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Feed the Future Innovation Lab for Small Scale Irrigation

Integrated Modeling and Scaling

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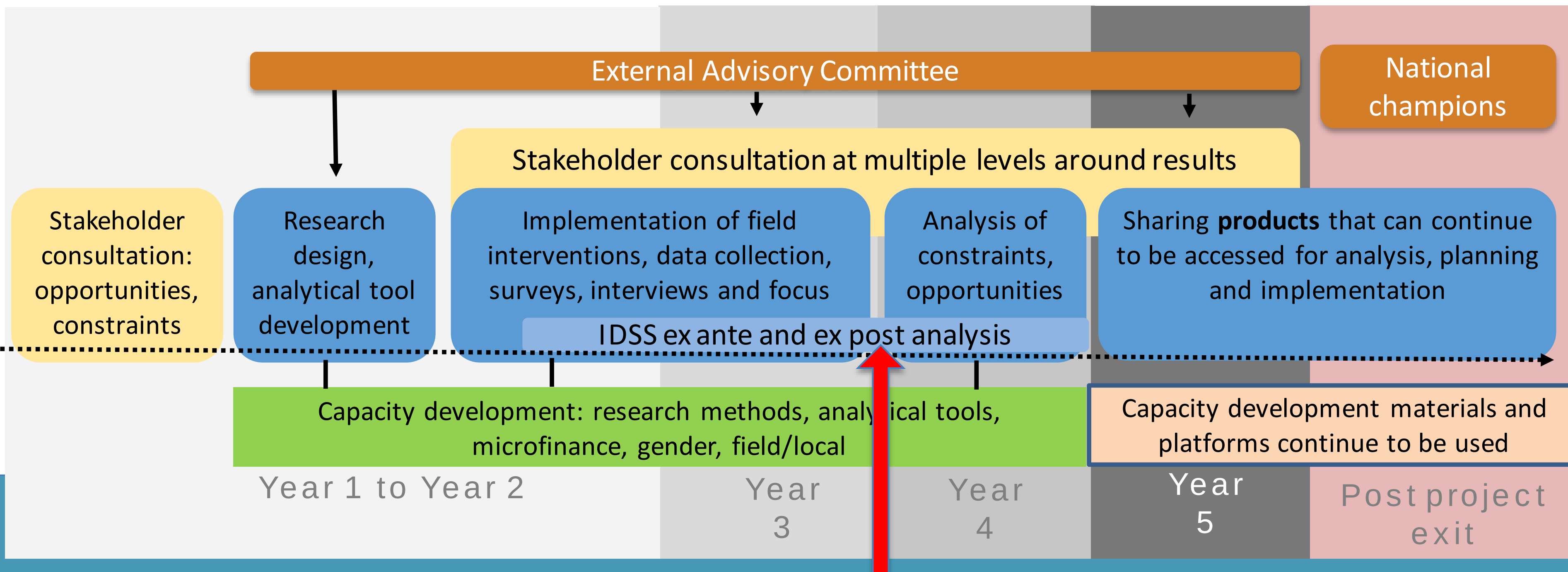
CONTRIBUTION OF MODELING TO PROJECT IMPACT



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Key Questions to answer for ILSSI

- How much water/land is available for irrigation?
- How many farmers/households can it support?
- How sustainable is it?
  - Now into future
- What are the bottlenecks & opportunities?
  - technologies, social/cultural, economics
- What are the optimum mixes of interventions?
- What difference will it make?
  - income, health, and in the lives of people
- What changes in policy, practice and investments are necessary?
  - local, regional, national

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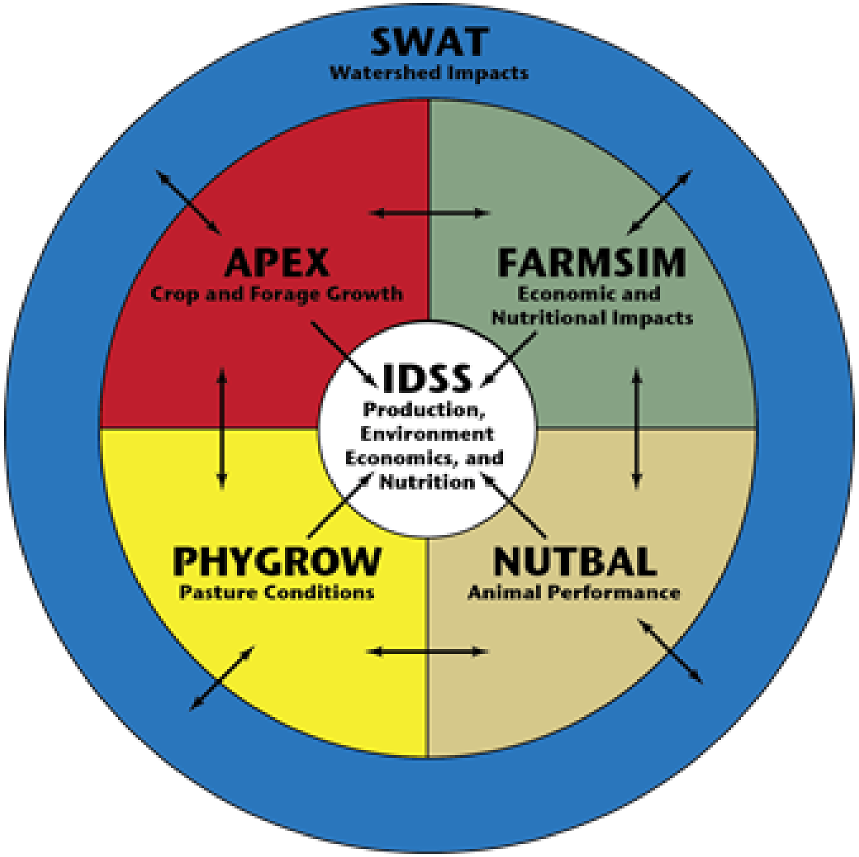
Integrated Decision Support System



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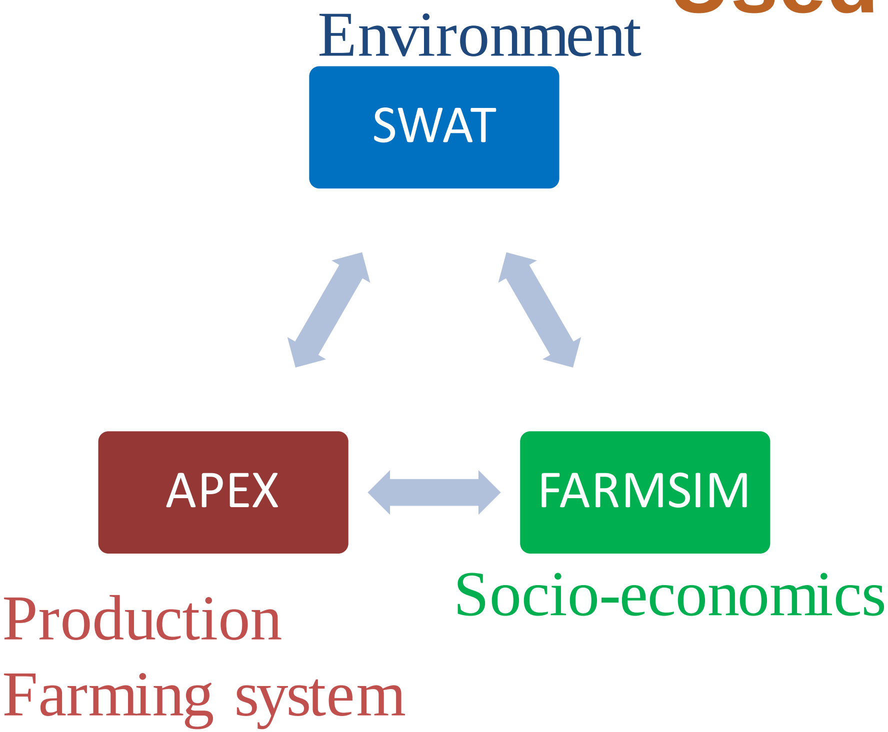
Integrated Decision Support System (IDSS) Used in ILSSI



- SWAT model to analyze the biophysical and environmental impacts of intensification of the interventions at the watershed scale
- APEX model to analyze cropping systems and to quantify benefits on crop yields at the farm scale
- FARMSIM assesses economic & nutrition impacts at the household

SWAT MODEL

- Predict the impact of land management practices on **water**, **sediment**, and **agricultural chemicals** in watersheds with varying **topography, soil**, **land use**, **weather,** and **management conditions**.
- A product of over 45 years of USDA/Texas A&M University cooperation.
- EPA and USDA NRCS/ARS use the SWAT model to predict the impact of land use management change/climate smart agriculture, and Best Management Practices (BMPs) on water quality and quantity, respectively.
- SWAT model is open source public domain with QSWAT (QGIS) interfaces.
- SWAT-CUP for calibration/sensitivity/uncertainty analysis, and
- Over 3,000 SWAT users and 30 active developers worldwide; more than 1,600 graduate students engaged in research; Estimate more than 1000 users in Africa.
- More than 3000 peer reviewed publications worldwide (1.3 papers/day)

APEX MODEL

- APEX: Agricultural Policy / Environmental eXtender
- Predict the impact of farm intervention on **water**, **sediment**, **crop yield** and **agricultural chemical yields** at field or small watersheds scale.
- **Management capabilities includes**: irrigation, drainage, best management practices (buffer strips, filter strips, grass water ways etc), fertilization, manure, reservoir, crop rotation, pesticide application, grazing and tillage.
- A product of over 45 years of Blackland Research and Extension Center, Texas A&M.
- EPA and USDA NRCS/ARS use the APEX model to predict the impact of agricultural management.
- APEX model source code is public domain, with public domain ArcAPEX and WinAPEX interfaces.

FARMSIM

- FARMSIM is a Monte Carlo farm level income and nutrition simulation model
- Small farm version of FLIPSIM a 40 year model at Texas A&M
- Simulates annual production, consumption, and marketing of crops and livestock on a small holder farm under alternative technology assumptions
- Stochastic prices and yields for crops and livestock incorporate risk
- Not an optimization, but a simulation of "What could be if technology is adopted at different rates."
- Projects changes to a farm family's income and nutrition uptake for alternative technologies
- Calculates NPV, B/C and IRR to evaluate alternative technologies

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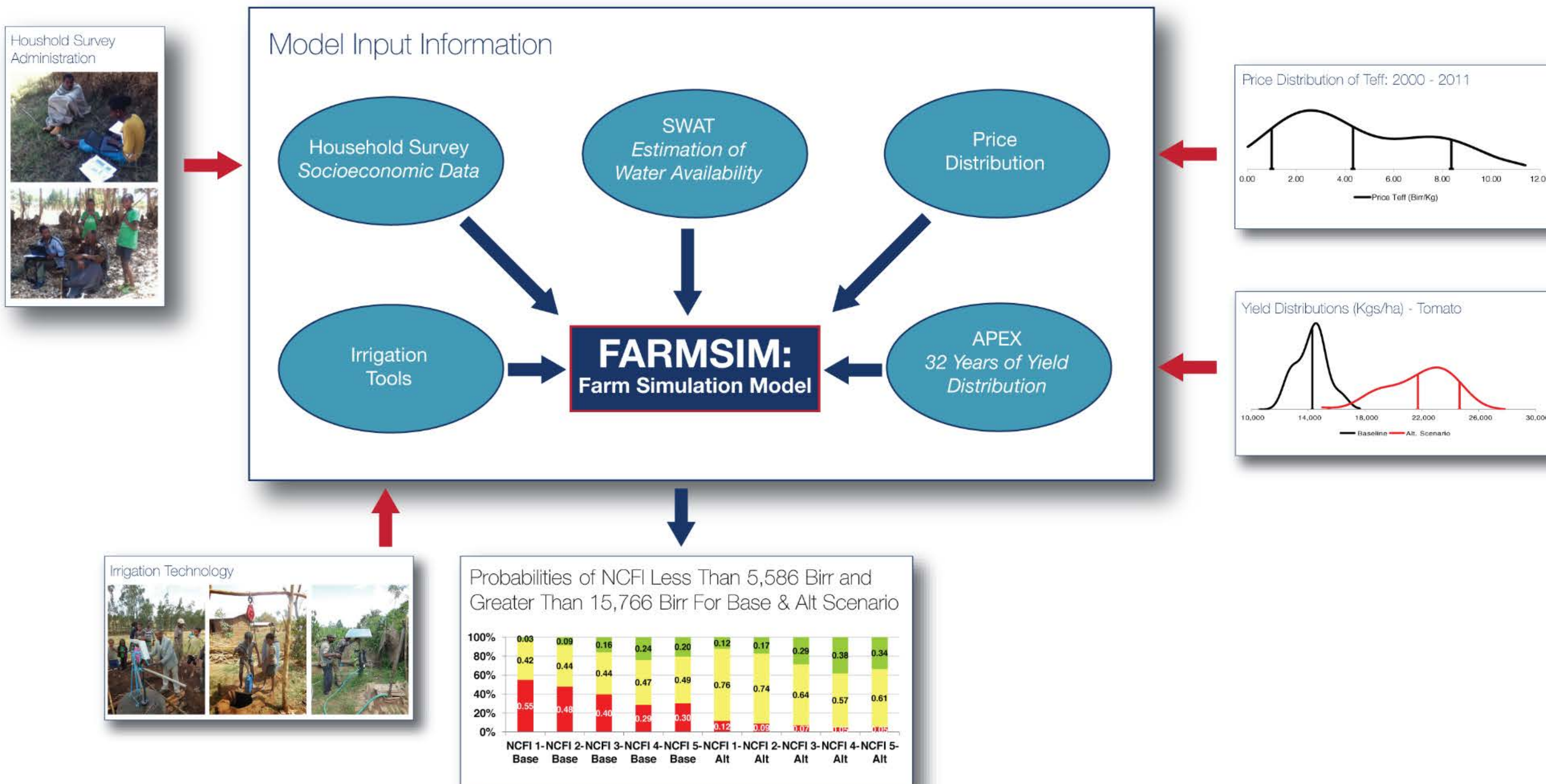
FARMSIM Model Input and Output



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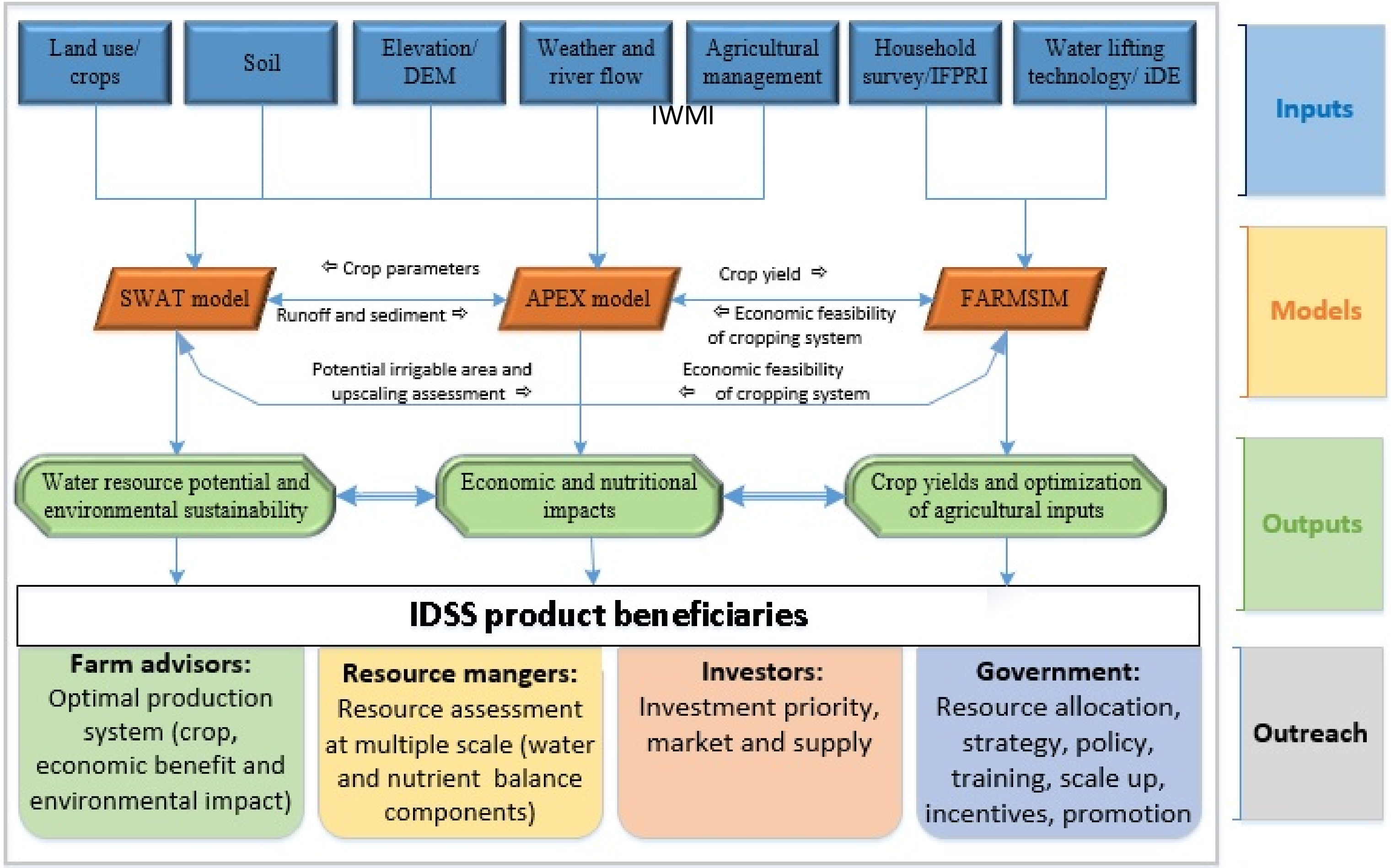
IDSS WORKFLOW



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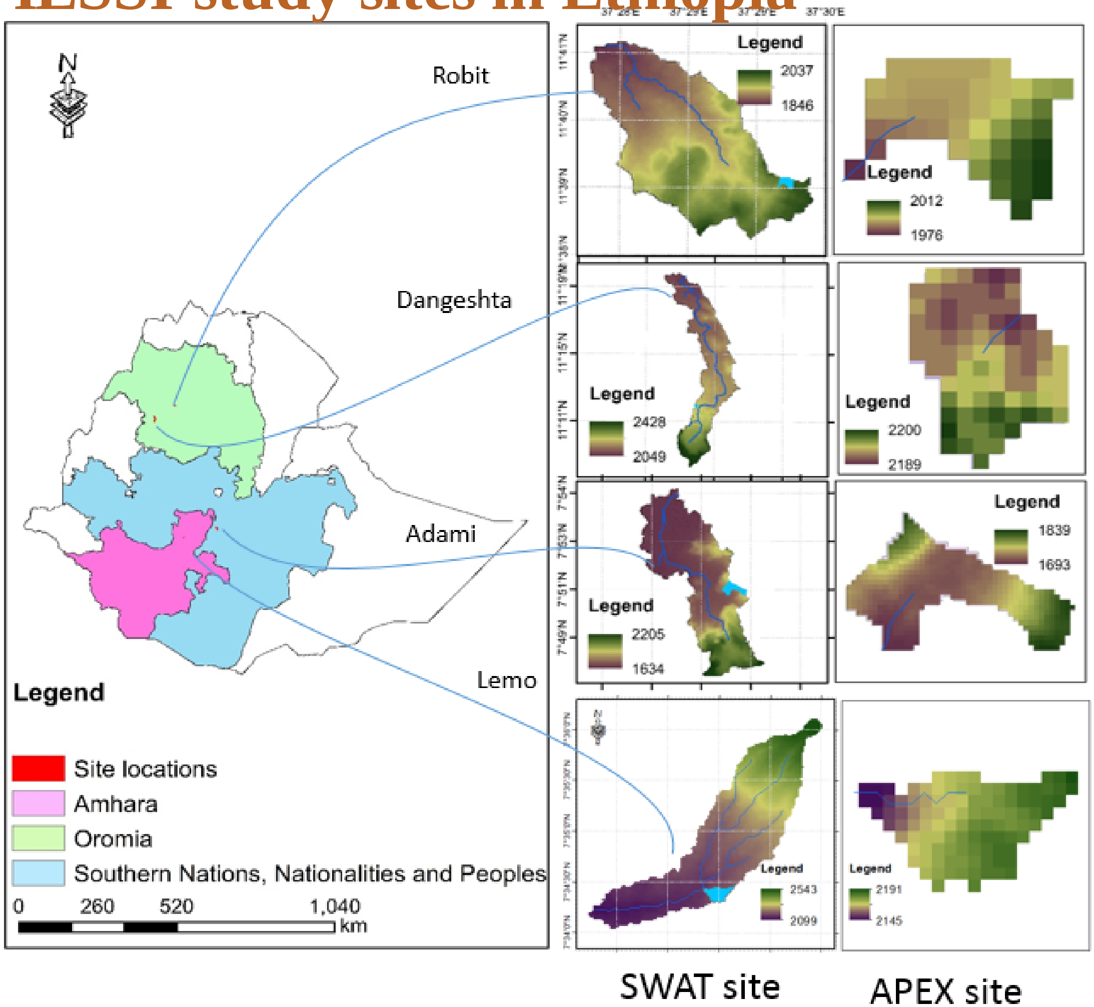
IDSS Contributions to the ILSSI project until now:

- Ex-ante analysis on small scale irrigation
  helped to scope the existing small scale irrigation (SSI) and understand their impact on agricultural production, environmental sustainability and economic and nutrition outcomes.
- Ex-post analysis on small scale irrigation
  the impact of SSI on agricultural production environmental sustainability and economic and nutrition outcomes was further explored using field collected data.
- Gap and constraint analysis
  helped us identify factors that limit the adoption of SSI and to suggest positions for mitigations.
- Upscaling analysis
  helped to study the potential for expanding SSI and its impacts.
- Capacity building
  will be presented in a separate slide.

ILSSI study sites in Ethiopia



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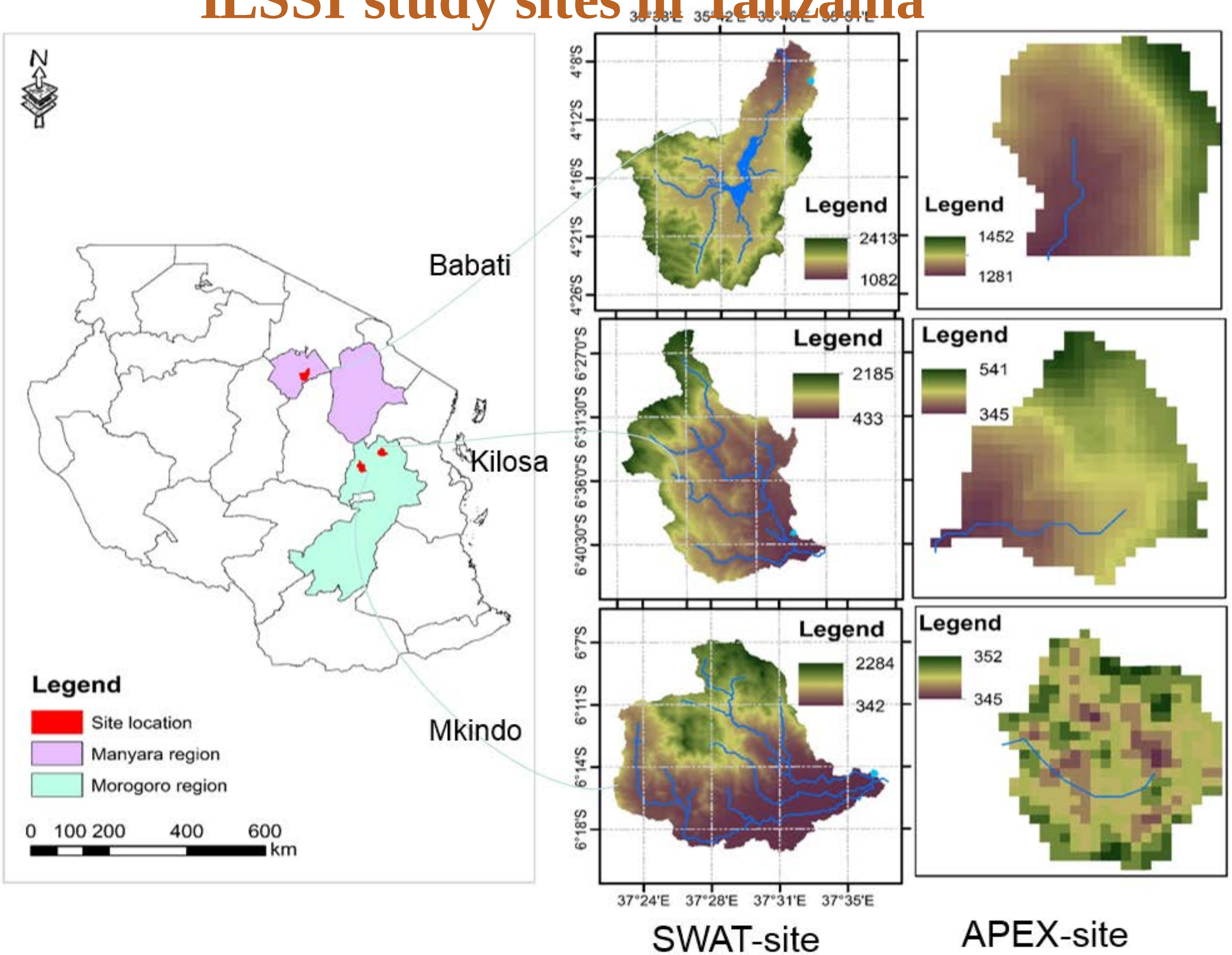
ILSSI study sites in Tanzania



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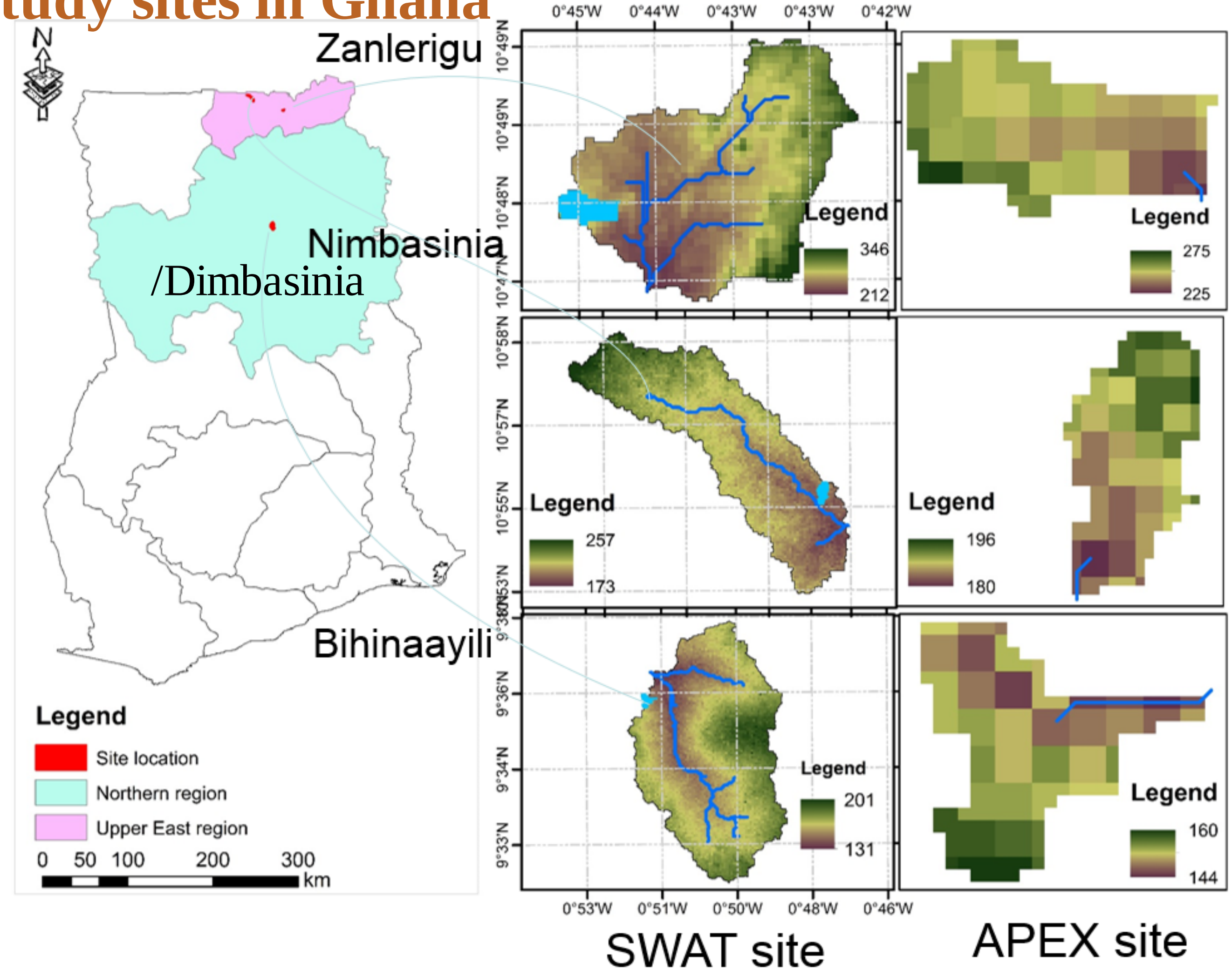
ILSSI study sites in Ghana



Ex-ante analysis

- Ex-analysis relied on existing small scale irrigation (SSI) in each of the three countries,
- Data was obtained from literature and secondary sources (e.g. biophysical and socio-economic data was received from partner research institutions),
- IDSS used all these inputs to understand their impact on agricultural production, environmental sustainability and economic and nutrition outcomes.
- Four sites in Ethiopia, and three each in Ghana and Tanzania were studied.

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Ex-ante case study: Dimbasinia site, Ghana

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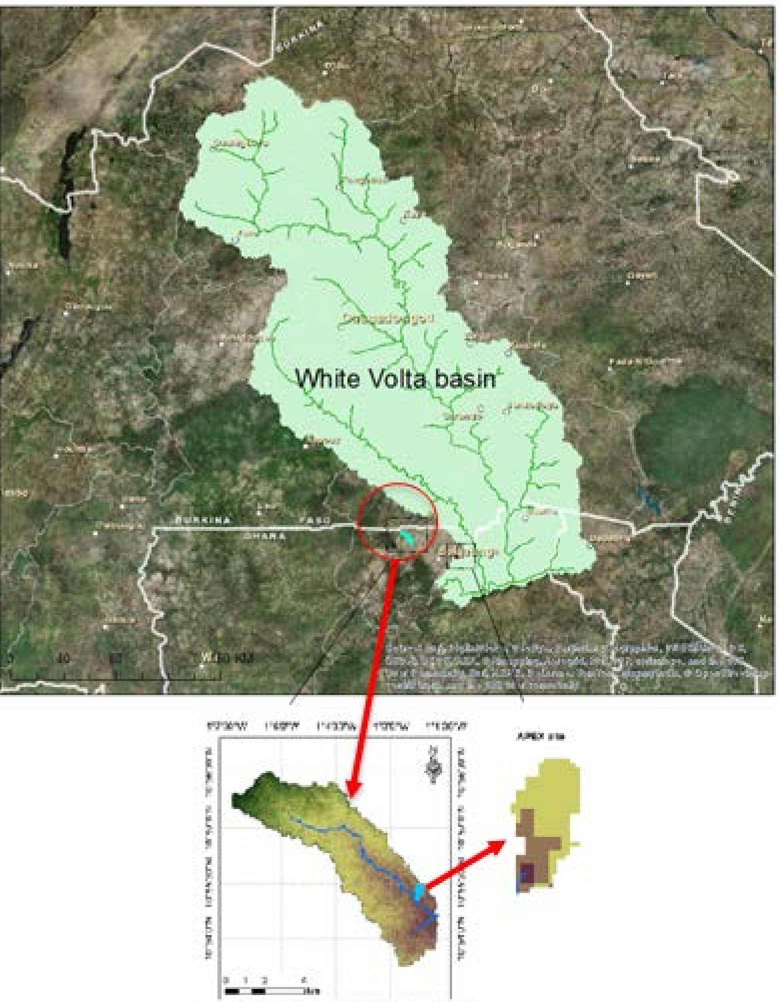
Calibration for Dimbasinia watershed



- SWAT calibrated parameters for a nearby watershed in **White Volta** basin transferred to Dimbasina SWAT site;
- APEX was setup for SWAT subarea;
- APEX is calibrated for **Corn** and **Sorghum** and the calibrated parameters for these crops were transferred back to SWAT
- Calibrated crop yields are entered in FARMSIM for economic analyses

Bizimana et al. 2017, Integrated report in Dimbasinia….

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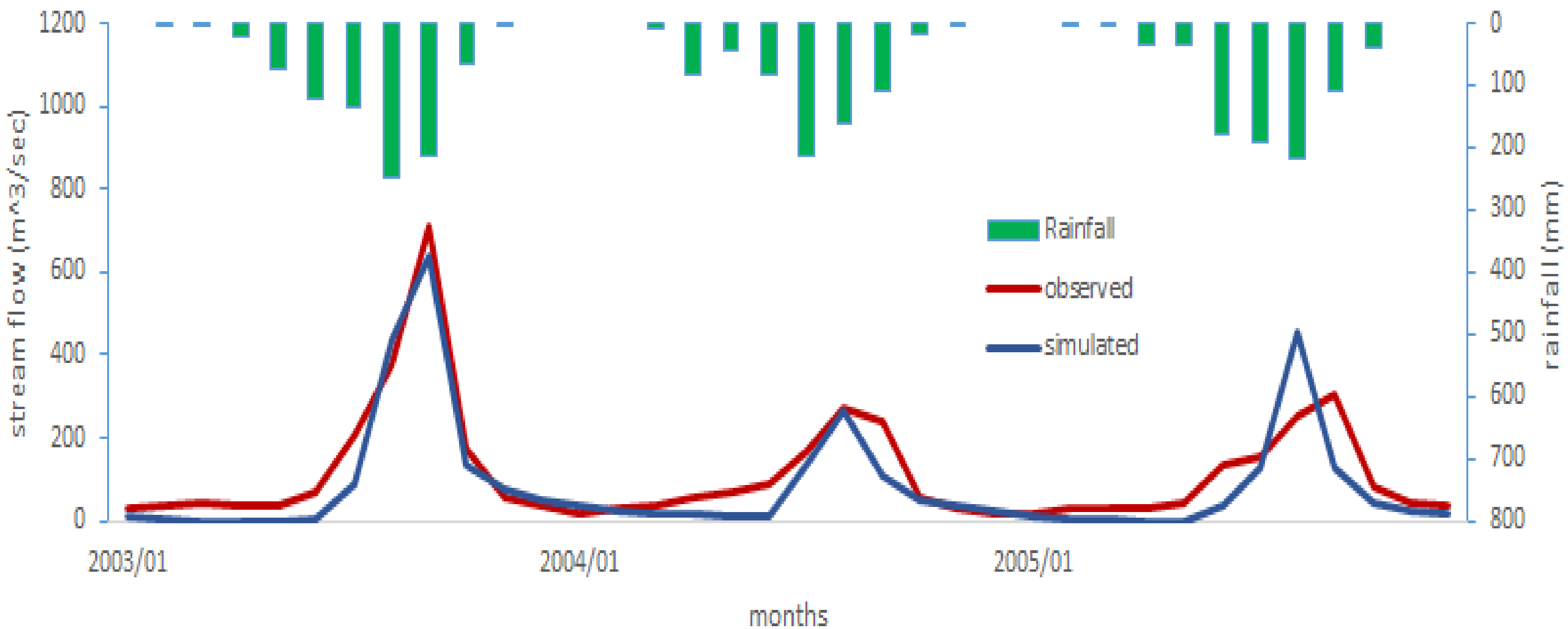
Calibration for White Volta Basin



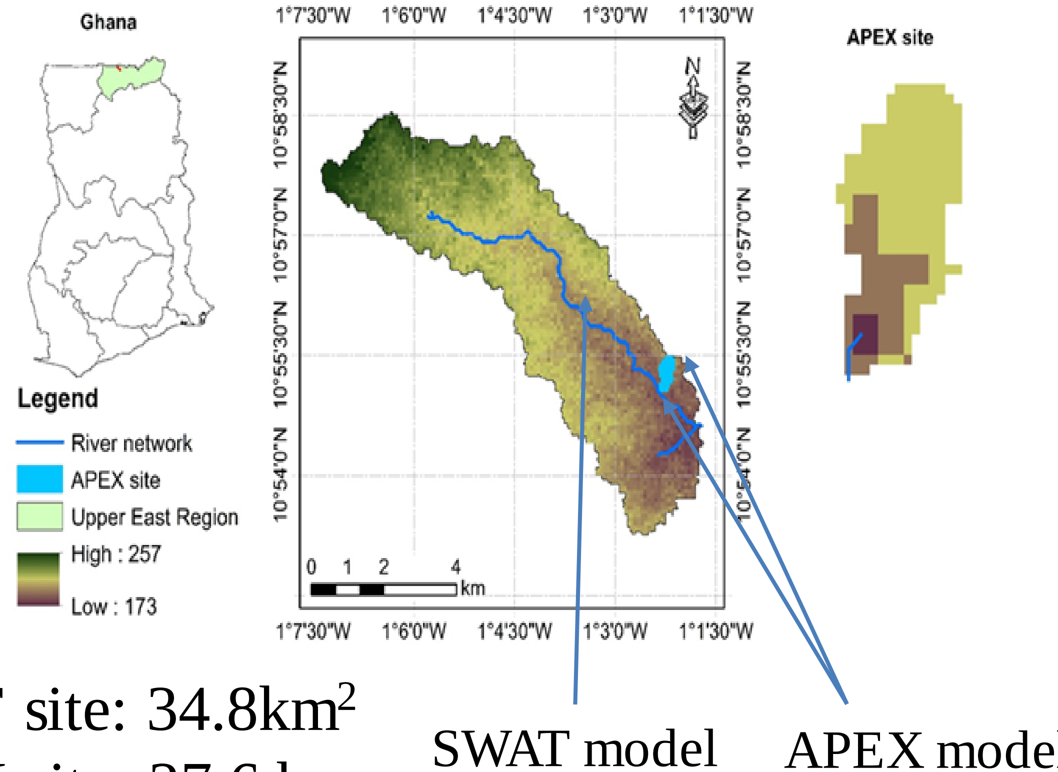
- SWAT model calibration was done using streamflow at the **Pwalugu river gauging** station in **White Volta**.

Dile et al., 2016. Individual SWAT modeling report in Dimbasinia…

APEX Calibration for Dimbasinia watershed

- APEX was setup for selected SWAT subarea;

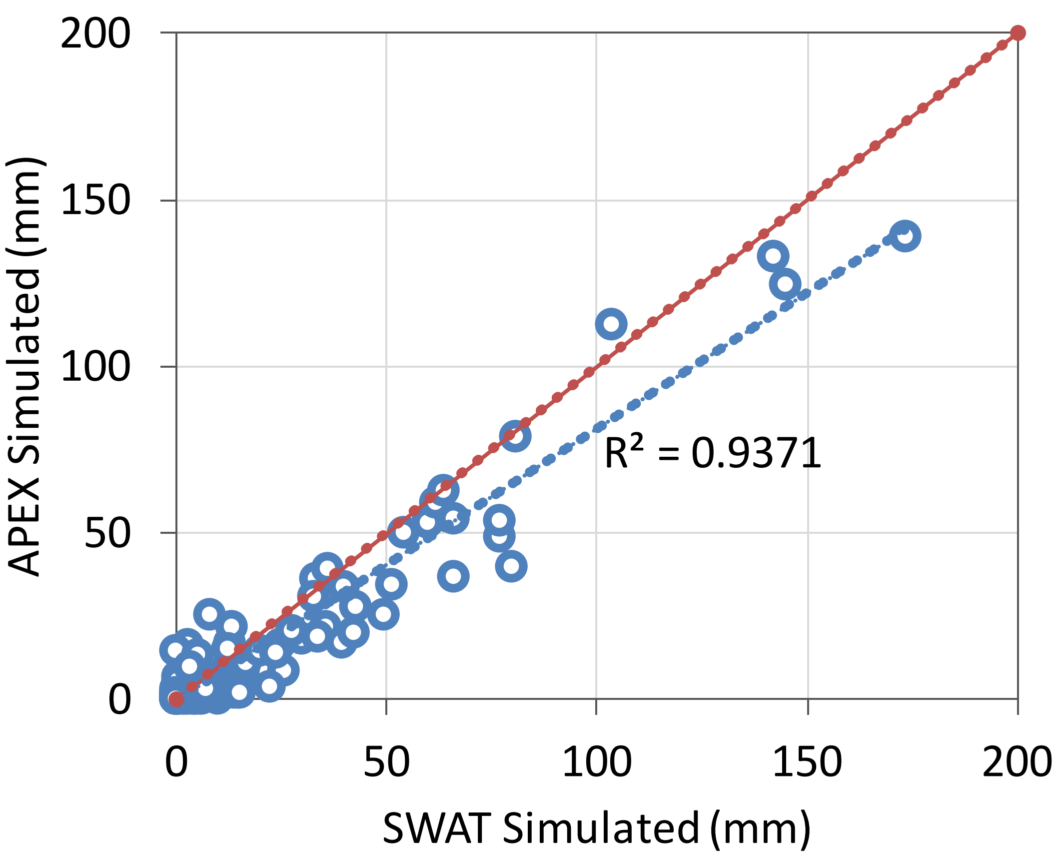
- APEX model was calibrated for the base period for rainfed **corn** and **sorghum**, and validated with FAOSTAT and SPAM crop yield data.



SWAT site: 34.8km^2
APEX site: 27.6 ha

Worqlul et al., 2016. Individual APEX modeling report in Dimbasinia…

CALIBRATION SWAT/APEX – RUNOFF



Nash-Sutcliff Efficiency (NSE)= 0.88
R-square value of 0.94

Worqlul et al., 2016. Individual APEX modeling report in Dimbasinia…

APEX BASELINE AND SCENARIOS

- ***Baseline:*** continuous planting of rainfed non-fertilized crops (maize and sorghum);
- ***Scenario 1***: multiple cropping of **non-fertilized maize** with **irrigated vegetables** (maize + tomato, maize + pepper, maize + fodder);
- ***Scenario 2***: multiple cropping of **non-fertilized sorghum** with **irrigated vegetables** (sorghum+ tomato, sorghum + pepper, sorghum + fodder);
- ***Scenario 3***: multiple cropping of **fertilized maize** with **irrigated vegetables** (fertilized maize + tomato, fertilized maize + pepper, fertilized maize + fodder);
- ***Scenario 4:*** multiple cropping of **fertilized sorghum** with **irrigated vegetables** (sorghum + tomato, sorghum + pepper, sorghum + fodder)

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RAINFED CROP MANAGEMENT -IFPRI SURVEY

Maize and Sorghum Practice	Dates	Baseline	With fertilizer
Tillage	15-May		
Tillage	1-Jun		
Tillage	15-Jun		
DAP fertilizer application	15-Jun	Don't apply	50 kg/ha
Planting	15-Jun		
1st stage urea fertilizer application	15-Jul	Don't apply	25 kg/ha
2nd stage urea fertilizer application	15-Aug	Don't apply	25 kg/ha
Harvest	15-Oct		

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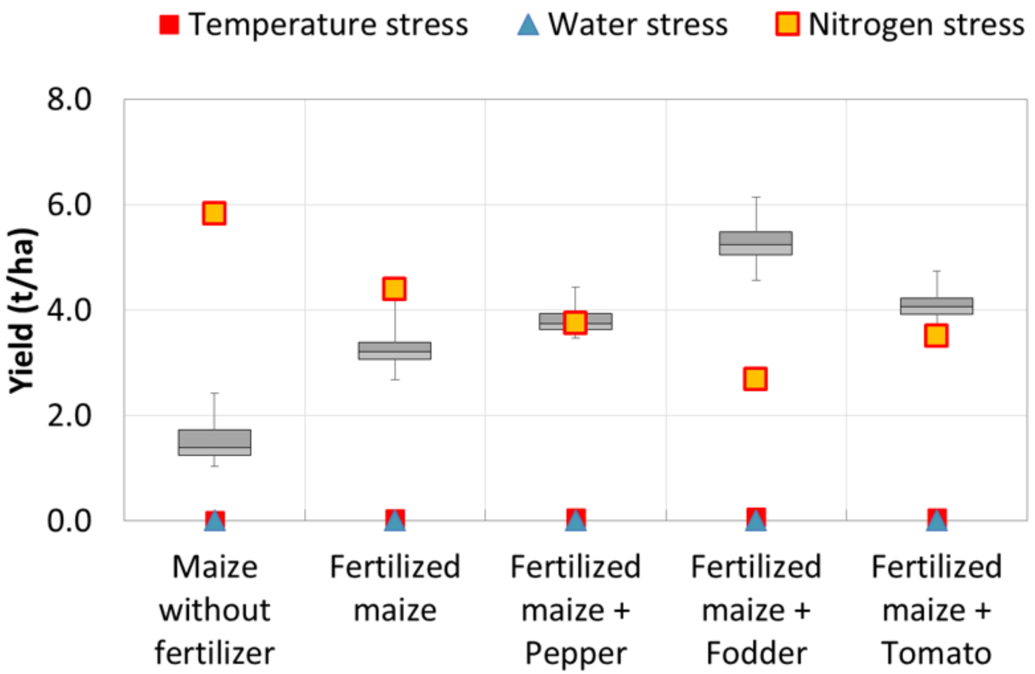
IRRIGATED CROPS MANAGEMENT

Operation	Tomato	Pepper	Fodder practice (Oats/Vetch)
Tillage	10-Nov	23-Nov	30-Nov
Tillage	25-Nov	8-Dec	15-Dec
DAP application (50 kg/ha)	25-Nov	8-Dec	15-Dec
Planting	25-Nov	8-Dec	15-Dec
1st stage urea application (25 kg/ha)	25-Nov	8-Dec	15-Dec
2nd stage urea application (25 kg/ha)	25-Dec	7-Jan	10-Jan
Harvest	11-Apr	26-Apr	13-Feb

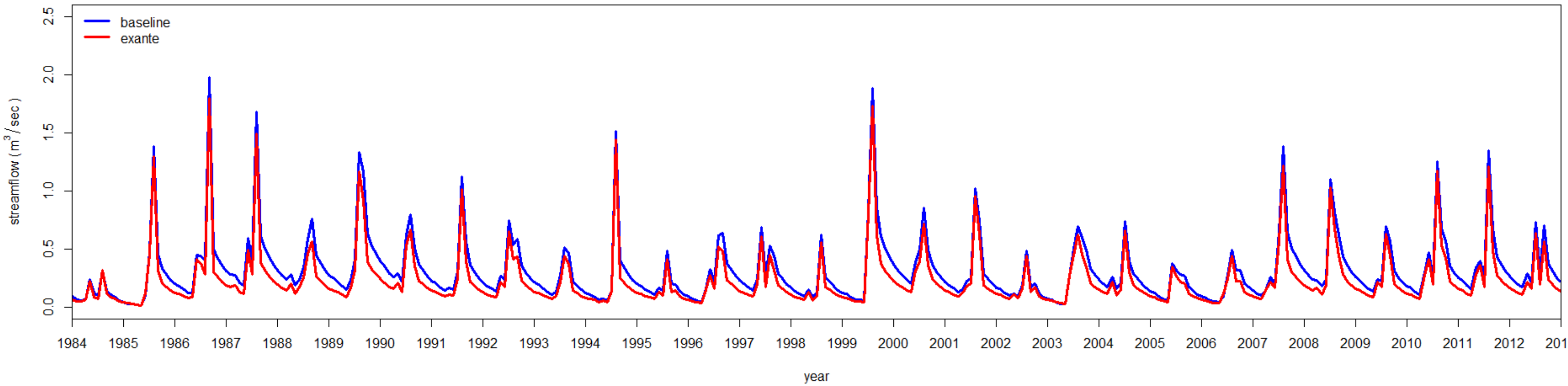
BASELINE AND SCENARIO-1/3 MAIZE YIELD



- Application of fertilizer (50 kg/ha urea and 50 kg/ha DAP) increased maize yield significantly compared to without fertilizer application;
- Crop rotation significantly improved soil fertility especially when maize is planted after legumes (fodder);

Worqlul et al., 2016. Individual APEX modeling report in Dimbasinia…

Stream flow Environmental impacts



- the ex-ante analysis indicated that the average monthly stream flow will be reduce by 25% with the implementation of irrigation from the shallow groundwater aquifer.
- There will be consistent reduction for monthly stream flows both on the high flows and low flows

Dile et al., 2016. Individual SWAT modeling report in Dimbasinia…

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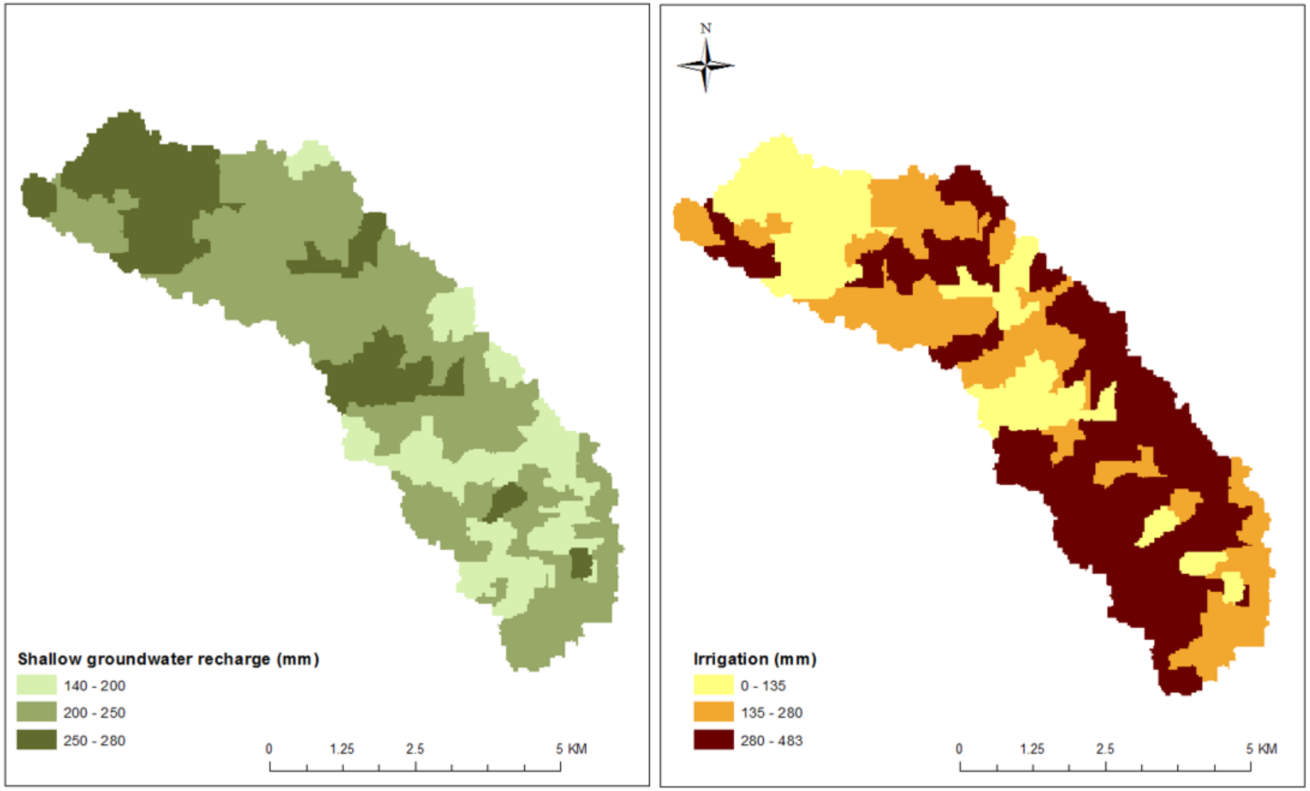
Long-term Environmental impacts on groundwater recharge (1984-2013)



- The average area-weighted irrigation was 248 mm, and shallow groundwater recharge was 227 mm.
- The annual shallow groundwater recharge cannot support the irrigation water requirement for producing pepper and Napier grass during the dry season.
- Reduce area of irrigation to sustainably irrigate.

Dile et al., 2016. Individual SWAT modeling report in Dimbasinia…

IWMI International Water Management Institute
ILRI International Livestock Research Institute
North Carolina A&T State University

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FARMSIM: Nimbasina community-Ghana

- Field data collected in 2014 by Africa Rising-IFPRI

- Baseline and alternative scenarios differ only on input costs and yields for grains and irrigated crops

- Simulation of profitability & nutrition with rain-fed grain crops and irrigated vegetables and fodder

- Irrigation costs:
  - Equipment costs: 2260 to 3000 GH₵ /family (Diesel and solar pump + accessories); pulley/bucket system: 250 GH₵
  - Operational costs (fuel, maintenance, rental): 235-290 GH₵/ha

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Economic and nutrition results

- Average values show economic profitability of investing in diesel pump with multiple cropping of sorghum, vegetables (tomato & pepper), and fodder
- Percentage change in the profit of Alt. vs. Baseline is positive and doubled for diesel pump use compared to pulley and solar pump
- Increase in daily intake of all nutrition variables from Baseline to Alt. scenarios and meets all minimum requirements except for calcium

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Conclusions for the Ex-ante Case Study

- Large water resource potential in the Dimbasinia watershed. However, the average annual irrigation water requirement for cultivating pepper/tomato and fodder was more than the average annual shallow groundwater recharge.
- The addition of 50 kg/ha of urea and 50 kg/ha of DAP doubled maize and sorghum yields.
- Additional fertilizer, multiple cropping, and irrigation performed better than baseline scenario. The diesel pump (rented or owned) was the preferred water-lifting technology.

Ex-post analysis

- Ex-post analysis used field experimental data to fine-tune the IDSS tools
- The field data were collected by IWMI in each of the three countries,
- Four sites in Ethiopia and three sites each in Ghana and Tanzania were studied – with several experimental fields in each site/watershed.
- The field data was instrumental to understand the impacts of SSI on agricultural production, environmental sustainability and economic and nutrition outcomes
- The ex-post analysis, thereby, was used to study gaps and constraint analysis and upscaling on SSI.

Ex-post case study: Robit site, Ethiopia

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Resource assessment at watershed scale: Robit case, Ethiopia

- Average annual rainfall = 1,400 mm

  → Average annual groundwater recharge = 280 mm
  (~4,000,000 m^3 over the watershed or 20% of the rainfall)

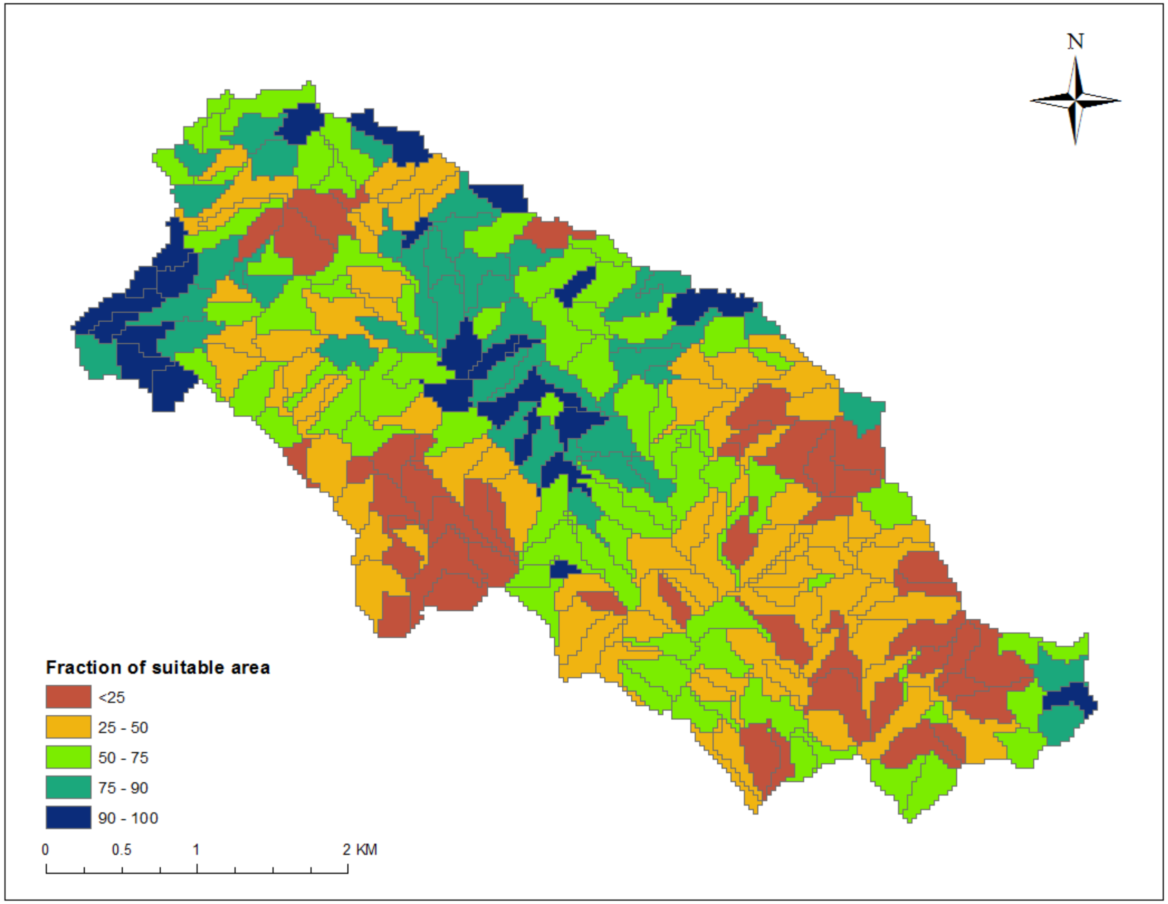
  → Average annual surface runoff = 520 mm
  (~7,000,000 m^3 over the watershed or 37% of the rainfall)

- Amount of water required for dry season irrigation for tomato = 1,500,000 m^3

  → ~40% of the **groundwater recharge**

- At the watershed scale, groundwater recharge can support irrigation for vegetables (in suitable areas) in a sustainable manner.

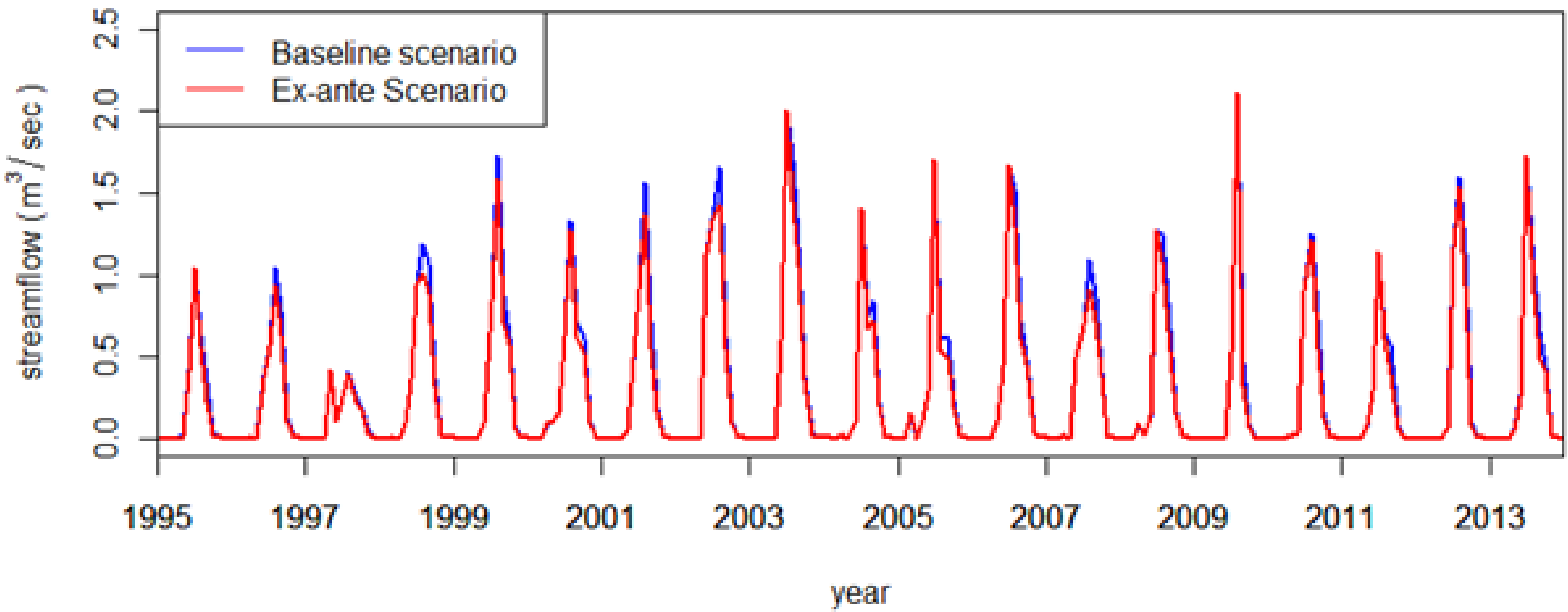
Land suitability for irrigation



- ~57% of the watershed is suitable for irrigation.
- Major rainfed crops were maize, teff, and finger millet.
- Dry season irrigated crops were tomato and onion. (others can be considered also)

Dile et al., 2016. Individual SWAT modeling report in Dimbasinia…

Environmental Impacts of SSI at the watershed



- The average monthly stream flow at the outlet of the Robit watershed reduced by ~6%, minor reductions in high flows.
- No major environmental impact such as erosion due to SSI

Dile et al., 2016. Individual SWAT modeling report in Dimbasinia…

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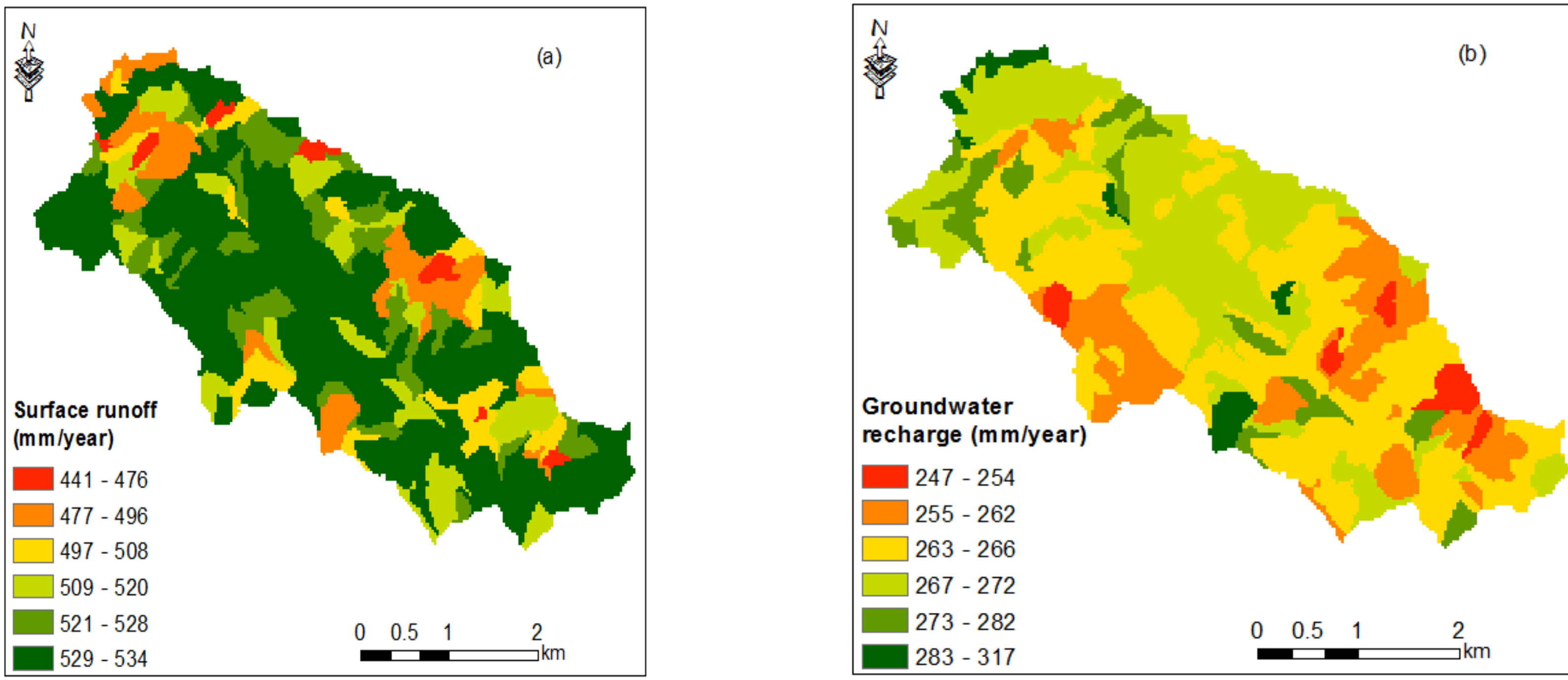
Robit surface runoff and shallow groundwater recharge



- The average annual surface runoff in the Robit watershed ranges b/n 441 mm/year and 534 mm/year.
- The average annual groundwater recharge in the Robit watershed ranges b/n 247 mm/year and 317 mm/year

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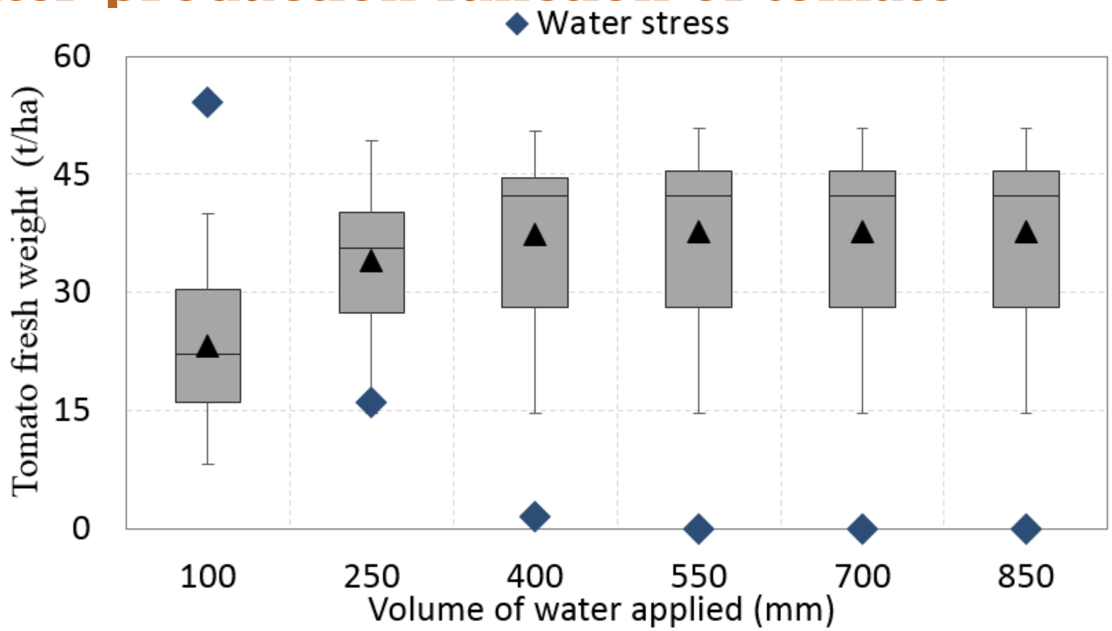
Robit watershed water production function of tomato



Irrigation management:

- Irrigation interval 2-days
- Fixed irrigation
- Furrow irrigation application

Season total (mm)	Application rate (mm/2-days)
100	1.4
250	3.5
400	5.7
550	7.8
700	9.9
850	12.1

- The average tomato yield ranges from 23 ton/ha and 37 ton/ha with 100 mm and 850 mm of irrigation, respectively.
- The optimal water required to maximize tomato yield (400 mm/year) is greater than the shallow groundwater recharge (247 mm to 317 mm).
- Water will be a constraint in Robit watershed if the source of irrigation is only groundwater.

Worqlul et al., 2017. Gap and constraint analysis in Robit ….

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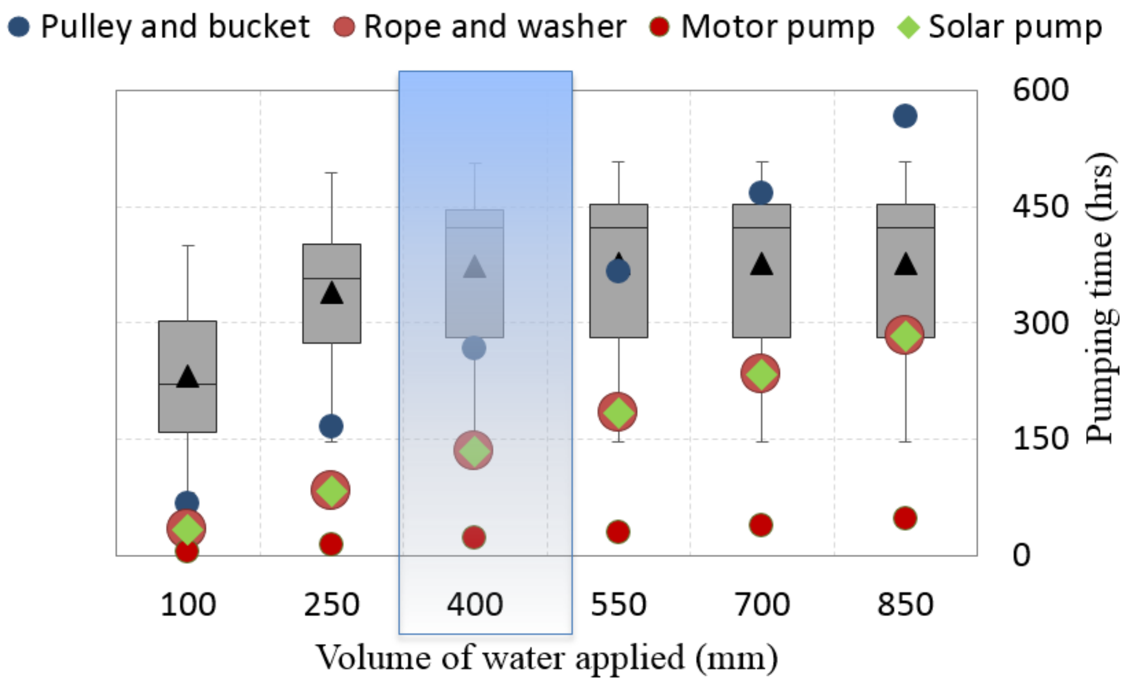
Water use function and pumping time of tomato

Water lifting technologies specification

Pumping method	Pumping rate (l/min)
Pulley/bucket	10
Rope and washer pump	20
Motor pump	120
Solar pump	20



Over irrigation effect:

- Limits irrigation expansion;
- Costs more time and money;

The pumping hours to irrigate 0.04 ha for 400 mm of irrigation will be 6, 33, 33 and 67 hours using motor, rope & washer, solar, and pulley & bucket pumps, respectively.

Worqlul et al., 2017. Gap and constraint analysis in Robit ….

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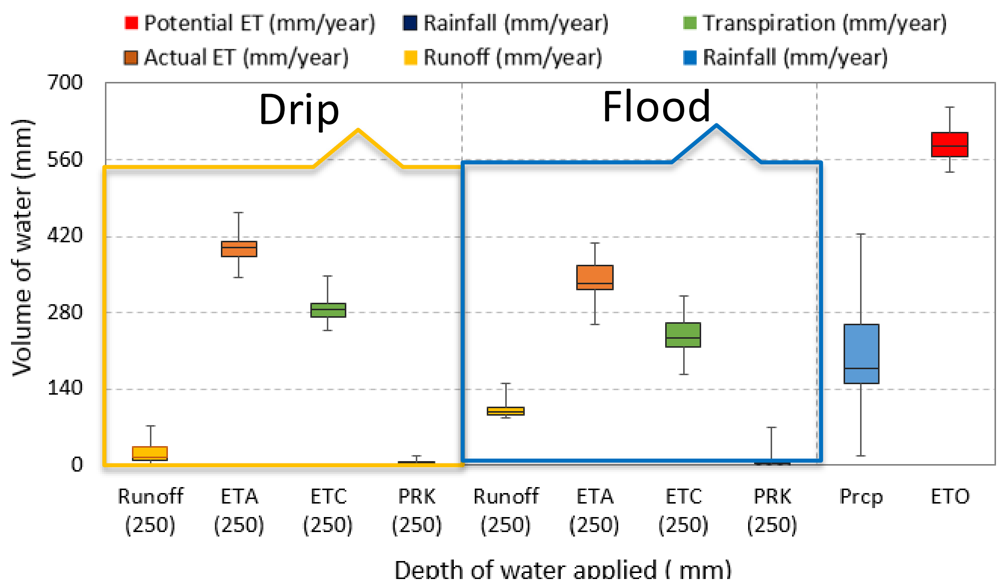
Optimizing water use efficiency

Water balance components of drip and flood/furrow irrigation



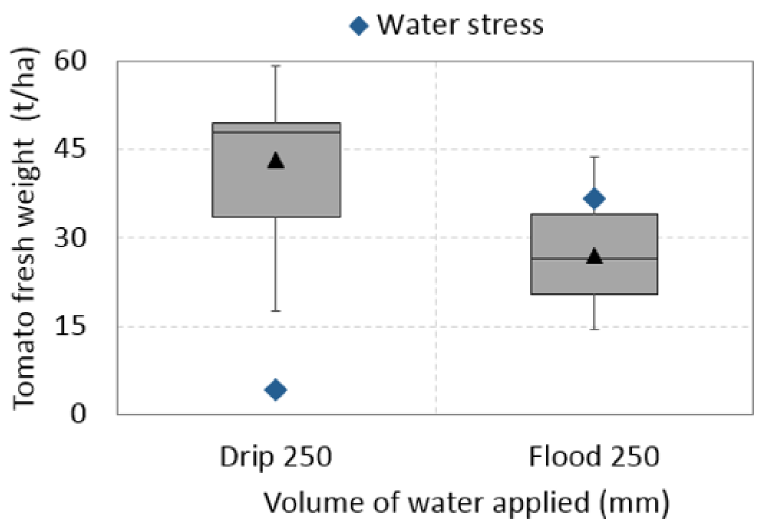
Flood (furrow) vs. drip irrigation on tomato yield

- Drip irrigation improves crop water productivity, while
- Flood irrigation causes water loss as depicted with higher surface runoff and percolation at field level.

Worqlul et al., 2017. Gap and constraint analysis in Robit ….

Optimizing water use efficiency

Crop yield and water stress days of drip and flood irrigation



Drip irrigation vs. flood irrigation effect on tomato yield

- For the same amount of irrigation, drip irrigation can increase yield by 60% (i.e. 43 ton/ha with drip vs 27 ton/ha with flood irrigation).

Worqlul et al., 2017. Gap and constraint analysis in Robit ….

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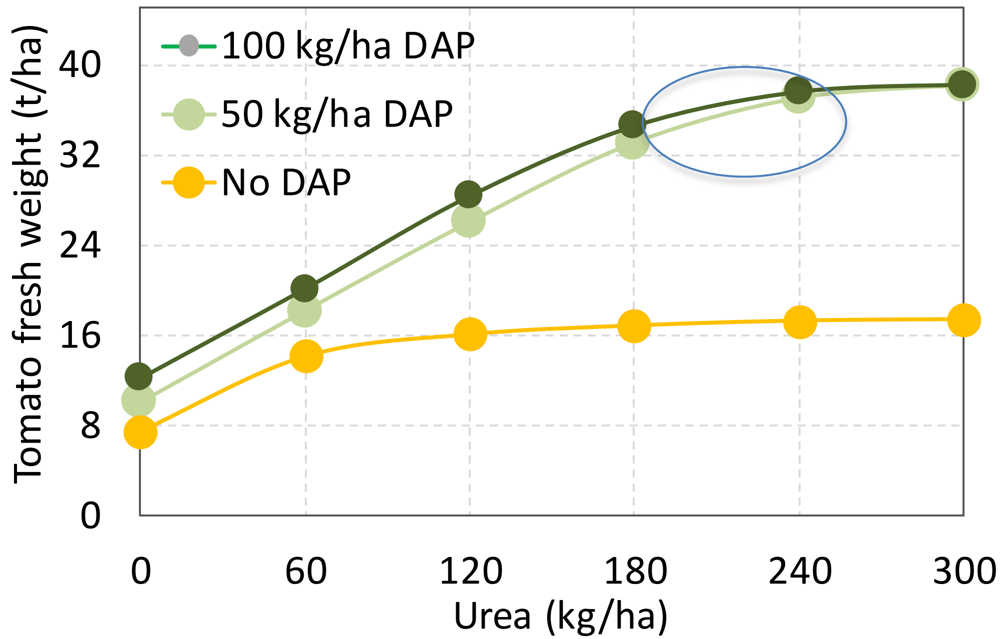
Fertilizer use efficiency of tomato Robit

Fertilizer use plan

	0/0	60/0	120/0	180/0	240/0	300/0
Urea	0	60	120	180	240	300
DAP	0					
Urea	0	60	120	180	240	300
DAP	50					
Urea	0	60	120	180	240	300
DAP	100					

Urea (NPK 46-0-0) and DAP (NPK 18-46-0)



Fertilizer use efficiency of tomato in Robit watershed

Optimal fertilizer use:

- 200 to 250 kg/ha Urea with 50 to 100 kg/ha DAP
- Farmers applied 100 to 200 kg/ha DAP with 200 to 400 kg/ha urea

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Worqlul et al., 2017. Gap and constraint analysis in Robit ….

FARMSIM: Robit kebele-Ethiopia

- Field data collected in 2015 & 2016 by IWMI-IFPRI used to specify irrigation scenarios
- Baseline and alternative scenarios differ only on input costs and yields for irrigated crops (grains input & yields were kept constant)
- Simulation of profitability & nutrition with rain-fed grain crops, irrigated vegetables and fodder

Scenario description

Baseline conditions: Baseline: No or minimal irrigation;

Alt. Scen400-550mm:	Alt.1--P-OI: Pulley used in optimally irrigated systems (400-550 mm)	WLT technology
Alt. Scen400-550mm:	Alt.2--R&W-OI: Rope & Washer pump used in optimally irrigated systems;	
Alt. Scen100mm:	Alt.3--P-UI: Pulley used in under-irrigated systems (100 mm)	Irrigation technology & constraints
Alt. Scen250mm:	Alt.4--P-GW: Pulley used in irrigated systems with groundwater (GW) only;	
Alt. Scen250&Drip:	Alt.5--P_Drip-GW-: Pulley used in drip-irrigated systems with GW only;	
Alt. Scen250&Furrow:	Alt.6--P_Furrow-GW: Pulley used in furrow-irrigated systems with GW only;	
Alt. ScenFert_Low:	Alt.7--P-OI&LF: Pulley used in Optimally irrigated & low fertilized systems;	Fertilizer technology & constraints
Alt. ScenFert_High:	Alt.8--P-OI&HF: Pulley used in Optimally irrigated & high fertilized systems;	

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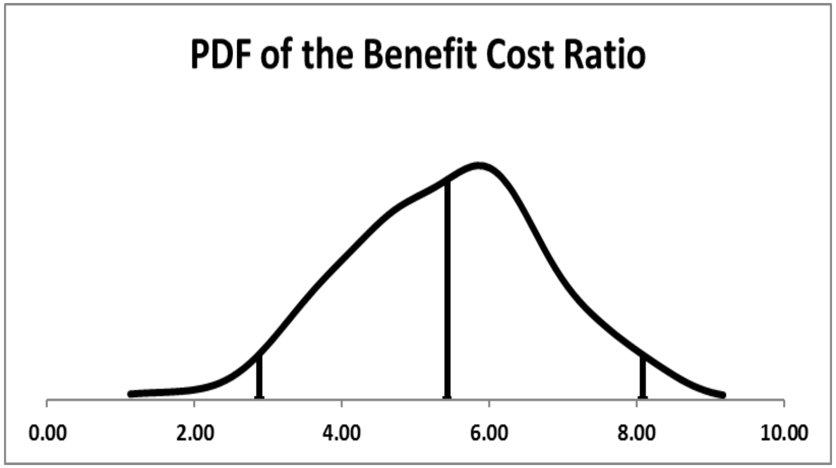
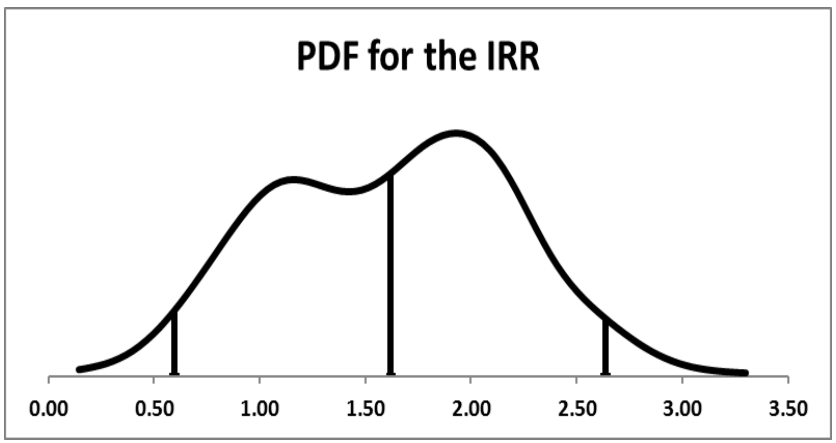
Profitability of SSI: Cost-Benefit analysis (B/C ratio and IRR)





- Probability distribution of benefit-cost ratio (Alt. 1-Pulley/Baseline)
- Profitability of irrigation technologies requires: B/C > 1
- **Avg. B/C** = 5**.3 and probability of B/C > 1 is 100%**

- Probability distribution of internal rate of return-IRR (Alt. 1-Pulley/Baseline)
- Profitability of irrigation technologies requires: IRR > Discount rate (0.10)
- **Avg. IRR** = 1**60% and probability of IRR > 0.1 is 100%**

Conclusion: SSI-Pulley use is profitable

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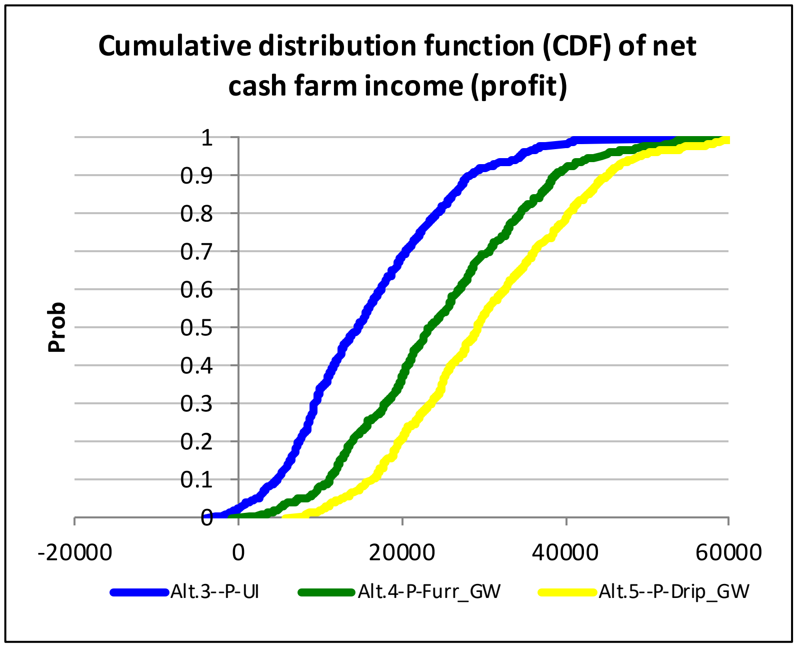
Constraint analysis: SSI technology



- Constraint: insufficient groundwater in Robit (250mm) to satisfy irrigation needs

*Optimal irrig. conditions require 400-550 mm

- Comparison of profit and ranking of 3 alternative scenarios under limited available groundwater (GW) for irrigation (100 and 250 mm)
- Alternative scenario (Alt. 5) using drip irrigation is more profitable and efficient in drought or limited water availability
- Lowest ranking and least profitable alternative scenario is Alt. 3 that uses furrow irrigation in extremely dry conditions (100 mm available only)

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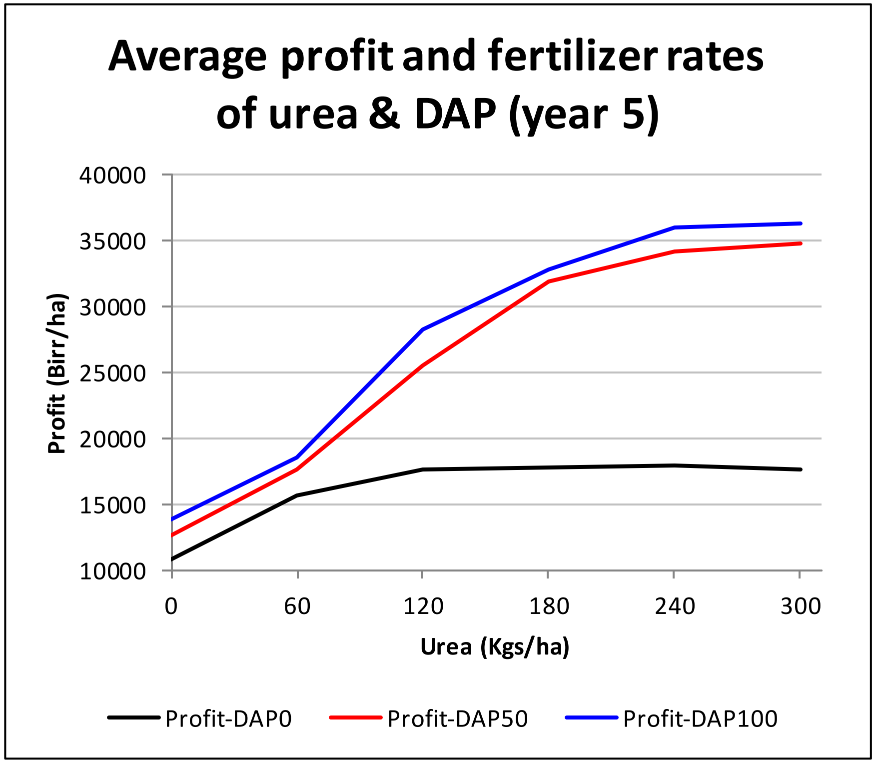
Constraint analysis: fertilizer technology



- Comparison of profit for tomato production using 18 fertilizer scenarios combining urea and DAP rates from APEX model:

  *3 levels of DAP: 0, 50, and 100 (Kgs/ha)
  *6 levels of urea: 0, 60, 120, 180, 240 and 300 (kgs/ha)

- Simulation results show profitability for a combination of DAP : 50-100 Kgs/ha and urea: 240-300 Kgs/ha (field trial rates)

- Least profitable scenarios involve the use of urea only (no DAP) for tomato production

Conclusions and implications of ex-post and gaps/constraint analysis

- Farm simulation results show profitability of using a pulley for vegetable/fodder irrigation
- Drip irrigation showed higher profitability (and efficiency) in dry conditions compared to furrow irrigation
- Economic profitability of SSI technologies when optimal rates of urea and DAP are used
- Nutrition results showed improvement of quantity intake from baseline to alternative scenarios and met the minimum daily requirement except for fat and calcium

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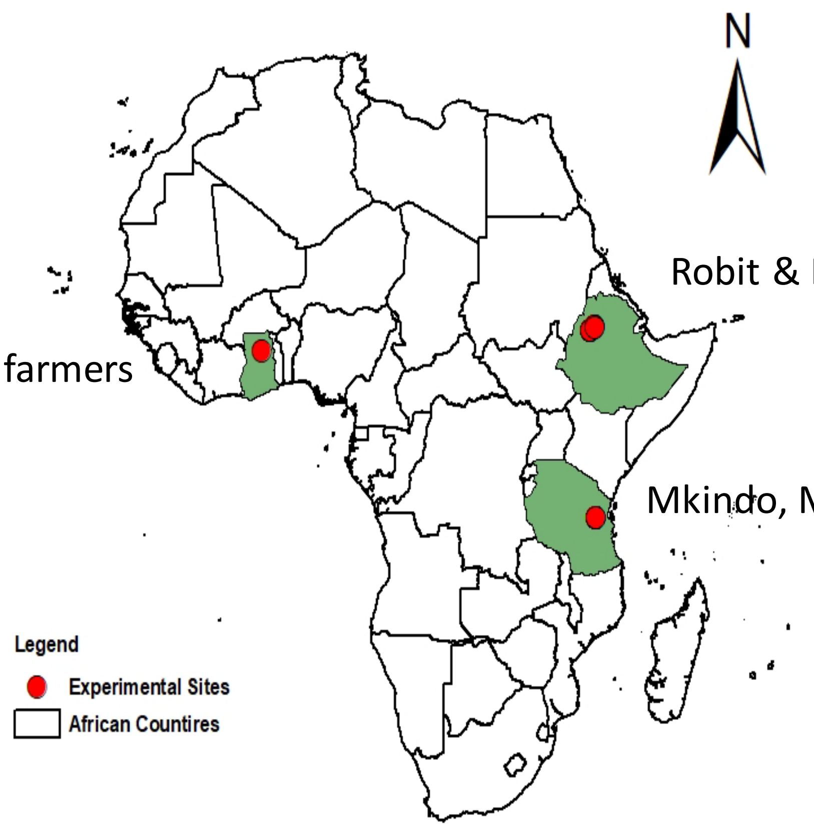
Commercial Vegetable Home Gardens (CVHGs)

CA: Conservation Agriculture
CT: Conventional Tillage



Each Farmer:
- 50 m^2 CA plot
- 50 m^2 CT plot

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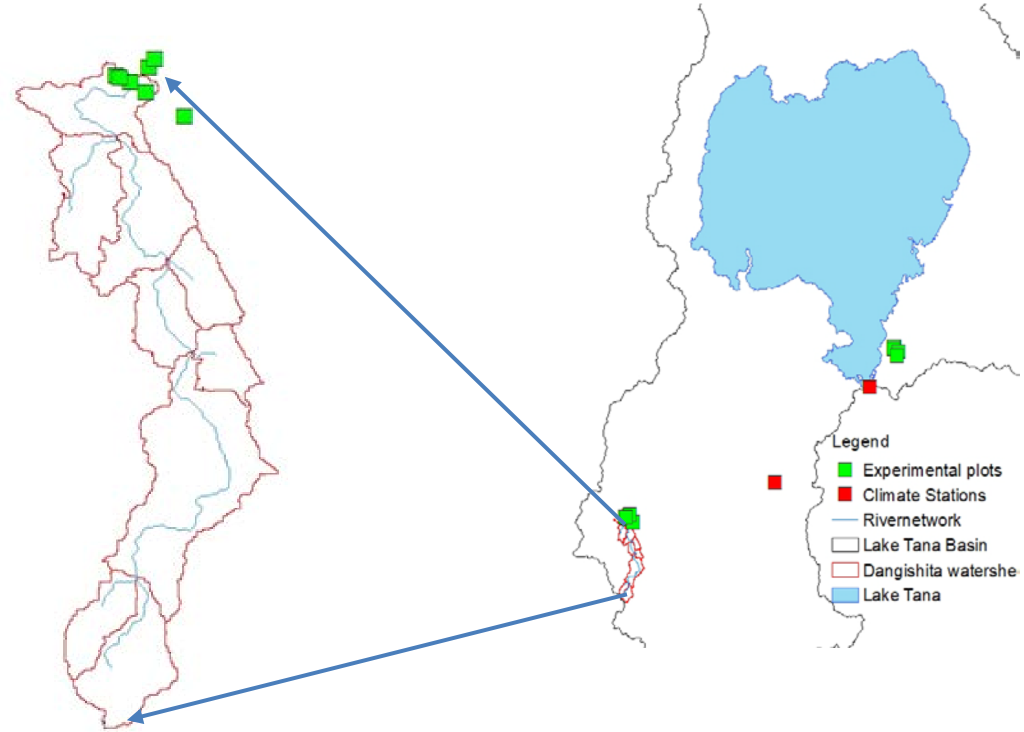
APEX model setup – Dangishita Watershed (Ethiopia)



User defined plot (50 m^2) → GIS data layers preprocessing → Input climatic data → Integrate operation schedule

Summary findings – CVHGs under CA

- APEX simulated stream flow with reasonable performance measures at Dangishita, Ethiopia (NSE = 0.64, RSR = 0.21, PBIAS = 6%)
- Evapotranspiration was found to decrease under CA (Dangishita 5%; Robit 7%; and, Mkindo 3%) as compared to CT
- Runoff was found to decrease in Ethiopia under CA (Dangishita 4% and Robit 1%)
- APEX simulated lower yield under CA in Dangishita, Robit and Mkindo due to higher nitrogen stress
- Continuity of Work:
    - Collect two more season of data at all sites (2017-2018)
    - Calibrate/validate APEX model for crop yield
    - Assessing large-scale and long-term impacts of CA practice in CVHGs

UPSCALING ANALYSIS, WHY?

- ILSSI's field, ex-ante and ex-post studies as well as other research has shown that small scale irrigation provides an opportunity for dry season cultivation to generate additional income. The main questions though are:
  - What is the appropriate scale of investment?
  - Where are those locations with high investment potential? and
  - What are the environmental and socio-economic impacts?

- Upscaling helps to assess the potential for expanding small scale irrigation.
- It also helps to study the impacts of intensification of small scale irrigation on crop production, environmental sustainability, and economic and nutrition outcomes.

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Upscaling analysis

- Suitability analysis
- SWAT modeling
- Agent-Based Model (ABM)

Studied crops include: tomatoes, cabbages, peppers, chickpeas, lentils and fodder

Dile et al., 2017. Upscaling methodological report…

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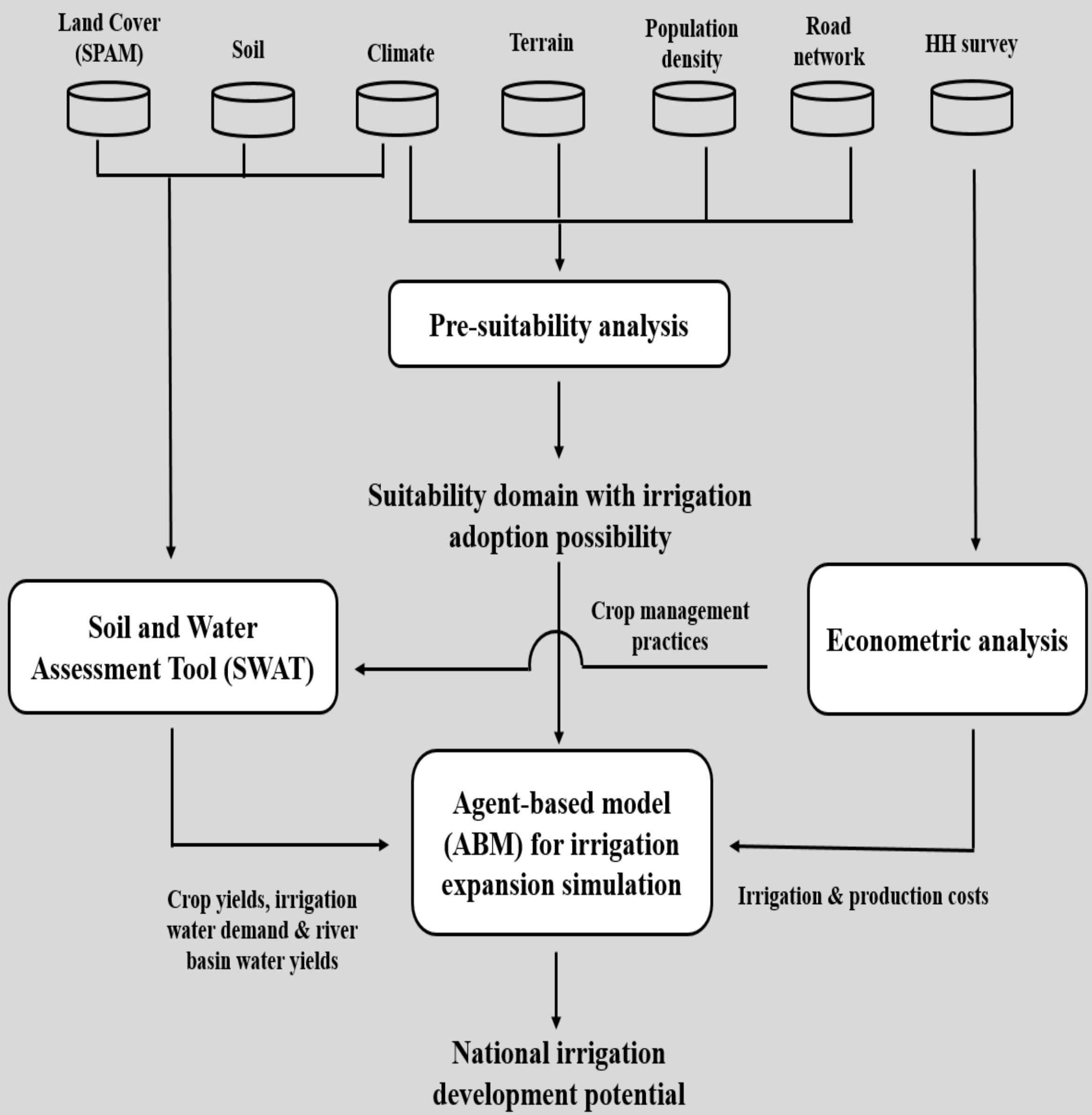
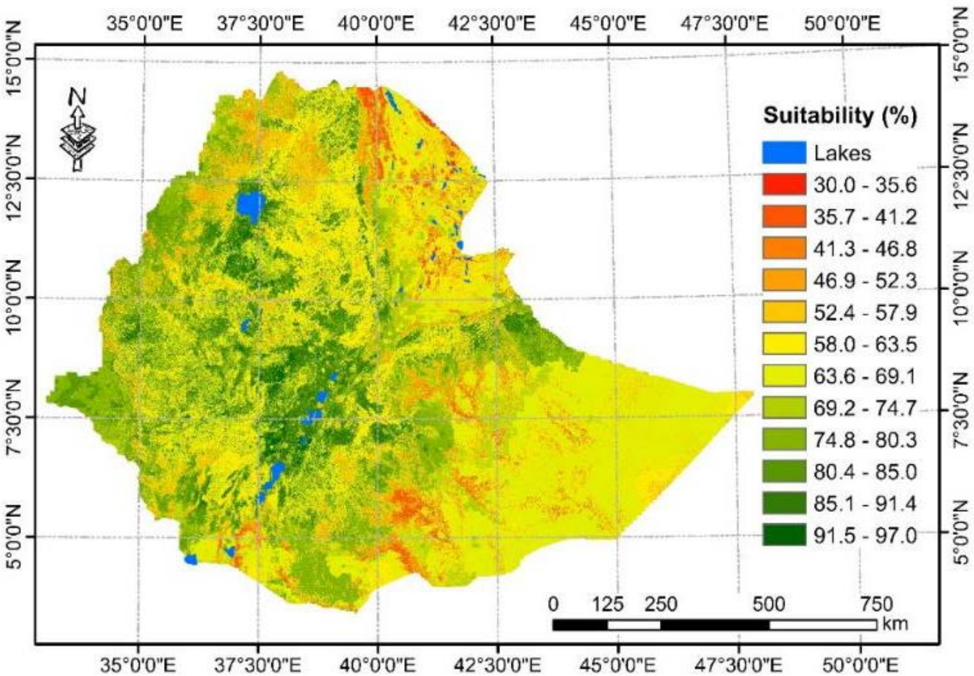
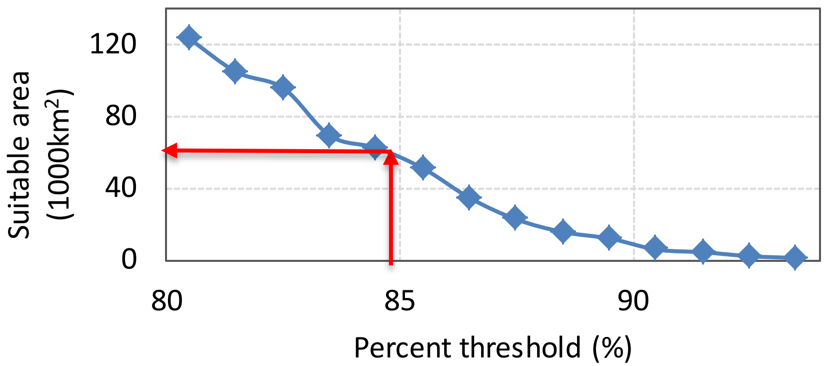
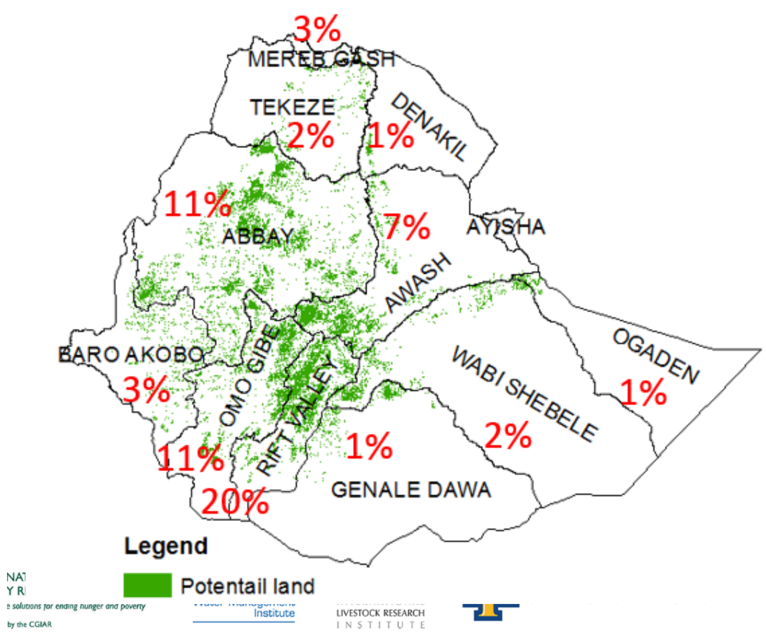


Preliminary suitable irrigable land in Ethiopia



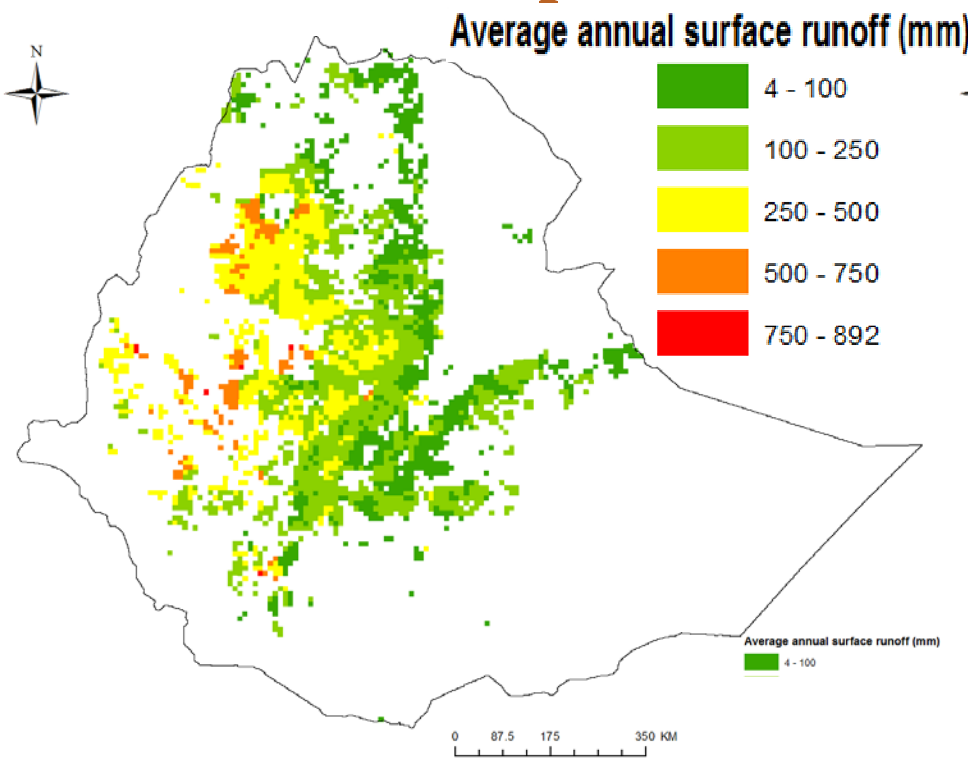


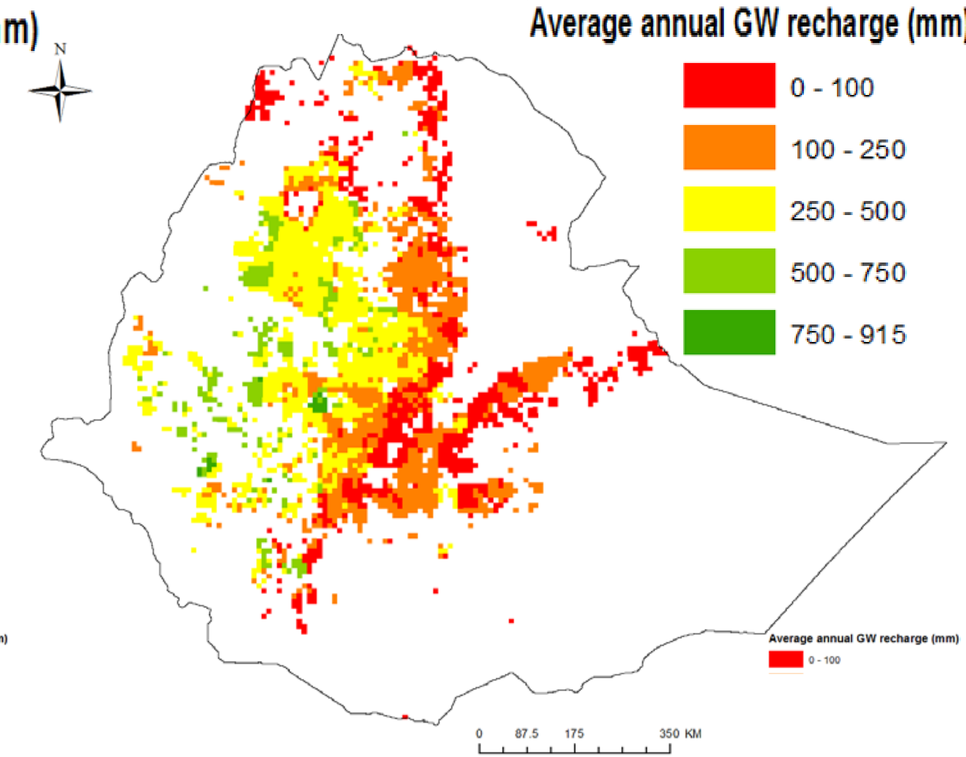


- 12 % rainfed land (6.0 M ha) is found to be suitable with the preliminary suitability analysis.

Worqlul et al., 2017….Land Suitability Analysis in Ethiopia.

Water resources potential

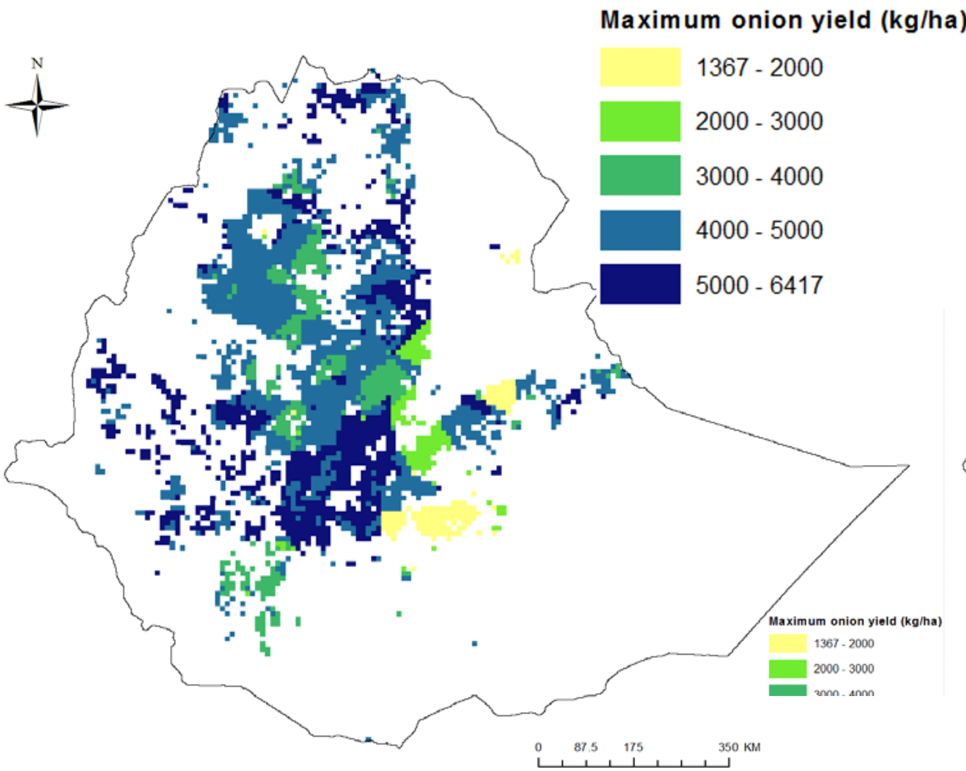


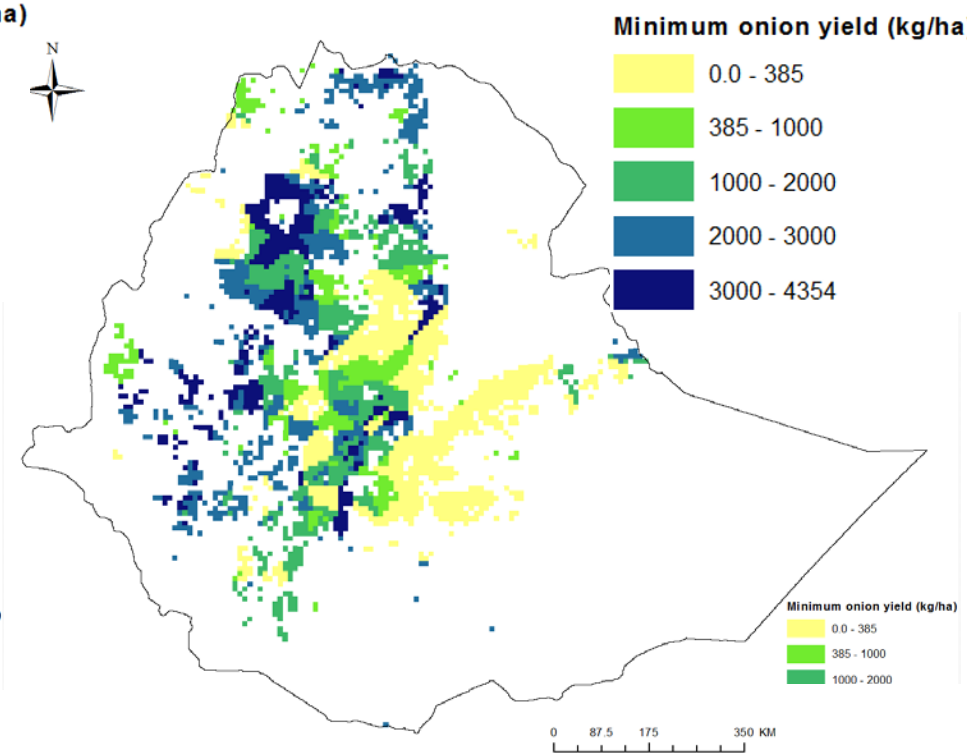


- The average annual surface runoff ranges b/n 4 mm (in arid regions) to 892 mm (in humid regions) across the country.
- The annual average groundwater recharge ranges b/n 0 mm (in arid regions) to 915 mm (in humid regions) across the country

Dile et al., 2017. Upscaling methodological report…

Potential for vegetable production

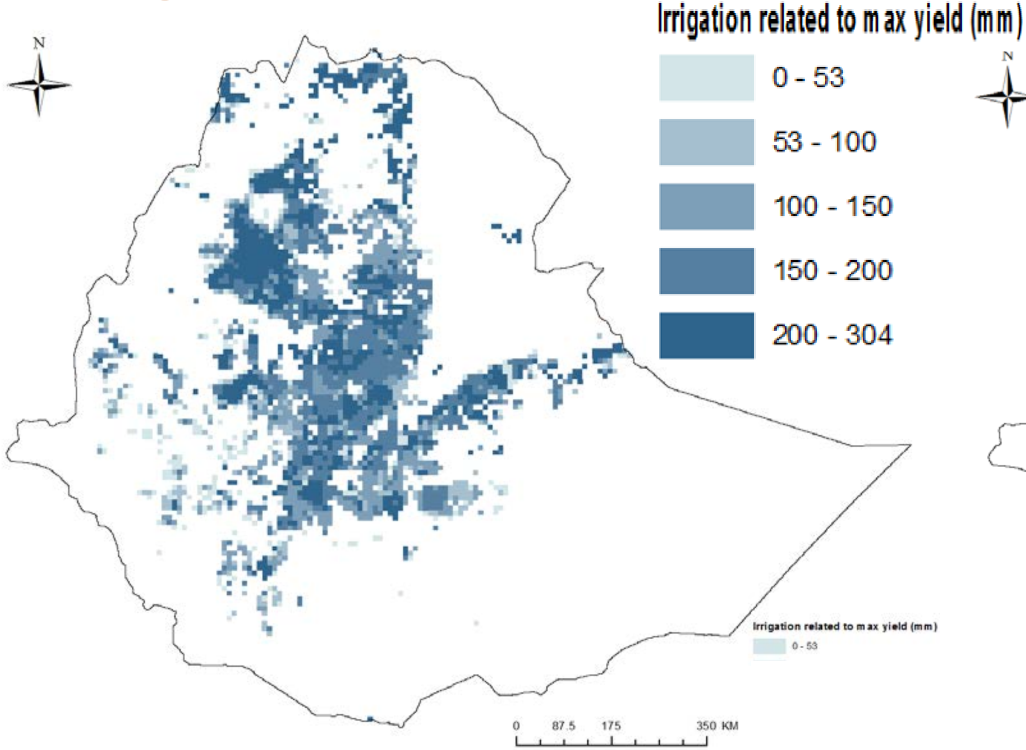


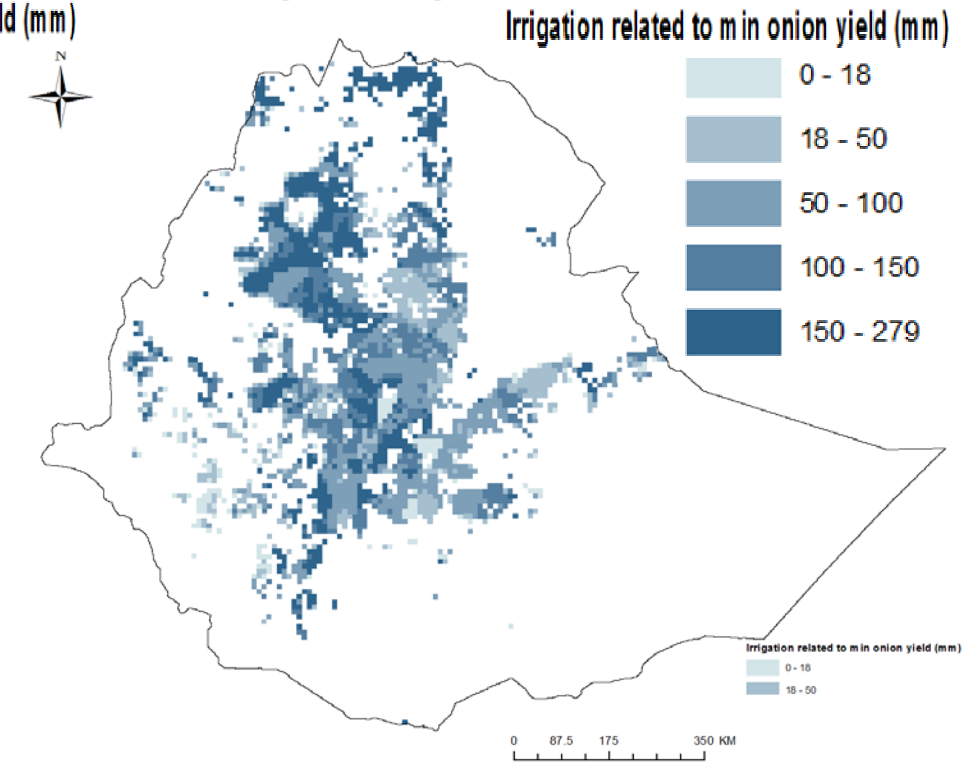


- During good climatic years, onion yield b/n 1,367 kg/ha and 6,417 kg/ha can be produced across Ethiopia.
- During bad climatic years, onion yield of b/n <385 kg/ha and 4,354 kg/ha can be produced across Ethiopia.

 Dile et al., 2017. Upscaling methodological report…

Irrigation for dry season cropping (e.g. onion)





- Irrigation water requirement during the dry season to cultivate onion ranges b/n <53 mm and 304 mm during high yielding seasons (across the country).
- Irrigation water requirement during the dry season to cultivate onion ranges b/n <18 mm and 279 mm during high yielding seasons (across the country)

Dile et al., 2017. Upscaling methodological report…

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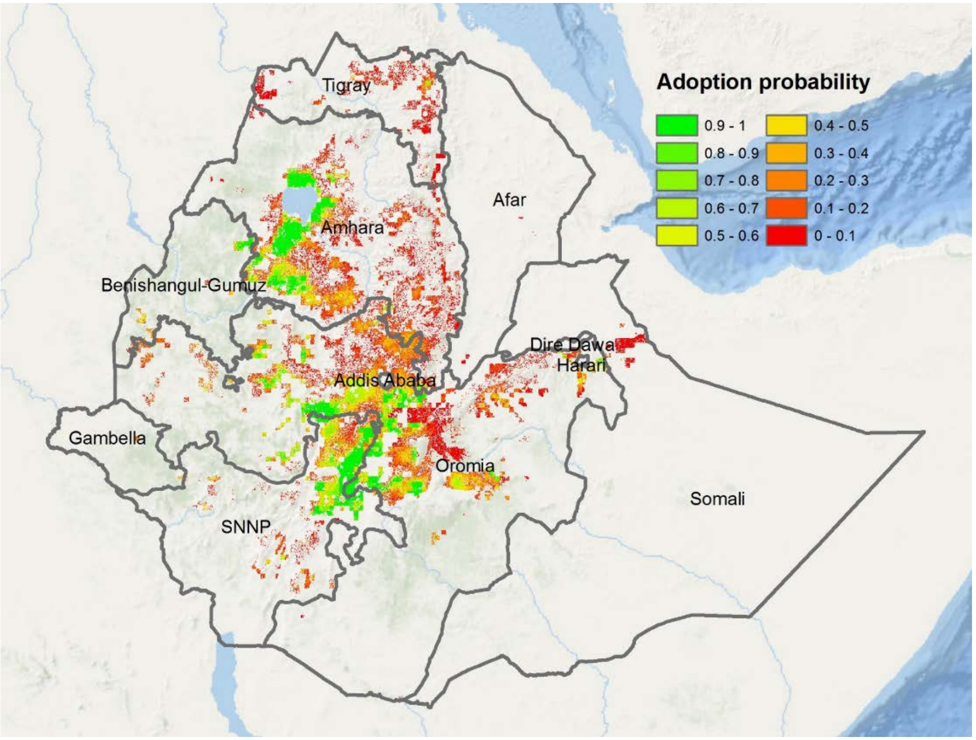
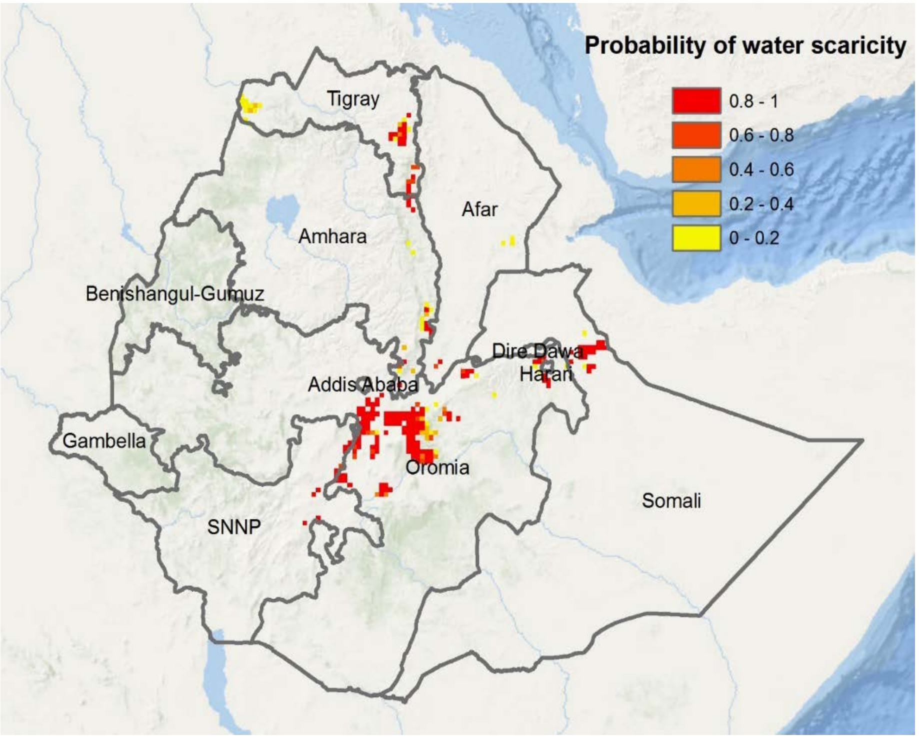
Probability of irrigation adoption and water scarcity





- The Ethiopian Great Rift Valley and Lake Tana areas are region found to be the regions with highest adoption probability for small scale irrigation.
- At the same time, small scale irrigation development may pose water scarcity in the Great Rift Valley.

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Dile et al., 2017. Upscaling methodological report…

Estimated small-scale irrigation adoption potential in Ethiopia

Regions (ha)	Vegetables (ha)	Pulses & Root crops (ha)	Total (ha)	Net revenue (million USD/yr)	Number of beneficiaries
Affar	55	0	55	0.015	312
Amhara	200,068	118,102	318,170	92	1,802,963
Benishangul-Gumuz	11,182	419	11,601	2.6	65,739
Gambella	320	9	329	0.12	1,864
Harari	194	398	592	0.13	3,355
SNNP	87,942	41,111	129,053	50	731,300
Tigray	9,847	457	10,304	3.2	58,389
Oromiya	179,885	150,908	330,793	101	1,874,494
Somali	413	83	496	0.4	2,811
Total	489,905	311,487	801,392	249.5	4,541,221

- About **0.8** million ha of land is **economically and biophysically** suitable for small-scale irrigation development in Ethiopia - **0.5 million ha** will be used for **vegetable production** and **0.3 million ha** will be used for **pulse and root crop production**.
- The net income from the small scale irrigation adoption will be **~250 million USD/year**.
- Amhara, Oromia and SNNPR have the highest small scale irrigation adoption potential.

Dile et al., 2017. Upscaling methodological report…

Outputs

- Several reports have been produced using IDSS tools - individual model per site reports, integrated site reports, and country reports for the three ILSSI countries.
- Several raw or processed data were generated and shared to partners, such as:
  - Groundwater depth,
  - Digital Elevation Model (DEM void-filled),
  - High-resolution soil and land use, and
  - Potential land suitability for small-scale irrigation (SSI)
- Tools and models
  - SWAT/APEX/FARMSIM models,
  - Land suitability mapping tool, and
  - Weather data bias correction tool

Outcome

- IDSS showed that the source of the water, and the most profitable technologies were different in each site and country, e.g.
  - Solar pumps are found to be economical and workable.
  - Labor was the major limitation on using low cost technology.
- Increased use of nutrients together with irrigation substantially improved agricultural production thereby providing a higher economic dividend.
- IDSS analysis showed that environmental impacts of SSI were minimal to modest as the interventions were implemented only on most suitable areas for irrigation – a fraction of watershed area.
- IDSS analysis was critical to identify strategies to mitigate gaps and constraints of SSI.
- Upscaling showed promising results in terms of potential expansion/intensification, adoption and economic profit.
- More in depth small scale irrigation options need to be investigated such as water harvesting, ponds/tanks for communal irrigation.

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PUBLICATIONS

PEER-REVIEWED

1. Abeyou Worqlul, Jaehak Jeong, **Yihun Taddele Dile**, Javier Osorio, Petra Schmitter, Tom Gerik, R Srinivasan, and Neville Clark. Assessing potential land suitable for surface irrigation using groundwater in Ethiopia. **Applied Geography** 85 (2017) 1-13.
2. Prasad Daggupati, Raghavan Srinivasan, **Yihun Taddele Dile**, Deepa Varma. Reconstructing the historical water regime of the contributing basins to the Hawizeh marsh: Implications of water control structures. Science of the Total Environment. Volume 580, 15 February 2017, Pages 832–845.
3. **Yihun Taddele Dile**, Prasad Daggupati, Chris George, R. Srinivasan, and Jeff Arnold, 2016. QSWAT: Introducing a New Open Source GIS User Interface for the SWAT Model. **Environmental Modeling and Software**. 85 (2016) 129-138. doi.org/10.1016/j.envsoft.2016.08.004
4. Neville Clark, Jean-Claude Bizimana, **Yihun Dile**, Abeyou Worqlul, Javier Osorio, Brian Herbst, James W.Richardson, Raghavan Srinivasan, Thomas J. Gerik, Jimmy Williams, Charles A. Jones, Jaehak Jeong, 2016. Evaluation of New Farming Technologies in Ethiopia using the Integrated Decision Support System (IDSS). **Agricultural Water Management**, http://dx.doi.org/10.1016/j.agwat.2016.07.023

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2. Jean-Claude Bizimana, Neville P. Clarke, **Yihun T. Dile**, Thomas J. Gerik, Jaehak Jeong, Javier M. Osorio Leyton, James W. Richardson, Raghavan Srinivasan, and Abeyou W. Worqlul. 2016. *Ex Ante* Analysis of Small-Scale Irrigation Interventions in Bihinaayili, Ghana.
3. Jean-Claude Bizimana, Neville P. Clarke, **Yihun T. Dile**, Thomas J. Gerik, Jaehak Jeong, Javier M. Osorio Leyton, James W. Richardson, Raghavan Srinivasan, and Abeyou W. Worqlul. 2016. *Ex Ante* Analysis of Small-Scale Irrigation Interventions in Nimbasinia, Ghana.
4. Jean-Claude Bizimana, Neville P. Clarke, Yihun T. Dile, Thomas J. Gerik, Jaehak Jeong, Javier M. Osorio Leyton, James W. Richardson, Raghavan Srinivasan, and Abeyou W. Worqlul. 2016. *Ex Ante* Analysis of Small-Scale Irrigation Interventions in Zanlerigu, Ghana.
5. Jean-Claude Bizimana, Neville P. Clarke, Yihun T. Dile, Thomas J. Gerik, Jaehak Jeong, Javier M. Osorio Leyton, James W. Richardson, Raghavan Srinivasan, and Abeyou W. Worqlul. 2015. Small-Scale Irrigation Applications for Smallholder Farmers in Tanzania: Ex Ante Analysis of Options.
6. Jean-Claude Bizimana, Neville P. Clarke, **Yihun T. Dile**, Thomas J. Gerik, Jaehak Jeong, Javier M. Osorio Leyton, James W. Richardson, Raghavan Srinivasan, and Abeyou W. Worqlul. 2015. *Ex Ante* Analysis of Small-Scale Irrigation Interventions in Babati, Tanzania.
7. Jean-Claude Bizimana, Neville P. Clarke, **Yihun T. Dile**, Thomas J. Gerik, Jaehak Jeong, Javier M. Osorio Leyton, James W. Richardson, Raghavan Srinivasan, and Abeyou W. Worqlul. 2015. *Ex Ante* Analysis of Small-Scale Irrigation Interventions in Mkindo, Tanzania.
8. Jean-Claude Bizimana, Neville P. Clarke, **Yihun T. Dile**, Thomas J. Gerik, Jaehak Jeong, Javier M. Osorio Leyton, James W. Richardson, Raghavan Srinivasan, and Abeyou W. Worqlul. 2015. *Ex Ante* Analysis of Small-Scale Irrigation Interventions in Kilosa, Tanzania.
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12. Jean-Claude Bizimana, Neville P. Clarke, **Yihun T. Dile**, Thomas J. Gerik, Jaehak Jeong, Javier M. Osorio Leyton, James W. Richardson, Raghavan Srinivasan, and Abeyou W. Worqlul. 2015. Ex Ante Analysis of Small-Scale Irrigation Interventions in Dangila, Ethiopia.
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20. Worqlul, A. W., Jeong, J., Dile, Y. T., Osorio, J., Schmitter, P., Gerik, T., Srinivasan, R., & Clarke Neville. (2017). Assessing potential land suitable for surface irrigation using groundwater in Ethiopia. Applied Geography, 85, 1-13.

Thank you! & Questions?