit: Alt to Baseline		154%	395%
Benefit-Cost Ratio: Alt/Baseline[b]		2.7	2.6
Internal rate of return: Alt/Base[b]		0.48	0.46

[a] See Table 1 for the description of baseline and alternative scenarios.
[b] Alternative scenario value divided by baseline value.

Table 3
Economic effects of SSI in Zanlerigu.[a]

	Baseline	Alt. 1—Watering Can	Alt. 2–Diesel-powered motorized pump
Average values are in GH₵/family			
Net present value	17,859	38,107	46,674
Avg. net profit (NCFI) in year 5	824	5,559	5,841
% change profit: Alt to Baseline		574%	608%
Benefit-Cost Ratio: Alt/Baseline[b]		2.8	1.4
Internal rate of return: Alt/Base[b]		0.51	0.19

[a] See Table 1 for the description of baseline and alternative scenarios.
[b] Alternative scenario value divided by baseline value.

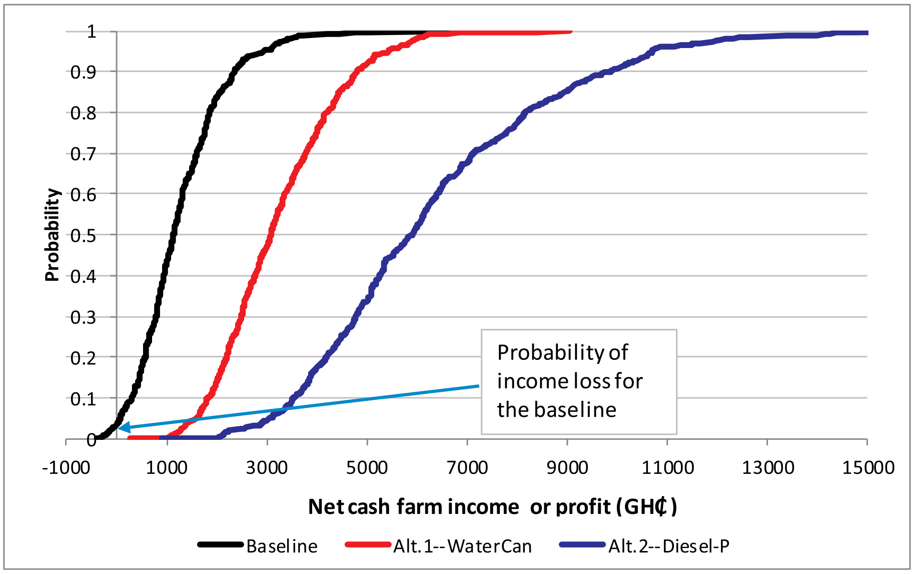

Fig. 3. Cumulative distribution function (CDF) of net cash farm income in Bihinaayili.

Bihinaayili shows a 3% probability that the baseline scenario will have a negative net income (loss). In Zanlerigu site, however, the scenario associated with the use of a watering-can has a higher net profit than the diesel pump scenario at the 50% probability mark (Fig. 4). In short, while use of diesel pump can generate higher revenues and profit than use of a watering can and the baseline scenario, this is achieved if one is ready to take a relatively high level of risk.

The benefit cost ratio (BCR) of the two alternative scenarios compared to the baseline show that both Alt. 1 and Alt. 2 have positive and greater than one, for example, in Bihinaayili site an average BCR of 2.7 (Alt. 1) and 2.6 (Alt. 2) (Table 2 and Fig. 5). Similarly, as depicted in Table 3 and Fig. 6, on average the BCR for the two technology scenarios in Zanlerigu site is greater than one. These ratios confirm the profitability and feasibility of the alternative scenarios. Moreover, in Bihinayili site the full distribution of BCR values from the CDF shows that all the values for both alternative scenarios lie to the right side of the break-even line, confirming a zero probability of having a BCR less than one from the 500 simulated values (Fig. 5). However, in Zanlerigu site although on average Alt. 2 has a BCR value of greater than 1, it has a 23% probability of having a BCR less than 1 (Fig. 6). Notice that, even though the profit from the diesel-powered pump (Alt. 2) is greater than twice that of the watering can irrigation (Alt.1), the BCR value of watering can is slightly higher than the BCR of diesel pump technology due to higher investment cost of the diesel-powered motorized

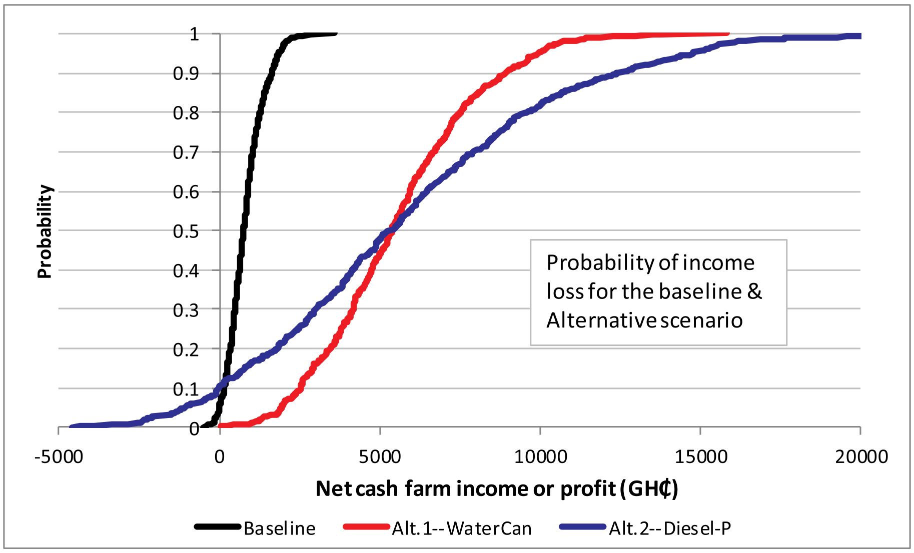

Fig. 4. Cumulative distribution function (CDF) of net cash farm income in Zanlerigu.

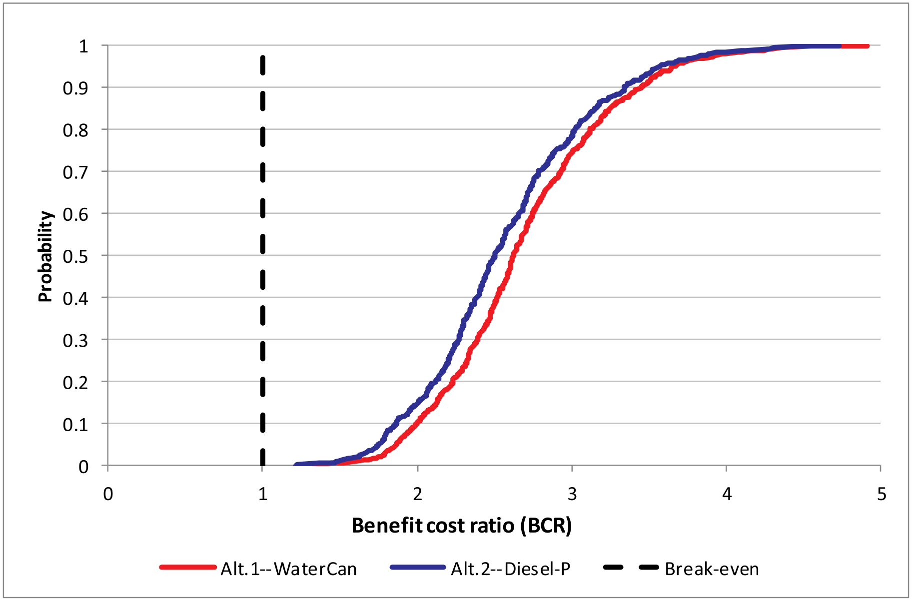

Fig. 5. CDF of the benefit-cost ratio (BCR) for alternative irrigation technologies (Bihinaayili).

pump technology.

A similar outcome as for the BCR is observed for the IRR. The average IRR values for Alt. 1 (watering can) and Alt. 2 (diesel pump) are respectively 0.48 and 0.46 and greater than the discount rate of 0.1 (capital cost) considered for this study.

5.2. *Household food consumption and nutrition*

In general, the adoption of agricultural technologies when properly used leads to an increase in quantity and variety of crops produced. The implications on the household food consumption and nutrition however vary according to the type of crops grown and consumed. Moreover, the surplus food can be sold and generate revenue to buy food items needed to complement the nutrition requirements. The types of crops grown and consumed by the study communities comprised of mainly maize, rice, corchorus and soybean to which were added moderate purchases of pinto beans, yam, sorghum, beef and milk as indicated by a household survey.

Table 4 presents nutrition simulation results for the Bihinaayili site. It shows an improvement in terms of quantity intake, from the baseline to the alternative scenarios, for all nutrition variables (calories, proteins, fat, calcium, iron and vitamin A). Particularly, the caloric intake available for the household is relatively high (2 times higher than the average required) due to large contribution in

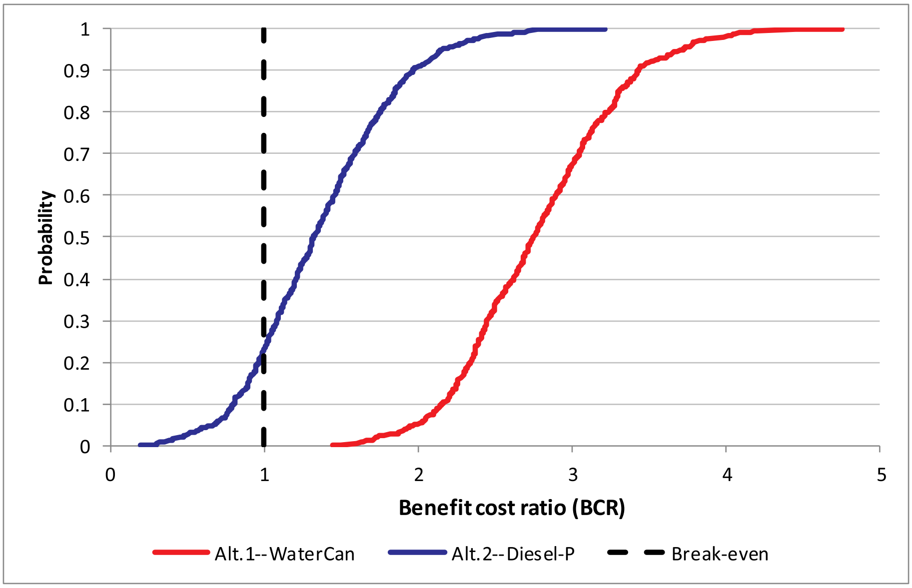

Fig. 6. CDF of the benefit-cost ratio (BCR) for alternative irrigation technologies (Zanlerigu).

Table 4
Nutrition effects of SSI in Bihinaayili community.*
* Note: AE = Adult Equivalent. Numbers in red show quantities of nutrients intake less than minimum required.

	Baseline	Alt. 1—Watering Can	Alt. 2--Diesel-P	
Averages daily nutrients in year 5				Min. required
Energy (calories/AE)	4620.0	4629.0	4652.0	1,750
Proteins (grs/AE)	93.5	94.1	95.6	41
Fat (grs/AE)	73.1	73.1	73.2	39
Calcium (grs/AE)	**0.18**	**0.24**	**0.37**	1
Iron (grs/AE)	0.012	0.012	0.013	0.009
Vitamin A (grs/AE)	**0.00002**	**0.00003**	**0.00003**	0.0006

calories by the soybean consumption, in addition to the cereals such as maize. It is worth mentioning that maize provided the largest contribution in available quantity intake for all nutrients except vitamin A. Most of vitamin A nutrients came from the consumption of corchorus and milk as indicated in the baseline household survey. Although definitive nutrition assessment cannot be achieved based on the crops considered in the model, there is a possibility of using the profit from irrigated crops to purchase complementary food needed for the household; this is an income-nutrition pathway as identified by Ref. [39].

Particularly, in Zanlerigu the calcium intake available for the household has significantly increased (5–7 times) in the alternative scenarios as compared to the baseline due to large contribution in calcium intake by amaranth consumption (Table 5). In the past nutrition studies in developing countries using the FARMSIM model, minimum calcium requirements have often been difficult to meet [46]. One of the possible reasons for calcium deficiency in developing countries could be linked to the low consumption of

Table 5
Nutrition effects of SSI in Zanlerigu community.*
* Note: AE = Adult Equivalent. Numbers in red show quantities of nutrients intake less than the minimum required.

	Baseline	Alt. 1--Watering Can	Alt. 2--Diesel-P	
Avg. daily nutrients in year 5				Min. required
Energy (calories/AE)	1967	2239	2475	1,750
Proteins (grs/AE)	50.6	73.2	90.0	41
Fat (grs/AE)	**24.5**	**26.0**	**27.2**	39
Calcium (grs/AE)	**0.4**	2	3	1
Iron (grs/AE)	0.015	0.037	0.052	0.009
Vitamin A (grs/AE)	**0.00007**	**0.00017**	**0.00024**	0.0006

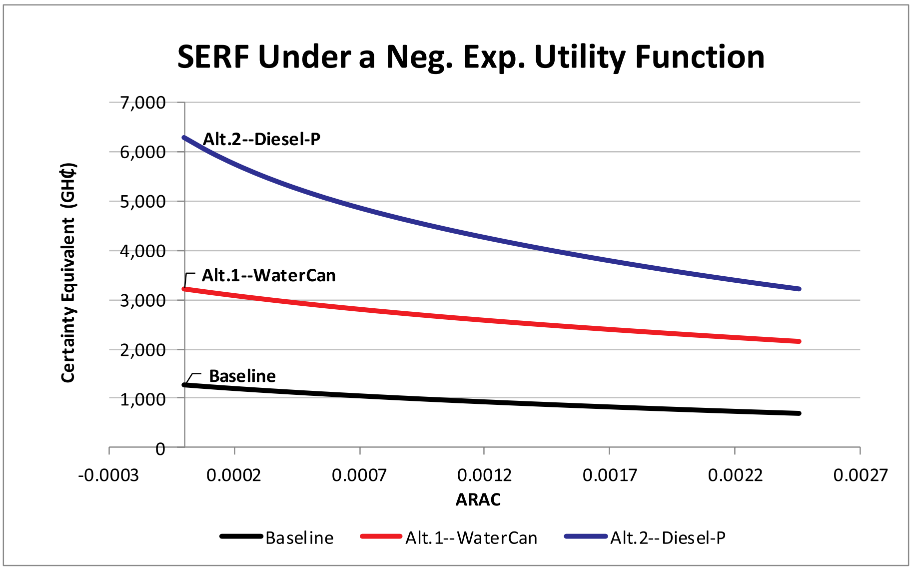

Fig. 7. SERF ranking of the baseline and alternative irrigation technologies in Bihinaayili.

animal source products such as milk, meat, eggs and cheese.

5.3. Risk analysis and technology ranking

The risk levels associated with each of the alternative irrigation technologies considered in the study were ranked based Stochastic Efficiency with Respect to a Function (SERF) values for profit at different levels of risk aversion (see section 4.2). This approach further considers all levels of risk aversion for a typical decision maker (from risk neutral to extremely risk averse). With risk factor included in the analysis, the two alternative technology scenarios perform differently in the two study sites. In Bihinaayili, the alternative scenario associated with the diesel pump (Alt 2) is the most preferred scenario at all levels of risk aversion (Fig. 7). However, there is a noticeable decreasing trend of Alt. 2 curve as the risk aversion level increases, which indicates that the decision maker is willing to take less profit to shield against the increase in risk. The next most preferred scenario in Bihinaayili is the watering can (Alt. 1). Its curve shows a lower decreasing rate as the risk aversion increases (Fig. 7). This may be due to the higher investment cost for the diesel pump compared to the watering can.

In Zanlerigu site, however, the alternative scenario associated with the watering can (Alt. 1) appears to be more preferred than Alt. 2 associated with diesel pump at all levels of risk aversion (Fig. 8). We notice a sharp decrease of Alt. 2 curve in CE values (profit)

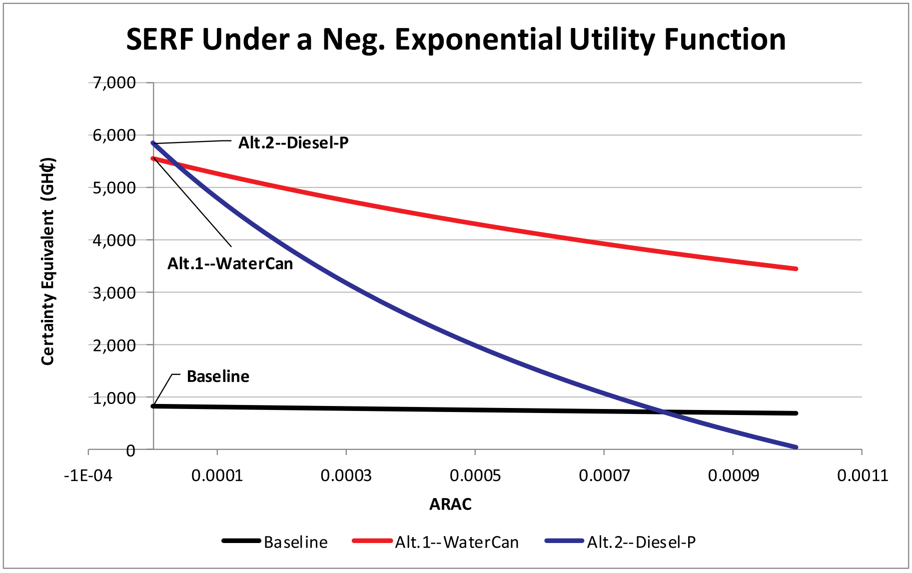

Fig. 8. SERF ranking of the baseline and alternative irrigation technologies in Zanlerigu.

to zero as the level of risk aversion increases; which means that extremely risk-averse decision makers would opt out of using a diesel pump given its high risk of loss and high investment cost. Under extreme risk aversion level, a typical decision maker would prefer the baseline option with a low profit to Alt. 2. The most preferred scenario is Alt. 1, which shows a smooth decline in CE values (profit) as the level of risk aversion increases. This is a commonly expected behaviour among most smallholder farm households, which are willing to take less profit in order to shield against potential risk [47,56].

6. Discussion and policy implications

The simulation results provide decision support evidence for promoting the adoption and upscaling of the SSI technologies. Comparison of the economic results on watering can and motorized pump technologies shows that the former SSI technology yields a relatively higher return per unit of money invested though the latter technology performs better in terms of higher overall net profit. Watering can is a traditional and highly labour-intensive technology; households are restricted to areas they water by hand using family labor and are also limited to crops with lower crop water requirements. This ultimately constrains expansion of irrigated area and could restrict the ability to meet food requirements in the market. On the other hand, the cost of fuel and upfront capital investment required to purchase fuel-powered motorized pumps constrain widespread adoption of this technology. First, in general, the high cost of borrowing in Ghana makes the upfront investment in irrigation technologies very expensive [57]). This is supported by other studies that show smallholder farmers are credit-constrained in northern Ghana [42]. For example, the inclusion in the simulation model of technology loan aimed at purchasing water lifting equipment such as a diesel-powered motorized pump at 10% interest rate payable between two and five years revealed to be a feasible and profitable option. However, the actual interest rate on agricultural loans can be 30% or above, which significantly hinders smallholder's access to credit. Thus, innovative financing options and targeted assistance may be needed to ensure that smallholders at lower levels of economic status can access financing mechanisms [58,59].[11] Secondly, to mitigate the impediment to SSI technology adoption that arises from high energy costs, alternative energy options, notably solar pumps, could be a promising option. This would simultaneously reduce labor cost and the operating costs associated with fossil-fuel based water pumps. Studies have shown that agriculture labor cost in Ghana is high, as is the opportunity cost of labor employed in agriculture in absolute terms, particularly as rural households increasingly depend on non-farm activities to boost income [60]. Again, the upfront cost of solar pumps is relatively expensive in Ghana compared to fossil fuel pumps, so affordable credit or innovative loan schemes need to be made available to enhance adoption.

Another interesting result that may help in the decision-making process of SSI adoption relates to higher risk in SSI technologies investment that was observed more in Zanlerigu than Bihinaayili community. The results on NCFI, scenario ranking and BCR (see Figs. 6–8) show an extremely risky situation in Zanlerigu with high variability in income and profit. A close look at the simulation results show that the source of risk in Zanlerigu comes mainly from the production costs of irrigated crops, in particular onion production. The production cost is about four times higher in Zanlerigu than in Bihinaayili and onion production alone represents 84% of the total cost of producing all other irrigated crops in Zanlerigu. Irrigation labour (digging wells and water application) and fertilizers costs seem to be the main factors of increased onion production costs in Zanlerigu. Farmers in Bihinaayili who produced and sold corchorus as their irrigated crop experienced less risk and variability in income due to lower production costs. Producing crops with higher production costs such as onion may not be the best option for certain categories of farmers with limited capital investment and that need to reduce their risks, such as in Zanlerigu. Opting for growing traditional and low-production cost vegetable crops such as amaranth and corchorus may be a better option for some groups of farmers. Diversifying production through inter-cropping may also be an option to explore.

As for the nutrition results, the production and consumption of traditional and low-production cost vegetables such as amaranth resulted in significant improvements in the nutrition status especially in providing and increasing the intake of calcium. Past studies using the FARMSIM model has showed consistently calcium intake deficiency, especially in Ethiopia [46]. A study carried out in Benin reports that the deficiency of calcium intake, especially for pregnant and reproductive age women is common in developing countries [61]; only 5.4% of pregnant women from that study sample had adequate calcium intake. We noticed a consistent deficiency in vitamin A as well, although the simulation results show a modest improvement in Vitamin A intake through the consumption of corchorus in Bihinaayili. The income pathway from irrigation to improved nutrition may become prominent to meet certain nutrient needs, especially animal-based food products that increase the daily intake of calcium and vitamin A.

7. Conclusions and recommendations

The purpose of this study was to evaluate the effects of adopting small-scale irrigation technologies on farm profitability and household nutrition in northern Ghana. A baseline scenario with current fertilizer application rates and no or minimal irrigation was compared to two alternative scenarios where recommended fertilizers rates and various SSI technologies were used to grow vegetable crops in selected communities in northern Ghana.

The preferred scenario, consisting of the application of recommended fertilizers in combination with the use of watering can or diesel-powered motorized pumps to irrigate corchorus, onions and amaranth, generated high income and profits for the farm households in the study communities. Although in all the case studies the diesel-powered pump generated the highest net income, the cost-benefit analysis showed the watering can provides more return on investment per unit money invested and at a lower risk level. The baseline scenario was the least preferred of all three scenarios analysed. Increasing risk and income variability were observed

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[11] The majority of farmers that adopt SSI technologies on their own are usually wealthier (upper quintile) and male (See: [59].

more in one study community (Zanlerigu) due to high production costs. The use of a diesel-powered pump in Zanlerigu coupled with high fertilizer and irrigation costs revealed to be a risky option as an alternative farming scenario that can lead to the risk of profit and income losses.

Household food consumption/nutrition levels improved significantly in the two alternative scenarios compared to the baseline scenario as a result of the improvements in crop yields. Noticeably the calcium intake available for household increased substantially due to direct consumption of irrigated vegetables. However, deficiencies in fat, calcium and vitamin A were observed in the two study communities.

The results further reveal that capital and financial constraints related to initial investment and operational costs (particularly fuel cost) are the key limiting factors to farmers. The choice to grow low-production cost vegetables using a simple watering can is less risky to farmers, but at the same time, generates low economic return. Farmers are likely to be less resilient and withstand shocks at these marginal levels. However, the options of using more capital-intensive SSI technologies such as solar-powered pumps to grow high value cash crops such as onions present a high risk due to high cost of capital. Enhanced access of smallholders to credit or irrigation equipment leasing arrangements may help ease this constraint and allow farmers to move from the current ‘low input – low output’ production to a more profitable dry-season farming system.

To build on the findings of this study, we suggest larger studies in additional communities and across a broader range of SSI technology options, such as drip, sprinkler, gravity-based system, and small reservoirs in combination with various water lifting and conveyance options, including solar-powered pumps. There is also lack of evidence on the effects of small-scale irrigation using low technology tools and high labor methods on resilience, including the effects of climate change and variability. The impact of climate change on surface and groundwater resources and food security were not addressed in this paper, but should be linked to future studies to better understand SSI as a resilience measure, in addition to its potential for income effects and nutrition.

Acknowledgements

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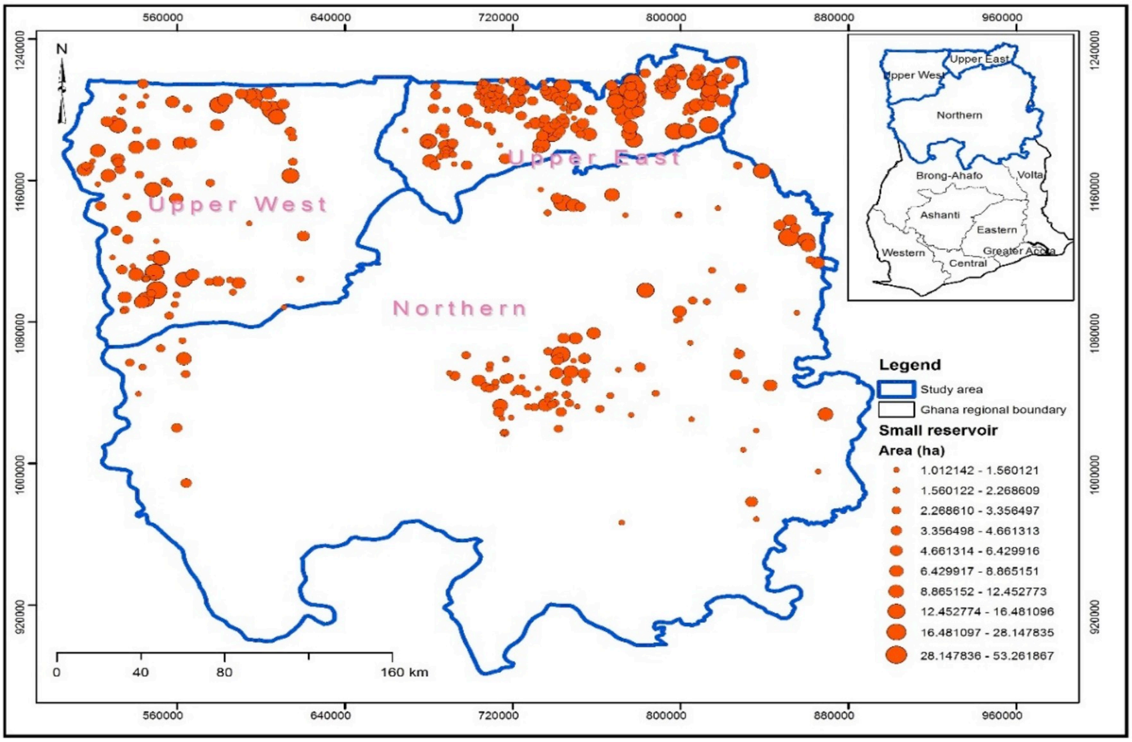
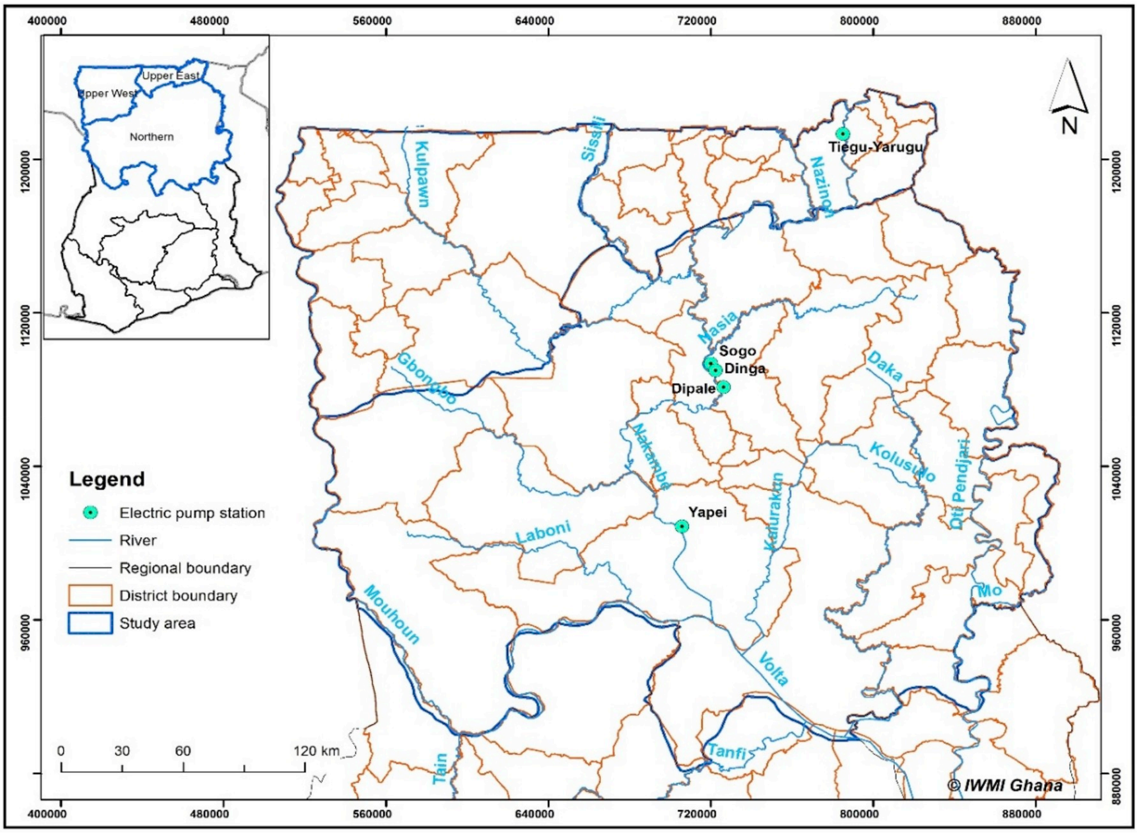
Appendices

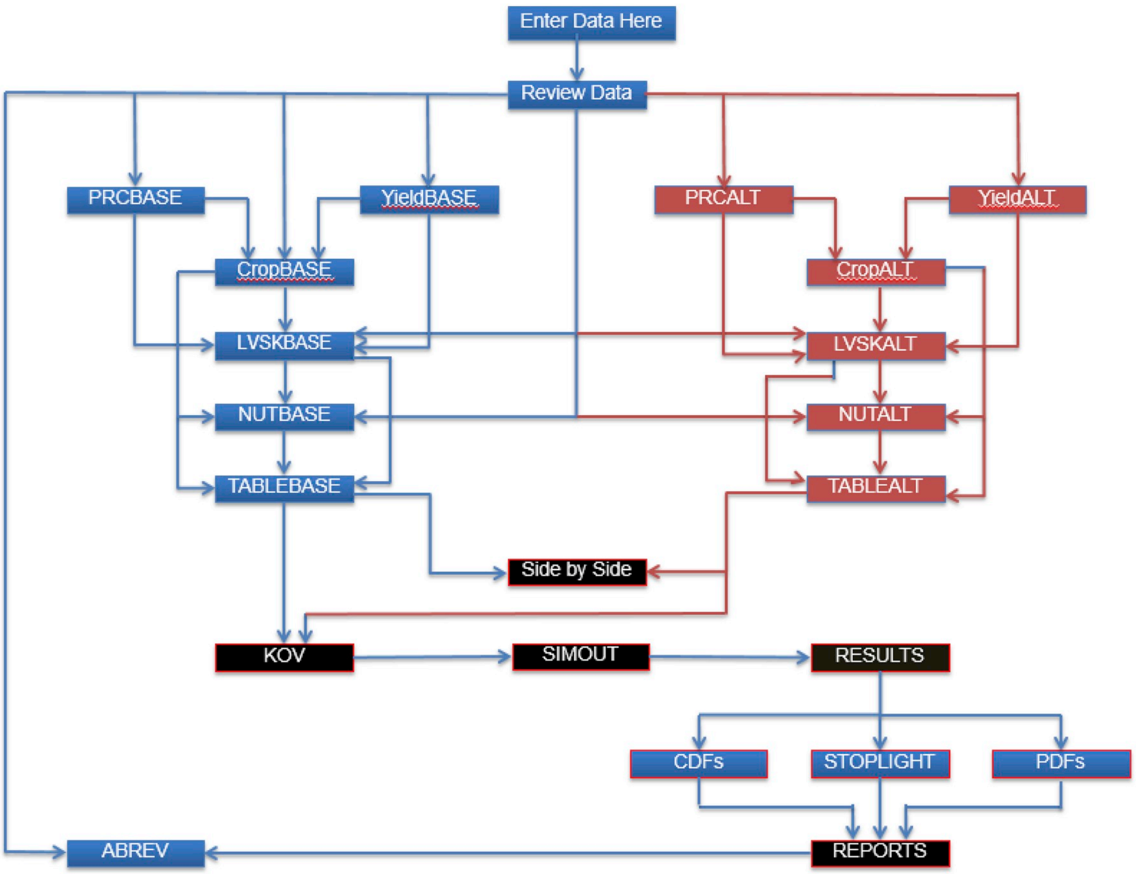
Appendix A. Distribution of multi-purpose small reservoirs in northern Ghana



Appendix B. Network of major Rivers in northern Ghana



Appendix C. FARMSIM flowchart (excel worksheet organization)



Abbreviations and meaning of different worksheets in FARMSIM

PRCBASE	price worksheet in baseline scenario
CropBASE	crop worksheet in baseline scenario
LVSKBASE	livestock worksheet in baseline scenario
NUTBASE	nutrition worksheet in baseline scenario
TABLEBASE	financial (table) worksheet in baseline scenario
Note	same meaning of the above worksheets applies to the alternative scenarios (CropALT)
KOV	key output variable
SIMOUT	simulation output

Appendix D1

Mean crop yields (Kg/ha) and input costs (GHc/ha) for the baseline and alternative scenarios in Bihinaayili.

Crops	Baseline scenario						Alternative scenario					
	Mean yield	Area planted	Cost fert.	Cost seed	Cost irrig	Other labor	Mean yield	Area planted	Cost fert.	Cost seed	Cost irrig	Other labor
	(Kgs/ha)	/hh (ha)	(GH ₵/ha)	(GH ₵/ha)	labor (GH ₵/ha)	cost (GH ₵/ha)	(Kgs/ha)	/hh (ha)	(GH ₵/ha)	(GH ₵/ha)	labor (GH ₵/ha)	cost (GH ₵/ha)
Maize	1504	2.3	64	6.6	0	24	1504	2.3	64	6.6	0	24
Rice	1714	0.53	407	14	0	326	1714	0.53	407	14	0	326
Soybean	2005	0.18	34	22	0	45	2005	0.18	34	22	0	45
Corchorus	1900	0.04	573	99	0	2223	21182	0.3	1937	940	1715	4289

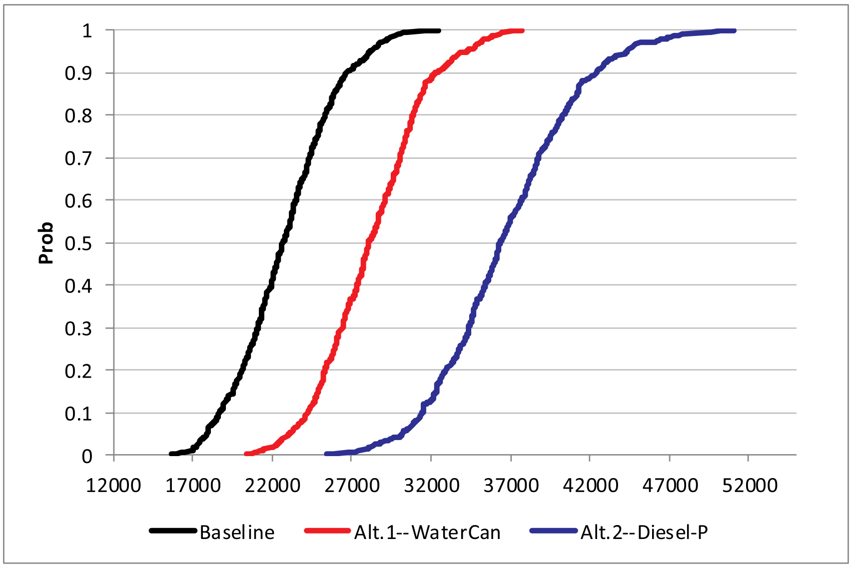
Note: hh = household; GH₵ = Ghanaian cedi (Ghana currency; 1 USD = 4.4 GH₵); irrig = irrigation; fert = fertilizer.

Appendix D2

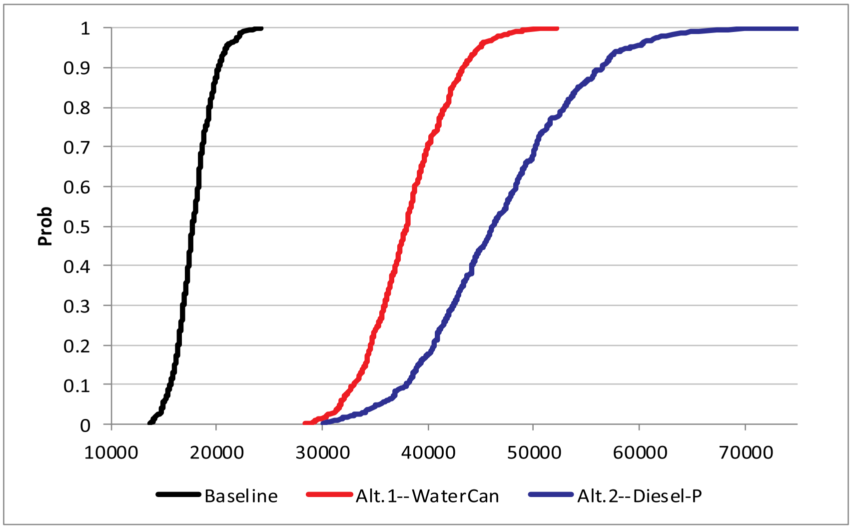
Mean crop yields (Kg/ha) and input costs (GHc/ha) for the baseline and alternative scenarios in Zanlerigu.

Crops	Baseline scenario						Alternative scenario					
	Mean yield (Kgs/ha)	Area planted /hh (ha)	Cost fert. (GH ₵/ha)	Cost seed (GH ₵/ha)	Cost irrig. labor (GH ₵/ha)	Other labor cost (GH ₵/ha)	Mean yield (Kgs/ha)	Area planted /hh (ha)	Cost fert. (GH ₵/ha)	Cost seed (GH ₵/ha)	Cost irrig labor (GH ₵/ha)	Other labor cost (GH ₵/ha)
Maize	1615	0.31	6	62	0	25	1615	0.31	6	62	0	25
Millet	1065	0.7	35	33	0	161.5	1065	0.7	35	33	0	161.5
Onions	3740	0.17	600	100	672	2017	12038	0.42	6239	800	3500	6579
Amaranth	2250	0.05	750	150	0	2464	15048	0.3	750	150	654	4039

Appendix E. CDF of the net present value for baseline and alternative technologies in Bihinaayili



Appendix F. CDF of the net present value for baseline and alternative technologies in Zanlerigu



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