Is Irrigation in Northern Ghana a Good Adaptation Strategy to Climate Change: A CGE-W Study

Arthur Gueneau (IFPRI) and Sherman Robinson (IFPRI)

Introduction

Despite the more than twenty years of rapid economic growth in Ghana, the historical North-South divide in standards of living has widened. The proportion of the population of the North living below the poverty line has increased. The Northern region of Ghana, which is sparsely populated, is considerable poorer that the areas closer to the coast. This region is poorly endowed with natural resources, lacks key infrastructure, and is subject to periods of floods and droughts. Moreover, climate change is likely to impact the region heavily.

In this paper we analyze one of the proposed adaptation to climate change for Northern Ghana: expanding irrigation. This is part of the Government of Ghana national strategy which lead to the development of the Savannah Accelerated Development Initiative (SADI) "to promote sustainable development using the notion of a forested and green north to catalyze climate change reversal and improve livelihoods of the most vulnerable citizens in the area."[1]

To do so, we use a CGE-W framework (Robinson et al., 2013; 2014) combining a Computable General Equilibrium (CGE) model of Ghana and a water model of the White Volta river basin, which spans most of Northern Savannah area of Ghana. Using historic data on rainfall, temperature and inflows, we describe how climate variability influences the agricultural production in the Northern Savannah (defined here as Northern, Upper East and Upper West provinces) as well as the agricultural commodities terms of trade in Ghana. We then introduce irrigation in gradual steps, with or without storage capacity. Finally we analyze whether irrigating 10% of the currently cropped land is a valid climate adaptation scenario (as measured only on the benefit side, using agricultural GDP, rural income and terms of trade).

Detailed Methodology

The CGE-W model of Ghana consists of an annual economywide computable general equilibrium (CGE) simulation model, a water demand module, a water basin management model (the Regional Water System Model for the White Volta, RWSM-WV), and an associated water allocation model that allocates available water to crops based on the impact of water stress on crop yields and crop values (called water allocation and stress model or WASM). The water models all run on a monthly time step. A separate hydrology model calculates monthly precipitation and runoff to the river systems, given different climate scenarios. All the component models in this implementation of the CGE-W framework are coded in the General Algebraic Model System (GAMS), which allows for integrated solution of the suite of models. Figure 1 presents a schematic view of how the system of simulation models operates year by year. Below, we describe shortly how the models are linked; Robinson and Gueneau (2014) provides a more complete description for the case of Pakistan.

---

[1] Government of Ghana, Ministry of Food and Agriculture, http://mofa.gov.gh/site/?page_id=282

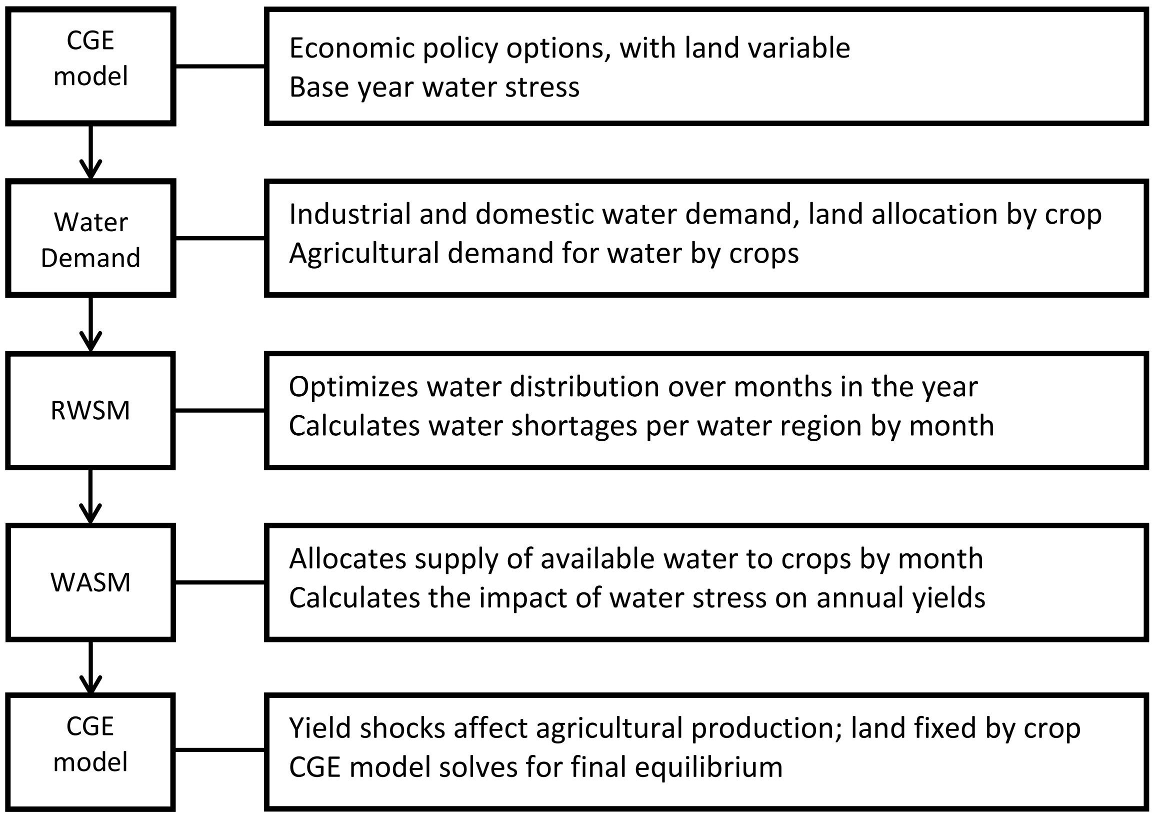

FIGURE 1. SCHEMATIC OF THE CGE-W FRAMEWORK

Each year the CGE model is run in a two-step procedure. It is first solved with average historical water stress to determine farmer decisions on cropping patterns based on expected water availability and economic trends. Then RWSM-Pak distributes actual inflows (provided by an external hydrology model, given climate information) to the different water areas of the Indus river basin, managing the reservoirs to maximize the share of demand for water that can be supplied. In each region, the water allocation module (WASM) then allocates available water to different crops based on the impact of water stress on yields and crop values. Finally, the CGE model is solved a second time given the yield shocks, but this time the allocation of land to crops is fixed and the model solves for the final values of all economic variables.

The CGE model

The CGE model includes agricultural detail that allows for a good representation of water shocks on the economy, as well as disaggregated labor and household categories to capture distributional impacts of policies. The 2005 Social Accounting Matrix (SAM) of Ghana developed by IFPRI (Breisinger et al., 2007) and disaggregated by agro-ecological zone by Diao (2010) includes 33 sectors of activity (including 21 agricultural sectors), 13 factors of production, and 9 household groups, allowing tracing of direct and indirect effects of potential scenarios through production and consumption linkages, including distributional effects. The agricultural sector includes nineteen crops in four regions (Coast, Forest, South Savannah and North Savannah). Land in the North Savannah (the region of interest for this study, composed of the Northern, Upper East and Upper West provinces) is divided between rainfed and land equipped for irrigation (which is currently marginal). Labor is also disaggregated in agriculture between own-farm farming in the different regions and unskilled farm labor (assumed to be somewhat mobile between regions). The model also takes into account non-agricultural unskilled and skilled workers.

The shock due to water stress is defined as the ratio of crop yields for the current year compared to the base year yield. The base year data define the equilibrium of the water system in 2007-2008 under an average weather pattern. In the first run of the CGE model in each year, the external water shock anticipated by farmers is assumed to be the average of the four previous years, so farmers anticipate a short-term running average level of water stress which allows for some adaptation. The CGE model then solves for the allocation of crops to irrigated and rainfed land based on these expectations.

The Water models

The Regional Water System Model (RWSM) relies on a node structure to distribute water across the river basin (or river basins if there are more than one relevant to the economy of the considered country). The model solves for monthly timesteps. At each node of the water system, the model performs a water balance between inflows, storage change (including net evaporation from the reservoir), withdrawals for consumption and spills to nodes downstream. Inflows can be of two natures: inflows spilled from a node upstream or runoff joining the river between the node(s) upstream and the current node.

RWSM distinguishes between agricultural and non-agricultural water demand. Agricultural water demand (or water demand for irrigation) is aggregated at the agro-economic zone scale. It is linearly related to the difference between potential evapo-transpiration and effective rainfall, using the FAO Kc approach (Allen et al., 1998). The inflows to the White Volta, as well as the runoff to each of the nodes of the river system come from a Water Evaluation And Planning System (WEAP) model developed by the Ghana Water Resource Commission. Climate data available to run this model spans nearly fifty years, so we have a good idea of the variability of the system. We further assume that groundwater pumping is negligible compared with the inflows in the White Volta River. Futhermore, we assume that small reservoirs in each zone can store water for up to a month of non-agricultural use, in case of a drought.

For every agro-ecological zone, total irrigation water demand is aggregated for all crops during the given timestep, taking into account the efficiency of the irrigation system. RWSM-WV calculates the solution so as to minimize the shortage of water for a given agro-economic zone as the difference between the aggregate demand and supply.

Water allocation is made through a module that takes into account yields and the value of crops. Water is allocated first to non-agricultural use then to agricultural uses. If there is a water shortage, yields are reduced according to the FAO Ky methodology (Doorenbos and Kassam, 1979). The model maximizes total profit given crop prices from the CGE model, although some inertia is introduced to preserve a balanced production in the area. Using this method we also calculate the difference in yields between rainfed (current production mode, water stressed) and irrigated production.

Impacts of Current Weather Variability

Using past weather data (1961 to 2002), we simulate the impact of different weather realizations on the 2008 year of the economy. This is controlled experiment as we only modify precipitations in the Northern region (still defined as the Northern, Upper East and Upper West provinces), and inflows in the

White Volta River basin, which is where all irrigation in the North is concentrated. This is thus a static experiment in terms of CGE modelling. Figure 2 shows how Agricultural GDP in Northern Ghana (measured in real value-added) varies with weather variability.

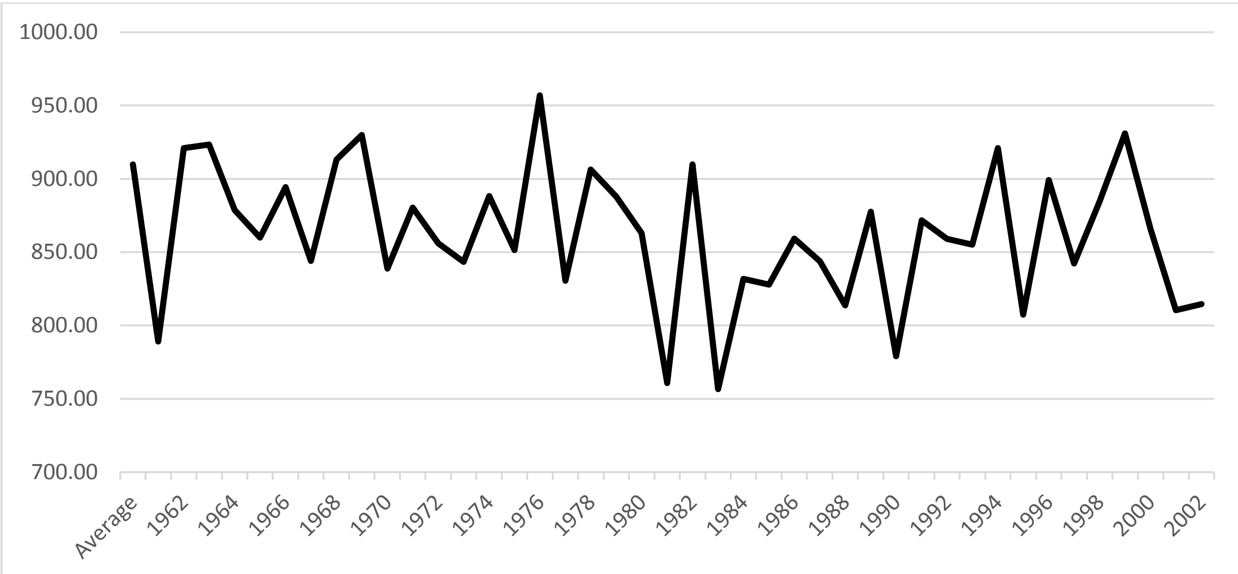

FIGURE 2. AGRICULTURAL GDP IN NORTHERN GHANA IN MILLION CEDIS OF 2008, AS SIMULATED BY CGE-W UNDER DIFFERENT WEATHER ASSUMPTIONS. THE FIRST VALUE IS AN AVERAGE WEATHER, THE FOLLOWING ARE REPRESENTATIVE OF YEARS 1961 THROUGH 2002.

Real agricultural GDP in Northern Ghana is extremely dependent to weather conditions. With a high of 950 million cedis and a low of 750 million cedis, the variability attains nearly 25%. This obviously has repercussions on the income of farmers. Using the household disaggregation of the SAM, we can plot in figure 3 the income of rural households in the Northern region.

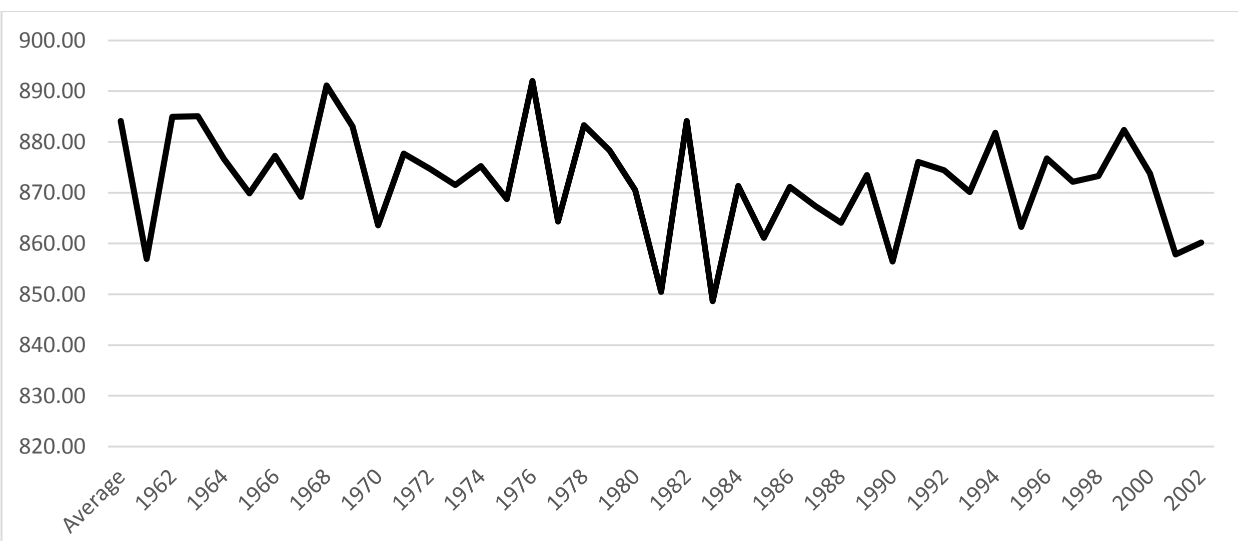

FIGURE 3. INCOME OF RURAL HOUSEHOLDS IN NORTHERN GHANA IN MILLION CEDIS OF 2008, AS SIMULATED BY CGE-W UNDER DIFFERENT WEATHER ASSUMPTIONS. THE FIRST VALUE IS AN AVERAGE WEATHER, THE FOLLOWING ARE REPRESENTATIVE OF YEARS 1961 THROUGH 2002.

The trends of rural income follow the same trends as the agricultural GDP. It is however smaller in magnitude as price effects compensate for the decrease in production. In figure 4 we plot the terms of trade for agriculture, that is the relative price of agricultural goods weighted by their baseyear production compared to the prices in the entire economy, also weighted by their baseyear production.

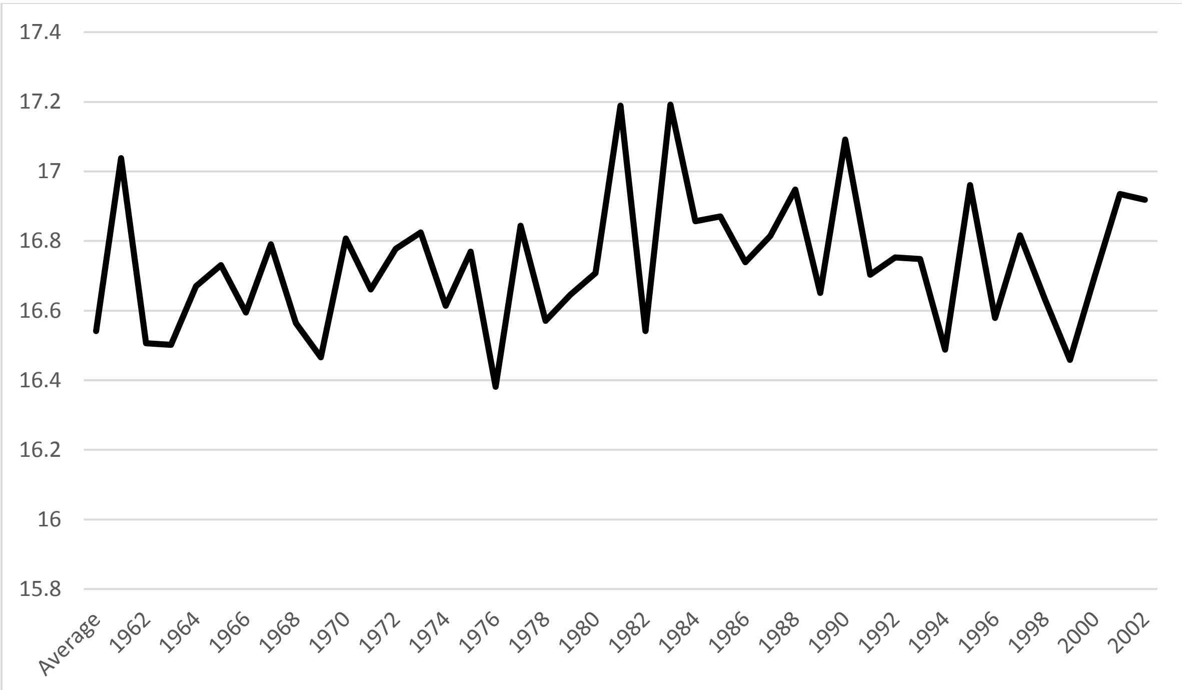

FIGURE 4. AGRICULTURAL TERMS OF TRADE IN PERCENT, AS SIMULATED BY CGE-W UNDER DIFFERENT WEATHER ASSUMPTIONS. THE FIRST VALUE IS AN AVERAGE WEATHER, THE FOLLOWING ARE REPRESENTATIVE OF YEARS 1961 THROUGH 2002.

As can be seen in the graph, the agricultural terms of trade can vary by as much as 5% in the entirety of Ghana (the commodity market in our CGE model is national) due to weather variability in the North only.

Weather variability is thus a serious issue for Northern Ghana, as agricultural GDP and rural income can vary a lot with rain and temperature. Moreover this is also an issue for the rest of Ghana, as agricultural commodity prices are linked to how the production in the Northern region.

Introducing Irrigation

To mitigate these impacts, it has been proposed to expand irrigation in the North (Namara et al., 2011; GIDA, 2013). The question is how much of this irrigation can be sustained by the water system. In this work we consider only surface water irrigation, and arbitrarily decide that all new irrigation will be situated in the Nawuni catchment, meaning it is able to draw water from the White Volta, the Red Volta, the Sisilli and the Kulpawn rivers.

No Added Storage Case

In this set of experiments we gradually increase irrigation from 0% of the currently cropped land in Northern Ghana to 45%, for all crops. We first do this without adding any storage to the system, while requiring that the outflow of the White Volta does not decrease by more than 25% (as it feeds into the Lake Volta and the critical Akosombo power plant). We display the results ranking the years in increasing order. Figure 5 describes the impact of installing irrigation by ranges of 5% until 45% on agricultural GDP in the North.

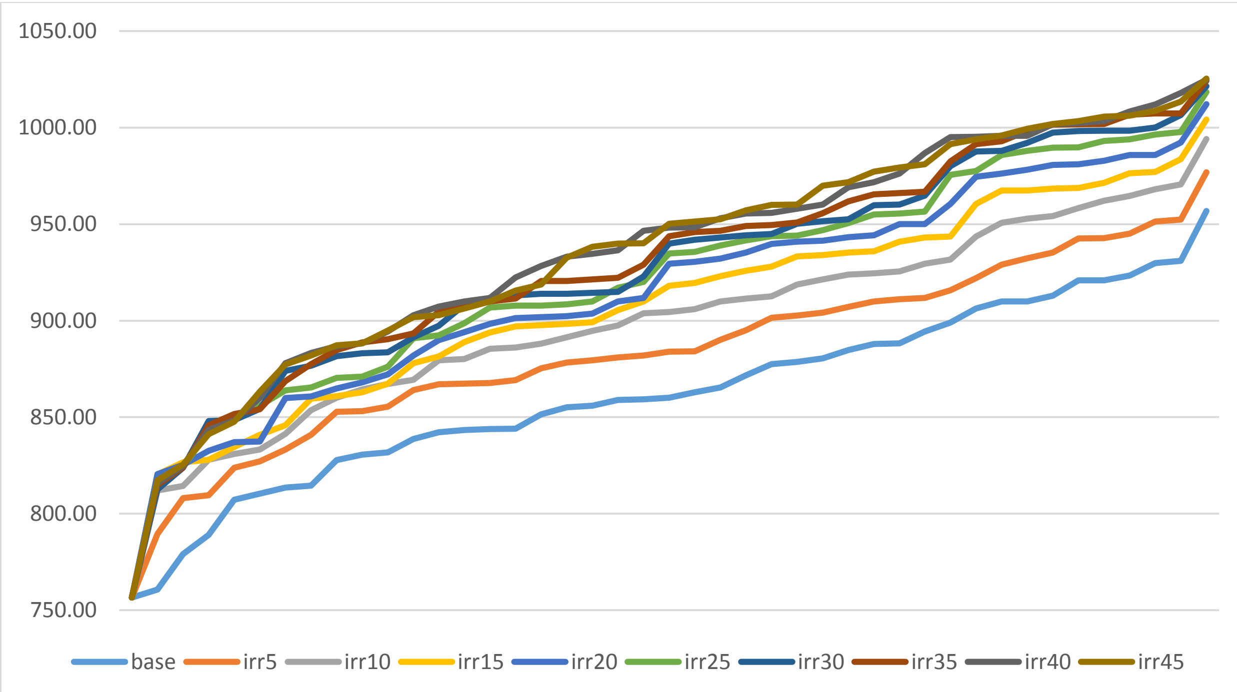

FIGURE 5. AGRICULTURAL GDP IN NORTHERN GHANA IN MILLION CEDIS OF 2008, AS SIMULATED BY CGE-W UNDER DIFFERENT WEATHER AND IRRIGATION GROWTH (BY INCREASING STEPS OF 5%) ASSUMPTIONS. THE VALUES ARE REPRESENTATIVE OF YEARS 1961 THROUGH 2002.

The benefits start leveling out with 20 to 25% of the land converted to irrigation. For 25% irrigation, the agricultural GDP of the Northern region increases on average by 7.1%. We also track the implications in terms of income for rural families. The graph obtained is entirely similar to the one obtained for the agricultural GDP. With 25% irrigation, income of rural households increase by 2.4%.

The levelling out of the benefits is due to the constraints on water withdrawals from the White Volta. Indeed there is no more water to be withdrawn during drier months. One remedial to this would be to build more storage capacity so crops can be irrigated year long.

Added Storage Case

To do this, we decide to implement the proposed Pwalugu dam, which is considered under the Ghana National Infrastructure Plan. Using data from the Government of Ghana website, the Pwalugu dam is estimated to have a live storage of 3260 million cubic meter (Johnston and McCartney, 2010). It is located upstream of the irrigation we are creating on the White Volta and Red Volta basin, though not on the Sisilli and Kulpawn rivers. RWSM takes into account net evaporation from the lake, and for this exercise we decide to run the dam to maximize irrigation benefits (although it is likely that electricity production would be a larger factor if the dam gets built).

We produce the same graph as previously with Pwalugu dam installed. Figure 6 shows the impact of installing irrigation by ranges of 5% until 45% on agricultural GDP in the North with Pwalugu dam.

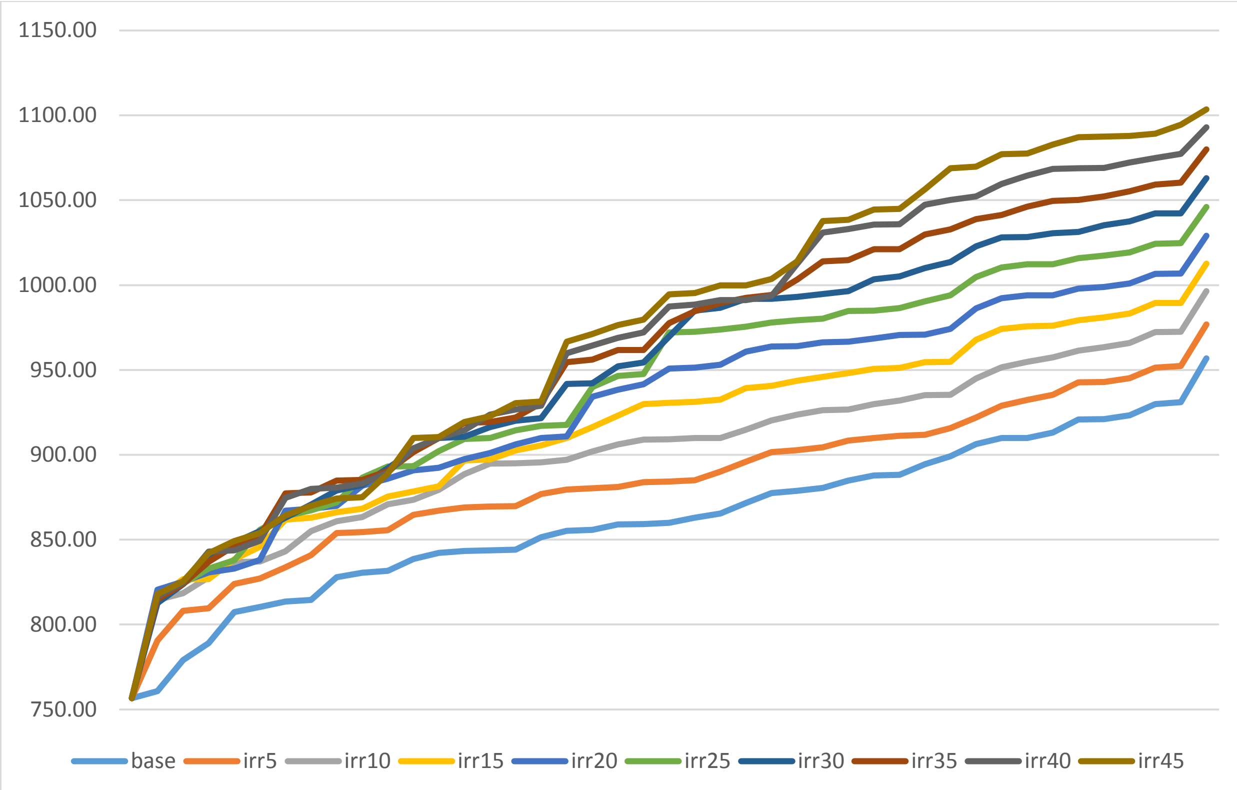

FIGURE 6. AGRICULTURAL GDP IN NORTHERN GHANA IN MILLION CEDIS OF 2008, AS SIMULATED BY CGE-W UNDER DIFFERENT WEATHER AND IRRIGATION GROWTH (BY INCREASING STEPS OF 5%) ASSUMPTIONS, ASSUMING PWALUGU DAM HAS BEEN BUILT. THE VALUES ARE REPRESENTATIVE OF YEARS 1961 THROUGH 2002.

It is evident that the dam makes a positive contribution to the agricultural GDP of the North. However, this contribution is only happening for more than 20% of irrigation developed and for the 50% wettest years. For example installing 45% of irrigation in this scenario, provides large benefits only in the 25% wettest years.

The income of rural household which had increased by 2.4% with 25% irrigation, increases by an extra 0.4% with the dam. However, the average rural income with 40% irrigation, which increased 2.6% without the dam, gains an extra 1%.

In conclusion, if cropping patterns stay the same, and there is no other efficiency improvement, increased large storage in the White Volta basin improves irrigation only for the wettest years. It actually starts to have a large effect when more than 25% of the current cropped area is irrigated.

An Effective Climate Change Adaptation Strategy

One of the main justifications for developing irrigation in Northern has been that it could be a good adaptation to a changing climate. To verify this, we shock the weather with extreme climate outcomes using downscaled climate data from the ISI-MIP project (Hempel et al., 2013). We use RCP 8.5 projections downscaled from four Global Circulation Models (HadGEM2-ES, GFDL-ESM2M, IPSL-CM5A-

LR and MIROC-ESM-CHEM, denoted HadGEM, GFDL, IPSL and MIROC for simplification for the rest of this paper). These downscaled values are run through a hydrology model, the IMPACT Global Hydrology Model (IGHM, described in Rosegrant et al., 2012) to get changes in evapotranspiration, runoff and river flow.

We use the projections from the year 2050 and apply the difference between 2050 and 2008 to the monthly evapotranspiration, rain, runoff and inflows (multiplicatively). The main climate driver that is impacting agricultural productivity is the rain deficit. Figure 7 shows the average monthly precipitation as modified by climate change models.

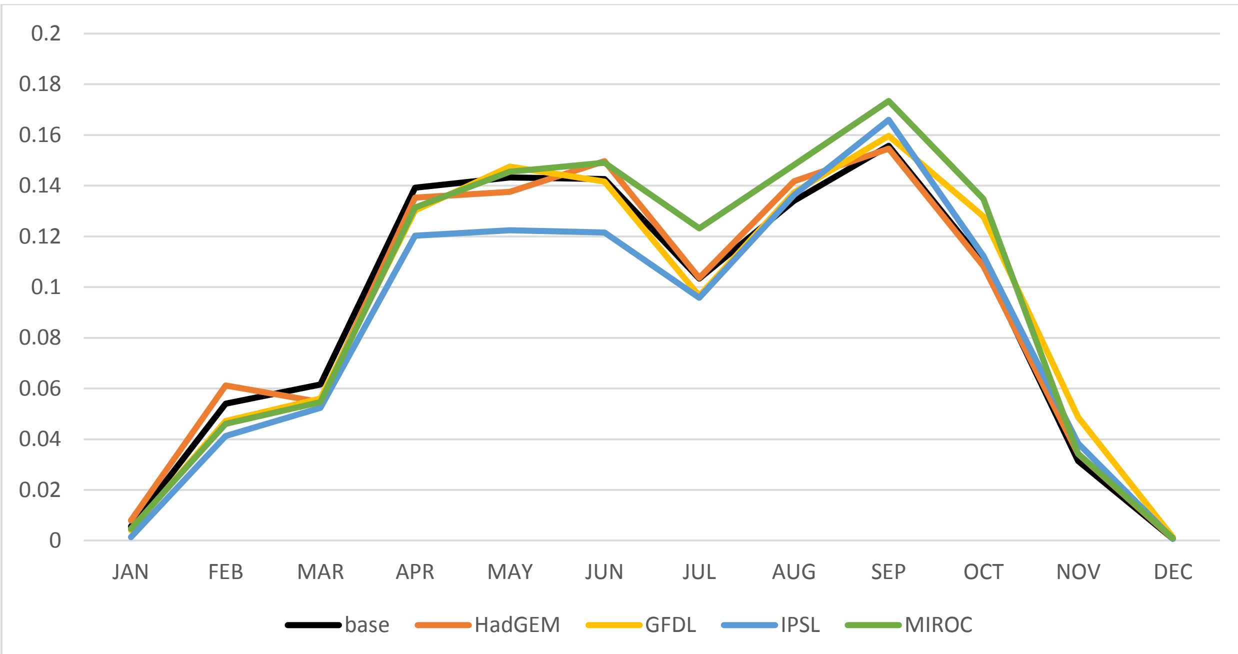

FIGURE 7. SIMULATED AVERAGE RAINFALL (IN MM) IN 2050 UNDER THE FOUR CLIMATE SCENARIOS. THESE ARE AVERAGED VALUES AFTER TREATMENT OVER THE 42 YEARS OF OUR SAMPLE.

In terms of rain, MIROC looks clearly beneficial while IPSL looks detrimental to the region. The other two scenarios, HadGEM and GFDL do not look as clear cut.

For this exercise we use a conversion of 10% of the cropped land to irrigation. This is large but not unrealistic, and as we showed in the previous section, adding or not storage does not affect its returns significantly. We choose here to add storage, as the dam is part of the National Infrastructure Plan, though we acknowledge overestimating the potential benefits. Figure 8 shows how climate change impacts the agricultural GDP of the Northern region both in the baseline and the 10% irrigated case.

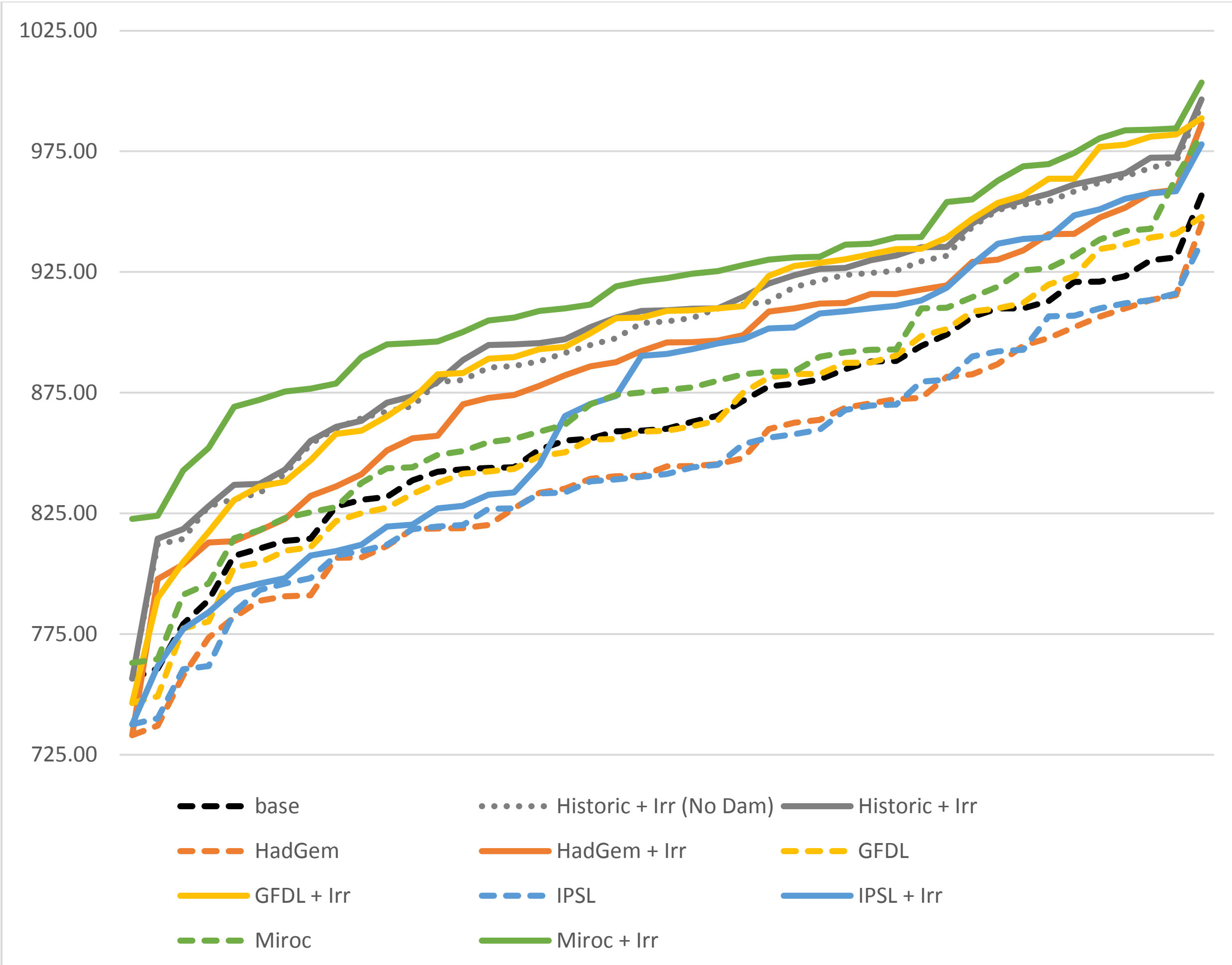

FIGURE 8. AGRICULTURAL GDP IN NORTHERN GHANA IN MILLION CEDIS OF 2008, AS SIMULATED BY CGE-W UNDER DIFFERENT WEATHER AND CLIMATE PATTERNS. THE VALUES ARE REPRESENTATIVE OF YEARS 1961 THROUGH 2002. DASHED LINES REPRESENT SCENARIOS WITHOUT IRRIGATION, THE DOTTED GREY LINE REPRESENT THE BASE SCENARIO WITH NO DAM, AND THE FULL LINES REPRESENT THE VALUES WITH IRRIGATION AND STORAGE.

As expected of the four GCM, only MIROC is beneficial to the region. GFDL is fairly neutral, while both HadGEM and IPSL reveal detrimental.[2] Also as the previous analysis showed, there is little difference between the storage scenario and the no-storage scenario, as can be evidenced by the base. This holds true for climate scenarios, even if it is not shown on the graph.

In the HadGEM case, adding 10% irrigation more than covers the detrimental effects of climate change. Actually after treatment, the end result becomes consistently better than the base at the exception of one exceptional drought year (all the way on the left in the graph). In the MIROC and GFDL case, both improve the outcome. However irrigation is relatively better against droughts under MIROC scenario, while under GFDL, the largest benefits occur under more average years. Finally in the IPSL scenario, benefits of the irrigation project are very small for the 30% driest years, which can be explained by the

[2] HadGEM being detrimental is explained by a higher evaporation, likely due to a higher temperature change in Northern Ghana than the other models.

fact that the IPSL model is the one that reduces runoff the most, leading to an absence of water to be pumped from the White Volta for irrigation, even with increased storage. For the 50% wettest years, it provides the same benefits as under the HadGEM scenario. Table 1 summarizes the impact of these different scenarios.

TABLE 1. AVERAGE CHANGE FROM THE BASE SCENARIO IN NORTHERN GHANA AGRICULTURAL GDP FOR DIFFERENT CLIMATE CHANGE AND IRRIGATION SCENARIOS. THE CHANGES ARE AVERAGED OVER 42 YEARS, REPRESENTATIVE OF THE YEARS 1961 THROUGH 2002.

Scenarios	Average Agricultural GDP change in Northern Ghana
Historic + Irr (No Dam)	4.4
Historic + Irr	4.8
HadGem	-2.2
HadGem + Irr	2.8
GFDL	-0.1
GFDL + Irr	4.7
IPSL	-2.1
IPSL + Irr	1.2
Miroc	1.2
Miroc + Irr	6.6

The irrigation investment is most beneficial under the MIROC scenario (+5.3%), which was expected as it has more benefits under a wettest weather. Conversely, it is at its worst under the IPSL scenario (+3.3% only). In short it is helpful to adapt to certain forms scenarios of climate change (ones with decreased rain but stable runoff) but not as much for others (ones with decreased precipitations and decreased runoff). Table 2 presents the effect of these on prices (measured by the agricultural terms of trade).

TABLE 2. AVERAGE TERMS OF TRADE AND CHANGE FROM THE BASE SCENARIO IN NORTHERN GHANA FOR DIFFERENT CLIMATE CHANGE AND IRRIGATION SCENARIOS. THE CHANGES ARE AVERAGED OVER 42 YEARS, REPRESENTATIVE OF THE YEARS 1961 THROUGH 2002.

Scenarios	Average Agricultural Terms of Trade	Difference from Base (in percent)
Historic	16.74	0
Historic + Irr (No Dam)	16.61	-0.77
Historic + Irr	16.60	-0.85
HadGem	16.82	0.45
HadGem + Irr	16.66	-0.46
GFDL	16.74	-0.02
GFDL + Irr	16.60	-0.85
IPSL	16.80	0.35
IPSL + Irr	16.70	-0.24
Miroc	16.72	-0.14
Miroc + Irr	16.53	-1.24

The effect of irrigation on terms of trade is exactly the opposite of the one on agricultural GDP, which is expected. This shows that not only Northern Ghana, but all of Ghana profits from expanding agriculture in the North.

Conclusion

CGE-W allows us to explore the impacts of expanding irrigation in Northern Ghana in detail, whether it is in the region itself, or in the rest of the country. The analysis shows that the region is very susceptible to weather variability, and that this variability has an impact on the entirety of the country. Introducing irrigation does not mitigate this variability, but it rises agricultural production across the board. Paired with expanded storage, the benefits increase in the wetter years, especially for larger amounts of irrigated land. Increased storage however does not improve significantly resilience to droughts, at constant irrigated area. Finally, different models show different results for the agricultural productivity of Northern Ghana, differing in sign. Irrigation is a good investment in most cases, as it raises agricultural productivity, rural income in the North and diminishes agricultural prices across Ghana. It however does not improve resilience to droughts under certain scenarios where runoff diminishes faster than rainfall.

Bibliography

Allen, Richard G., Luis S. Pereira, Dirk Raes, and Martin Smith. (1998) *Crop evapotranspiration-Guidelines for computing crop water requirements-FAO,* Irrigation and drainage paper 56. Food and Agricultural Organization (FAO), Rome, Italy.

Breisinger, Clemens, James Thurlow, and Magnus Duncan. (2007) *A 2005 Social Accounting Matrix (SAM) for Ghana*. Ghana Strategy Support Program (GSSP) Working Paper, International Food Policy Research Institute (IFPRI), Washington, D.C.

Diao, Xinshen. (2010) *Economic Importance of Agriculture for Sustainable Development and Poverty Reduction: Findings from a Case Study of Ghana*. Proceedings of the OECD Global Forum on Agriculture: November 29-30, 2010, Paris, France.

Doorenbos, J., and Kassam, A. H. (1979). *Yield Response to Water*, Irrigation and Drainage Paper, Food and Agricultural Organization (FAO), Rome, Italy.

Ghana Irrigation Development Agency (GIDA). (2013) *GIDA To Develop Irrigation Schemes In The North,* Ghana Government Portal, retrieved 04/09/2014 (http://www.ghana.gov.gh/index.php/2012-02-08-08-32-47/general-news/2267-ghana-irrigation-development-authority-to-develop-irrigation-schemes-in-the-north)

Hempel, Stephanie, K. Frieler, L. Warszawski, J. Schewe, and F. Piontek. (2013) "A trend-preserving bias correction-the ISI-MIP approach." *Earth System Dynamics* 4, no. 2.

Johnston, Robyn M., and Matthew McCartney. *Inventory of water storage types in the Blue Nile and Volta River Basins*. IWMI, 2010.

Namara, Regassa E., Leah Horowitz, Ben Nyamadi, and Boubacar Barry. (2011) *Irrigation Development in Ghana: Past experiences, emerging opportunities, and future directions*, Ghana Strategy Support Program (GSSP) Working Paper, International Food Policy Research Institute (IFPRI), Washington, D.C.

Robinson, Sherman, and Arthur Gueneau. (2013). *CGE-W: an Integrated Modeling Framework for Analyzing Water-Economy Links Applied to Pakistan*. Proceedings of the 16th Annual Conference on Global Economic Analysis: June 12-14, 2013, Shanghai, China.

Robinson, Sherman and Arthur Gueneau. (2014). *Economic evaluation of the Diamer-Basha dam: Analysis with an integrated economic/water simulation model of Pakistan*. Pakistan Strategy Support Program (PSSP) Working Paper, International Food Policy Research Institute (IFPRI), Washington, D.C.

Rosegrant, M.W. and the IMPACT Development Team. (2012). *International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description*, International Food Policy Research Institute (IFPRI), Washington, D.C.