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Article

Modeling Impact of Climate Change on Water Resources and Agriculture Demand in the Volta Basin and other Basin Systems in Ghana

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Abstract: An assessment of the impacts of projected climate change on water availability and crop production in the Volta Basin and the southwestern and coastal basin systems of Ghana has been undertaken as a component of the impacts and adaptation study for Ghana by UNU-WIDER and the University of Ghana. Four climate change scenarios were considered in addition to a reference (no change) scenario—two dry and two wet scenarios. To conduct the analysis, a portion of a special framework using three water models was used; the framework is called the Strategic Analysis of Climate resilient Development (SACReD). First, the CliRun water balance model was used to simulate catchment runoffs using projected rainfall and temperature under the scenarios. Second, climate impacts on yields of the economically important Ghana crops were modeled using the AquaCrop software. Third, the Water Evaluation and Planning (WEAP) software was used for the water allocation modeling. The results show that all water demands (municipal, hydropower, and agriculture) cannot be simultaneously met currently, or under any of the scenarios used, including the wet scenarios. This calls for an evaluation of groundwater as an additional source of water supply and an integrated water resources management plan in the catchments to balance demand with supply and ensure sustainable socio-economic development. In addition, the AquaCrop model forecasts negative impacts for the crop yields studied, with some crops and regions seeing larger impacts than others.

Keywords: Ghana; water resources; agriculture; climate change

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1. Introduction

The water resources of the Volta Basin of West Africa are under severe stress due to poor climatic conditions and competing demands on the resources by the riparian countries [1]. Climatic conditions in the region are such that there is high variability in both temporal and spatial distribution of rainfall over the basin causing a corresponding high variability in streamflow. The effect of this is that most streamflow, particularly in the northern parts of the basin, occur in just a few months of the year with little or no flow for much of the year [2]. In addition, the agricultural sector is highly vulnerable because it is largely rainfed and has a low level of irrigation development [3].The agriculture sector comprises approximately 30 percent of the country's GDP to date and employs about 50 percent of the population. Though agriculture may have the potential to grow by as much as 6 percent, climate change could inhibit such progress in the long run, given the sector's vulnerability [4].

Variable climatic conditions, coupled with non-climatic factors such as population growth and increased economic activity, has led to the widespread construction of hydraulic infrastructure. This infrastructure contains various types and sizes for water mobilization throughout the basin, particularly in Burkina Faso and Ghana that together cover about 85 percent of the basin area. These hydraulic facilities include numerous small-scale reservoirs in Burkina Faso and northern Ghana mainly for agricultural purposes in the long dry season. In addition, there are large-scale irrigation systems such as those in Tono, Vea, and Botanga in northern Ghana, and Bagre, and Kompienga (both also used for hydropower generation) in Burkina Faso. There is also the huge Volta Lake in Ghana powering the nearly 1200 MW hydropower generation facilities at Akosombo and Kpong in the Lower Volta with turbine flow of up to 1200 m^3/s. A 400 MW plant on the Black Volta in Ghana is due to be fully operational in 2014 with several relatively smaller ones planned for the future in both Burkina Faso and Ghana.

Thus, the riparian countries of the Volta Basin rely heavily on its water resources for their socio-economic sustenance. However, the improper exploitation of these resources in the past has caused serious environmental problems in the basin, which is diminishing the resources [5]. To avoid or reduce these problems in the basin, institutional mechanisms such as the establishment of the Volta Basin Authority (VBA), have been put in place to drive and co-ordinate the proper water resources management in the basin. Unfortunately, climatic factors may have the upper hand in determining the availability of water resources in the basin. Climate change, in particular, could be a serious problem. It is projected to exacerbate the problem of diminishing basin water resources [6,7].

The river basins in Ghana but outside the Volta systems are the southwestern and coastal (SWC) systems, as they are called in Ghana. These systems are also under stress from both climatic and non-climatic factors and studies have shown that climate change is likely to have adverse impacts on the water resources [8,9].

This study, therefore, seeks to determine the levels at which projected climate change could impact water availability to meet municipal, hydropower, and agricultural demands in the Volta Basin and the rest of the river basins in Ghana. This water resources component of an impacts and adaptation study for

Ghana has been undertaken by UNU-WIDER and the University of Ghana (UG), and features a focus on climate change impacts and adaptations using the Strategic Analysis of Climate Resilient Development (SACReD) framework.

The study used the Water Evaluation and Planning software, WEAP, of the Stockholm Environment Institute (SEI) to model the water availability and allocation to the various water demands in the Volta and SWC basin systems. A separate water balance model, CliRun, was used to simulate surface water runoff as the supply input to WEAP and the Food and Agriculture Organization of the United Nations (FAO) AquaCrop model was used to determine irrigation demands.

The following sections start with a brief description of the drainage, hydrology, and agriculture in the study area. Then, the WEAP setup and the input data used to run WEAP are described. This is followed by the results obtained from the WEAP runs, the analyses and discussion of these results, and the conclusions and recommendations derived from them.

2. Study Area

The study area for this analysis covers the entire Volta Basin and the rest of Ghana river basins—the SWC basins. The Volta Basin (Figure 1) spans various sections of the six West African countries of Benin, Burkina Faso, Ghana, Côte d'Ivoire, Mali, and Togo. The areas of each country within the basin are indicated in Table 1. As the table shows, more than 84 percent of the basin area lies in Burkina Faso and Ghana.

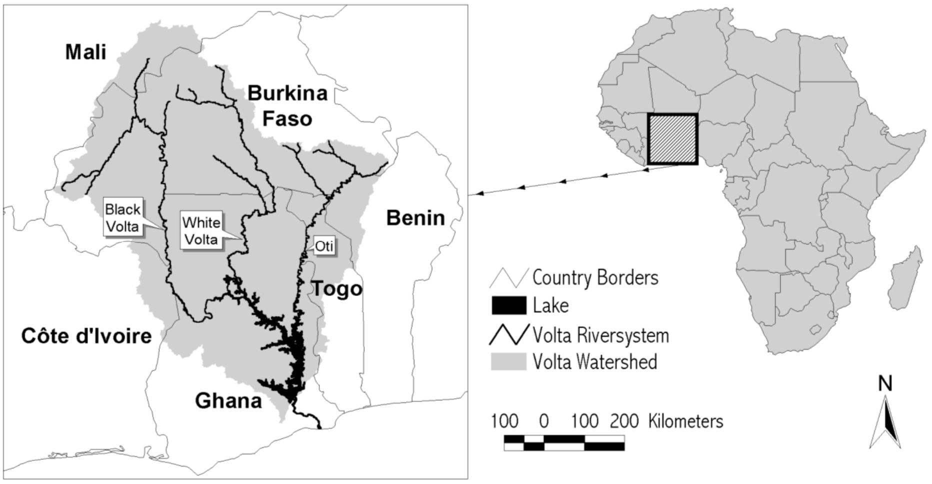


Figure 1. Volta Basin. [10].

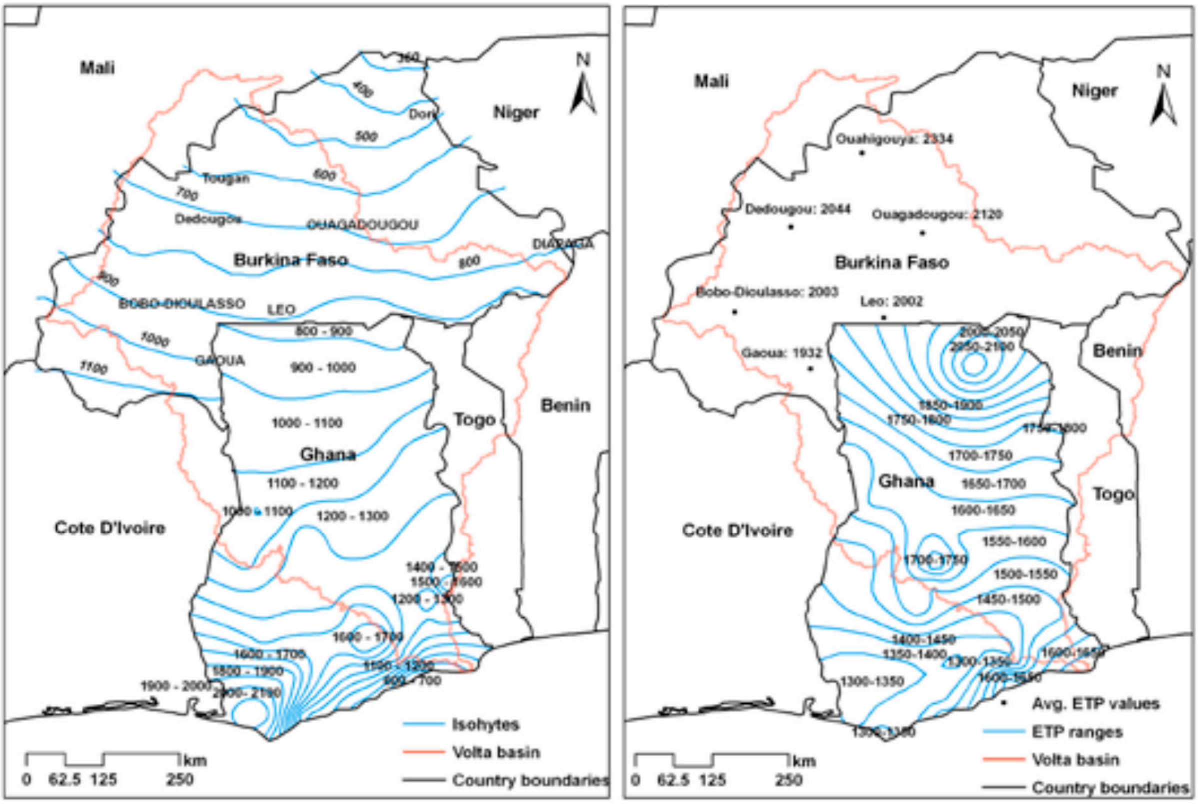
Table 1. Volta basin areas by country [11].

Country	Area of basin (km^2)	% of basin area	% of country area
Benin	13,590	3.41	12.1
Burkina Faso	171,105	42.95	62.4
Côte d'Ivoire	9890	2.48	3.1
Ghana	165,830	41.63	70.1
Mali	12,430	3.12	1.0
Togo	25,545	6.41	45.0
Total	398,390	100.00	

The basin is drained by the Black Volta, White Volta (with a major tributary of the Red Volta), Main Volta (formed below the confluence of the Black and White Volta), Oti, and the Lower Volta below the Akosombo and Kpong hydropower facilities in Ghana. The major landmark in the basin is the 8500 km^2 VoltaLake formed from the damming of the Main Volta at Akosombo for hydropower production in Ghana [1].

Rainfall increases from less than 500 mm per annum in the northernmost parts of the basin in Mali to about 1600 mm per annum in the southernmost portion (Figure 2a). Potential evapotranspiration on the other hand, increases moving northwards (Figure 2b). Rainfall is uni-modal in the northern and middle sections of the basin but becomes bi-modal further south in southern Ghana. Thus, the drainage system of the basin moves water from more arid regions in the north to wetter regions in the south of the basin. Mean annual observed streamflows for the main sub-basins of the Volta are shown in Table 2. Maximum annual flow through the turbines at Akosombo (maximum turbine flow) is 1200 m^3 or 38 × 10^9 m^3 [1] and constitutes the Lower Volta streamflow.

The SWC basins are the river basins in Ghana outside the Volta system and cover about 30 percent of the country. The southwestern river system comprising the Pra, Ankobra, Tano, and Bia is the wettest in the country (Figure 3). Kakum, Amissa, Nakwa, Densu, and Ayensu, form the coastal system and are drier in average terms than even the part of the Volta system in Ghana. Estimated mean annual streamflows for sub-basins in this basin system are also shown in Table 2. All of the nine sub-basins in the SWC basin system are stand-alone basins as each discharges directly to the sea.



(**a**) (**b**)

Figure 2. Annual rainfall (**a**) and potential evapotranspiration (**b**) distributions in the Volta and SWC (Southwestern and Coastal) basin systems of Ghana [12].

Table 2. Observed mean flows in the main sub-basins of the Volta and SWC basin systems [1,13,14].

Main sub-basin	Observed mean annual flow (m^3/s)
Black Volta	200
White Volta	220
Oti	280
Main Volta	500
LowerVolta (turbine flow)	1,200
Kakum	5.8
Amisa	12.8
Nakwa	8.3
Densu	13.4
Ayensu	9.3
Bia	54.4
Tano	122.7
Ankobra	70.5
Pra	190

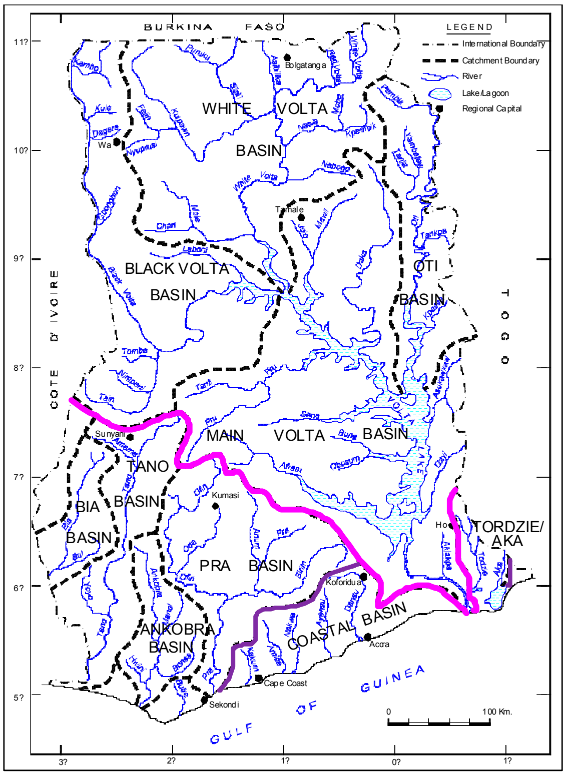


Figure 3. River basin systems in Ghana [6,8].

The most agriculturally productive area of Ghana is the southwest corner of the nation and includes the western, eastern, Ashanti and central administrative districts. Tubers, such as cassava, are especially prominent in this area, as Figure 4 below illustrates. Most other crops are also present in this region. Cropping areas for grains such as maize and sorghum extend further north, into the central area of the country. The far north, along the border with Burkina Faso, contains productive pockets also, but does not attain the yields of the southern region.

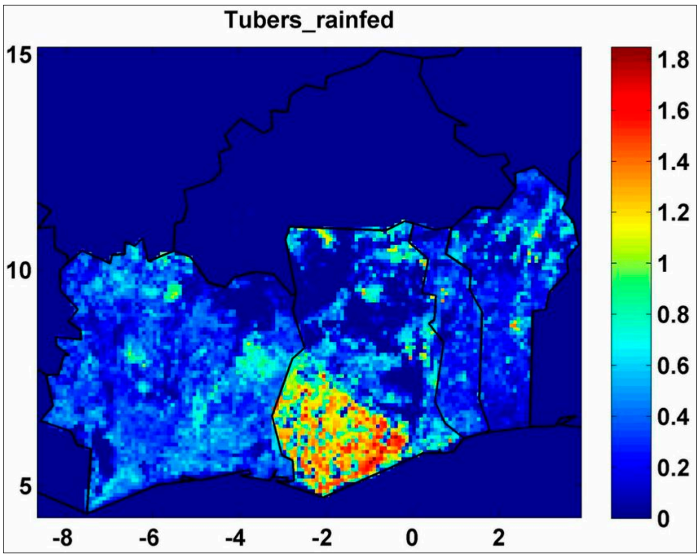


Figure 4. Tubers yield by location (metric tons per hectare).

The most economically important crops in Ghana include yams, cassava, cocoa, rice, maize and tomatoes. Table 3 shows the top 10 agricultural commodity crops for Ghana by production value and quantity, according to the FAO.

Table 3. Ghana's top commodity crops (2011) [15].

Rank	Commodity	Production (Int'l $1000)	Production (MT)
1	Yams	1,605,618	6,295,453
2	Cassava	1,487,644	14,240,867
3	Plantains	747,344	3,619,834
4	Cocoa beans	726,962	700,020
5	Taro	275,638	1,299,645
6	Groundnuts	197,370	465,103
7	Rice, paddy	126,387	463,975
8	Maize	126,063	1,683,984
9	Tomatoes	118,445	320,500
10	Oranges	115,955	600,000

As of 2014, Ghana's municipal water coverage was below 70% (not necessarily due to lack of water resources but more due to inadequate infrastructure) [16]. Certain river basins in the SWC, for example Kakum, often have inadequate water to satisfy their population's water demand. Also, current irrigation in Ghana is not at the potential level. Currently, Akosombo and Bui are producing less than 70% of their installed capacities because of low levels of water in the two reservoirs.

3. Methodology

In this section, the methodology is presented beginning with an overview of the multi-model framework. The following is an overview of Ghana's catchments and the climate change scenarios. Finally, each of the three models used are presented.

3.1. SACReD

The overall Systematic Analysis of Climate Resilient Development (SACReD) Framework was originally designed to translate scientific and biophysical processes of global change (water, environment and climate) into economic outcomes [17]. The framework traces the implications of changes in climate outcomes through a series of important impact channels including production of hydropower, agricultural yield, water supply/demand balance (and eventually costs of maintaining infrastructure and other installed capital). Variants of the SACRED framework have been applied to Ethiopia, Ghana, Malawi, Mozambique, South Africa, Tanzania, Vietnam and Zambia [17]. For this study, only the climate scenarios and three models (CLIRun, AquaCrop, and WEAP) were used.

3.2. Catchment Delineations

In all, 29 catchments were delineated—19 in the entire Volta Basin and 10 in the SWC basins of Ghana. The SWC basins cover about 30 percent of the land area of the country and are the basins outside of the Volta system. The shape files for the Volta Basin catchment delineation were the same used in [6,7]. Those for the SWC sub-basins were obtained from the Council for Scientific and Industrial Research—Water Research Institute (CSIR-WRI), Accra. The catchment delineations are shown in Figure 5.

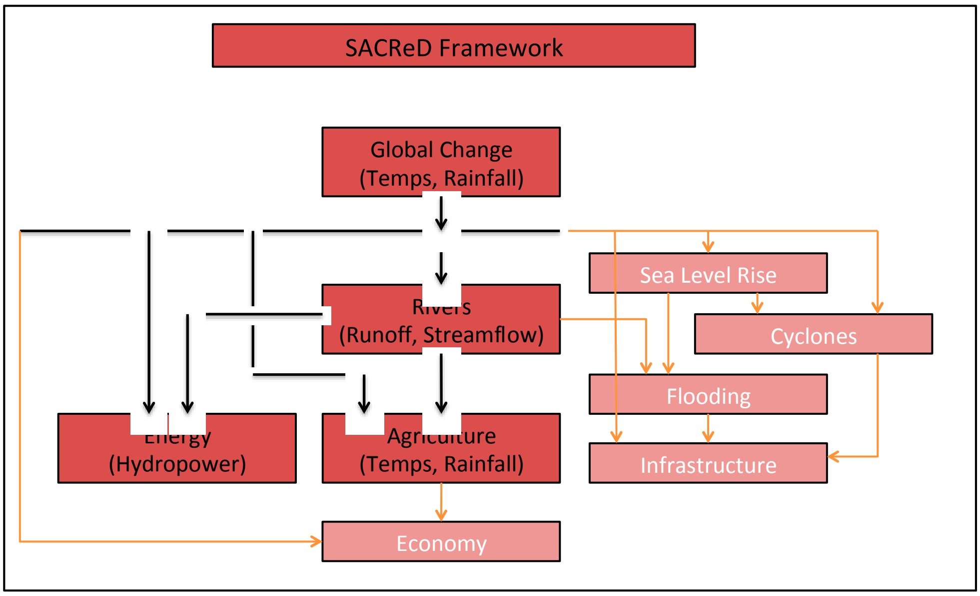


Figure 5. Overall SACReD Framework.

3.3. Climate Change Scenarios

Four possible future climate scenarios were used in this analysis: Global Wet, Global Dry, Ghana Wet and Ghana Dry. These were compared to a baseline scenario. The baseline scenario assumed the same climate conditions to those between 1950 and 2000. The time period for the future projections was 2010–2050. Climate projections from the NCAR (National Center for Atmospheric Research) and CSIRO (Commonwealth Scientific and Industrial Research Organisation) models were used to generate the Global Wet (NCAR_CCSM3_0 A2) and Global Dry (CSIRO_MK3_0 A2) scenarios. To generate the Ghana Wet (NCAR_PCM1 A1b) and Ghana Dry (IPSL_CM4 B1) scenarios, climate projections from the two GCM/SRES (Global Circulation Models/Special Report on Emissions Scenarios [18]) combinations with the lowest and highest climate moisture index (CMI) for Ghana were used. It is important to note that in the case of Ghana, the globally 'wettest' GCM actually projects a drier future climate for Ghana than the globally 'driest' scenario [3]. These scenarios include projections for both temperature and precipitation. All climate data, including historical data used to generate the baseline, came from the "Global Meteorological Forcing Dataset for Land Surface M odeling," at the Princeton Data Source [19].

Next, the methodology for each model in the framework is described.

3.4. Runoff (CliRun)

The CliRun model was used to model changes in runoff. It is a two-layer, one-dimensional infiltration and runoff estimation tool that uses historic runoff as a means to estimate soil characteristics [20,21]. CliRun was calibrated using historical gauged flow in the Volta and Ghana Basins. Historical streamflow and climate data is limited (and streamflow data is gauged data, meaning it includes the impacts of upstream storage and abstractions). This made the process of calibrating a natural runoff hydrologic model, CLIRUN, difficult. Additionally, some of the key basins had no gauges.

The lack of both quality climate data and runoff data made the normal calibration/validation impossible. As this analysis is targeted to the climate change, which is provided as relative changes in climate variables, we are concerned that the model is properly capturing the elasticity of runoff to temperature and precipitation change.

CLIRUN has been used globally in climate change studies and its validity for properly capturing CC Runoff elasticities has been documented (Strzepek, 2010) [10].

Given acceptable elasticities but poor estimations of historic "naturalized" flows, a Bias-Correction technique (developed at MIT by Strzepek *et al.* 2012, and used in various African water resource studies [17]) was used to produce representative baseline historic runoff time series, as well as climate change runoff time series as inputs to WEAP Model. The observed flows exclude both upstream and within catchment water abstractions such as for municipal supply or irrigation. Therefore, they should be lower than the modeled runoff that includes these abstractions.

CliRun's generated monthly runoff from 2011–2050 for each catchment and climate change were inputs to WEAP. There were difficulties simulating flows for the last sub-basin in the SWC, Tordzie, so it was left out in the WEAP modeling and analysis. Tordzie is a small sub-basin downstream of the very large Volta Lake and has very little impact on upstream sub-basins.

3.5. Irrigation Demand (AquaCrop)

The FAO's modeling tool AquaCrop [8] was used to model crop yield and water needs under various climate conditions and in different parts of Ghana. AquaCrop is a computer model used to simulate a crop's yield in response to water. It is developed by FAO, and is a revised version of CropWat. As a model it is especially useful in addressing conditions where water is a limiting factor in crop production. This makes the model very useful in predicting changes in both water demand, and yields, over time under different climate change scenarios [22].

The primary data components for AquaCrop's crop-grown calculations are: climate, crop, soil, and management (which includes irrigation and field management). While AquaCrop can model the effects of CO_2 fertilization, that feature was not used in this analysis. Adjustments were made to the characteristics of AquaCrop's pre-set crops (*i.e.*, planting calendar, flowering, senescence, plant maturity, etc.) to reflect local conditions and farming practices in Ghana. The analysis used soil information from the FAO Soil Map of the World.

Management components include both irrigation and field management. Adjustments were made to the irrigation component to approximate conditions under which irrigation water might be used. Due to the absence of extensive farmer surveys on actual irrigation practices in the field, the analysis assumes the farmers are diligent to maintain adequate soil moisture so that the crops exhibit either no water stress or an insignificant water stress as compared to the water stress exhibited by their dry-land counterpart. AquaCrop contains no geographic scale data; therefore adding total area under irrigation is a post-process step. To model irrigation, the irrigated area was added slowly over time, assuming that infrastructure may be built incrementally. There was some discrepancy in the literature as to the amount of land currently under irrigation, and how much to include for the ending point. The starting number selected was 40,000 hectares. This was based on private interviews with Agriculture Ministry personnel, who put the number at 40,000 hectares, and an assumption that new infrastructure has been built since 2007, the year in which the best published numbers were available. A 2011 IFPRI report places total current area at 33,000 hectares in 2007, with government schemes making up 9000 and the rest private sector irrigation [23]. More has likely been added since 2007. Furthermore, a Remote Sensing Journal article estimates 30,900 hectares under irrigation, but does not include wetlands and inland valleys [24]. The analysis added irrigation over time from the current baseline.

The model also required target acreage for the final number of hectares under irrigation. Though official documents indicate plans to increase irrigation area to over 500,000 hectares [25], Gumma places the total possible irrigation scheme in all of Ghana at 346,000 hectares. Since the final third of this scheme would lie in geographic areas that are difficult to reach, and assuming that maximum irrigation would lie beyond a 40-year time horizon (only 9000 hectares are currently under government management), the research team concluded that 250,000 hectares would be used for the model.

The field management default components within AquaCrop were left mostly unchanged for the analysis. This analysis assumes farmers do not adapt to the new climate conditions. Of course, in reality farmers are likely to make adjustments to their management in order to protect the investments they have made. However, properly modeling these management adjustments requires either predicting what these adjustments will be, which is a difficult task, or modeling the variety of adaptation options available. As this study is focused on the risks across various GHG mitigation options, we leave the task of properly assessing adaptation options to future research.

A special model needed to be built for cocoa. Cocoa is a significant crop in Ghana, but AquaCrop does not include it. The cocoa analysis therefore used data from [26]. This data was extrapolated to build the Ghana model within AquaCrop. Once the output was generated, the data was checked to ensure it reflected actual irrigation and yields. Where the numbers were in conflict, adjustments were made either in the AquaCrop production input (as a calibration step) or as a coefficient for yield or water demand after the run. The projections of AquaCrop's monthly irrigation water demand from 2011–2050 for each of the 29 catchments and each climate change scenario are inputs to WEAP.

The effect of CO_2 on crop production was not included in this analysis. The exact effect of CO_2 on water demands for all crops studied was considered ambiguous to the depth needed for proper modeling [27]. AquaCrop, for example, uses a rather simple adjustment factor for calculating the stomata closure caused by increases in CO_2. In addition, by 2050, the end of this analysis, CO_2 levels in the atmosphere are high, but not high enough to make a substantial difference in water demands, at least as currently as the CO_2 effect currently understood. For these reasons, the CO_2 effect was not included in the analysis to prevent introduction of more uncertainty in the modeling.

3.6. WEAP

The WEAP model [28] was used to evaluate water availability and allocation to the various water demands in the Volta and SWC basin system. A WEAP schematic representing all catchments and establishing water supply and demand nodes was first created before inputting the necessary data and running the model. The input catchment runoffs, agriculture water demands and populations (for municipal water demand computations) were obtained at the catchment level as described in the previous sections. The model was run on a monthly time step from 2011–2050. Municipal was given highest priority to meet its demand with the available supply followed by agriculture, then hydropower. All local irrigation and water supply infrastructure currently existing in the study area were excluded from the WEAP schematic. This also applied to all local dams except those for hydropower purposes.

3.7. Municipal demand

Municipal water demands are driven by population. Catchment level population data for 2000 and 2010 for all 29 catchments was compiled from the Gridded Population of the World version 3 [29]. For the population data, the growth rate from 2000–2010 for each catchment was computed and used to interpolate exponentially for annual catchment populations from 2011–2050. The Pra basin had the highest 2010 population of more than 5.9 million while Arly, the upper most catchment of the Oti sub-basin, is the least populated with a 2010 population of a little over 180,000. The assumed per capita daily water demands used to estimate municipal water demand, which covers domestic, industrial, and mining demands are presented in Table 4. These demands are applicable at the catchment level, *i.e.* they apply to all 29 delineated catchments.

Table 4. Assumed per capita water demand used in WEAP.

Year	Litres per capita per day (lpcd)demand
2010	60
2015	70
2020	80
2025	90
2030	100
2035	105
2040	110
2045	115
2050	120

These demands were then converted to m^3/year and input into WEAP for the computation of municipal (domestic and industrial) water demand. Currently, municipal water supply in Ghana meets just a little over 60 percent of demand due to poor and inadequate water treatment and delivery infrastructure and not due to lack of availability of water [30]. Ghana's current water availability of more than 2000 m^3/person means the country has adequate water resources to meet at least municipal demand. For Accra it is estimated that current (2014) supply is equivalent to only about 80 lpcd instead of up to 120 lpcd used for planning purposes by the Ghana Water Company Ltd. (GWCL). For rural supply, 20–40 lpcd is usually considered by the Community Water and Sanitation Agency (CWSA) of Ghana in its water delivery programs, but in the WEAP setup rural and urban demands have been aggregated so that the demand figures in Table 4 are total per capita municipal demands. The 2010 figure was obtained from the average of 80 lpcd (urban) and 40 lcp (rural) currently applicable in Ghana. It is assumed that by 2050, the population in the region will be mostly urban so 120 lcpd is used as total per capita demand. Linear interpolation was then applied to estimate demands for the rest of the years in Table 4. Combined rural and urban demand estimates were used because the population data available were not disaggregated into rural and urban populations.

3.8. Hydropower

Hydropower characteristics for current and planned facilities were obtained from literature [6,7,30–32]. Hydropower demand is taken as the maximum capacity, in terms of both energy production and turbine flow. Current facilities are the Bagre (Wayen catchment) and Kompienga facilities in Burkina Faso and the Akosombo-Kpong (Main Volta or Senchi catchment) in Ghana. Four planned facilities (all in Ghana) are included in the schematic. These are Bui (Bamboi catchment of the Black Volta Basin), Pwalugu (Pwalugu catchment of the White Volta Basin), Juale (Sabari catchment of the Oti Basin) and Hermang (Pra sub-basin of the SWC Basins). Bui is due to be fully operational in 2014. When the remaining three planned facilities will come on stream is still unknown—2025 was assumed as the start year for these [31] and input into WEAP. The maximum power generating capacities of the facilities are shown in Table 5. It can be seen from the table that the Akosombo/Kpong and the Bui are the largest among the seven facilities.

Table 5. Installed capacities of the hydropower generating facilities [6,7,30–32].

Hydropower facility	Country	Capacity (MW)
Main Volta Akosombo and Kpong dams	Ghana	1180
Bui dam	Ghana	400
Pwalugu dam	Ghana	48
SabariJuale dam	Ghana	87
Kompienga dam	Burkina Faso	14
Bagre dam	Burkina Faso	10
PraHermang dam	Ghana	93

4. Results and Discussion

4.1. Impact of Climate Change on Catchment Runoff

Mean annual catchment runoff relative to reference scenario for all catchments and also at sub-basin level are presented in Table 6 for the four climate change scenarios. (Mean flows are taken for the 40-year simulation period of 2011–2050 before computing the changes. At the sub-basin level for the Volta basin, the sum of the runoffs for all catchments in the sub-basin is used to compute the change. The changes are computed as: pc = (MSR-MRR) × 100/MRR where pc is the relative change in percent, MSR is the mean runoff for a scenario and MRR is the mean runoff for the reference).

Table 6. Change in predicted mean catchment runoff for the climate change scenarios relative to the reference scenario.

Main sub-basin	**Catchment**	**Percent change from the Reference scenario**			
		Ghana Dry scenario	**Ghana Wet scenario**	**Global Wet scenario**	**Global Dry scenario**
Black Volta	Lerinord	−8.5	1.0	11.8	−1.8
	Nwokuy	−16.5	−1.9	2.2	−5.8
	Dapola	−11.1	−1.7	4.9	−4.3
	Noumbiel	−9.7	−4.9	1.0	−7.2
	Bamboi	−8.0	3.3	1.0	−8.2
Sub-basin level		−10.6	−0.5	3.6	−5.7
WhiteVolta	Wayen	−7.5	−0.3	13.2	−0.9
	Yakala	−9.5	0.5	6.7	−2.0
	Nangodi	−10.1	0.5	5.3	−2.6
	Pwalugu	−9.7	−0.1	2.0	−3.3
	Nawuni	−8.9	0.2	0.7	−5.4
Sub-basin level		−8.9	0.2	4.1	−3.7
Oti	Arly	−8.6	3.4	−1.0	−0.7
	Kompienga	−9.9	0.8	4.0	−2.2
	Mango	−8.2	3.3	0.9	−1.4
	Koumangou	−9.7	3.5	−0.4	−1.9
	Sabari	−9.0	2.5	−0.5	−4.1
	Ekumdipe	−8.3	2.8	−0.4	−7.3
Sub-basin level		−8.8	2.9	0.3	−2.8
MainVolta	Prang	−7.5	9.5	0.5	−9.5
	Senchi	−7.5	6.2	−0.5	−9.1
Sub-basin level		−7.5	6.5	−0.4	−9.1
Lower Volta	Delta	−9.1	7.8	0.9	−10.1
Densu	Densu	−18.8	35.7	−2.8	−17.3
Ayensu	Ayensu	−16.2	35.4	−1.9	−14.3
Nakwa	Nakwa	−31.1	71.7	12.9	−17.8
Amissa	Amissa	−21.3	60.6	−0.8	−18.6
Kakum	Kakum	−20.3	81.1	4.1	−17.8
Pra	Pra	−25.9	60.9	−12.2	−34.4
Ankobra	Ankobra	−22.8	71.6	−4.6	−21.5
Tano	Tano	−26.0	32.4	−12.8	−30.6
Bia	Bia	−12.7	13.2	−4.3	−15.1

The results in Table 6 show that while for the Black and White Volta main sub-basins the Global Wet scenario is generally wetter than the Ghana Wet, it is the opposite for the other sub-basins. In fact, for the SWC basin systems, for example, the Global Wet is not wet at all. The results also show that the Ghana Dry scenario projects dryer conditions than the Global Dry scenario for most of the catchments. It is the wetter sub-basins of the Main Volta and the southwestern sub-basins of the Pra, Tano, and Bia that are the exceptions. Since the hydrological model could not simulate the runoffs in the SWC basin systems very well, it is likely that the change results for these two basin systems are not accurate. On the whole, it appears that the global scenarios project less severe conditions than the Ghana scenarios, as far as water resources availability in the Volta and Ghana is concerned. Nevertheless, the inconsistency in the direction of change of predicted runoffs across the basins reaffirms the uncertainty of the level of climate change impacts on water resources at the local scale.

4.2. Impact of Climate Change on Irrigation Demand

The AquaCrop model indicates that irrigation water demand will rise under all four scenarios, when compared to the baseline. The model projects increased irrigation water demand based on both newly built irrigation infrastructure, and climate change. Figure 6 shows the increased average annual irrigation demand over and above the baseline for each of the climate scenarios in the analysis. Units are MCM/year averaged over the 40 years of the study.

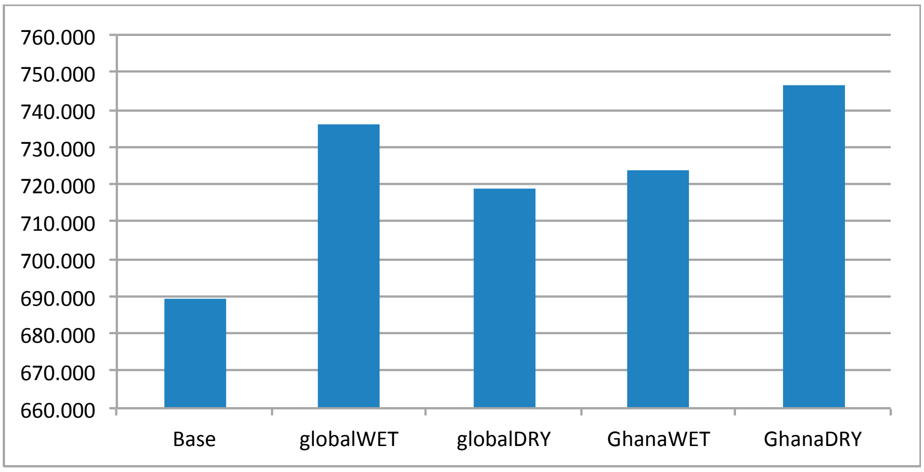


Figure 6. Average annual irrigation demand for water for all years in analysis (base is current withdrawal) Source: Authors' Compilation.

Figure 7 shows Ghana's annual projected irrigation water demand during the forecasted period. The gradual upslope illustrates the increased irrigation demand over time and added infrastructure modeled. The variance between the baseline and each scenario illustrates the increased irrigation demand due to a changing climate in any given year. During the later years for the analysis, the increased irrigation demand for all four scenarios over the baseline is more pronounced.

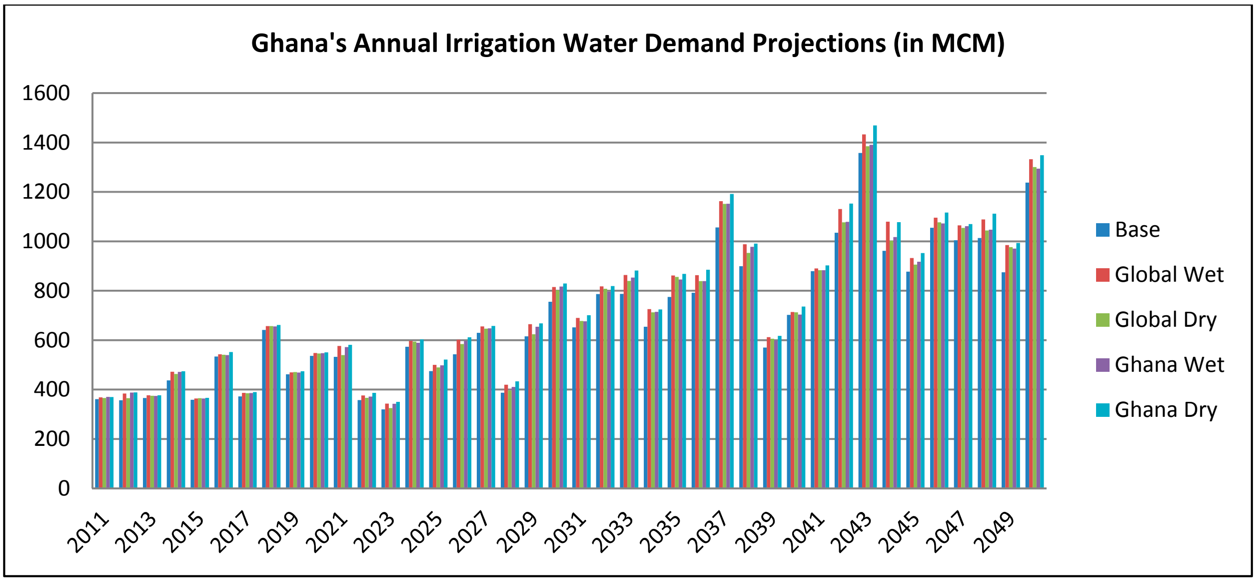


Figure 7. Irrigation water demand projections year for base and four scenarios.

Mean annual agricultural water demand coverage averaged over the climate change scenario periods are presented in Figure 8 for all catchments and scenarios. It is observed from Figure 6 that agricultural water demands for the simulation period are not fully met except for the wet scenarios. The shortfall is rather large for the water stressed catchments of Wayen, Densu, and Kakum. The coverage from Pra is also very low and though the sub-basin is not water stressed, it has huge municipal (most populated among all the catchments) and hydropower demands to satisfy.

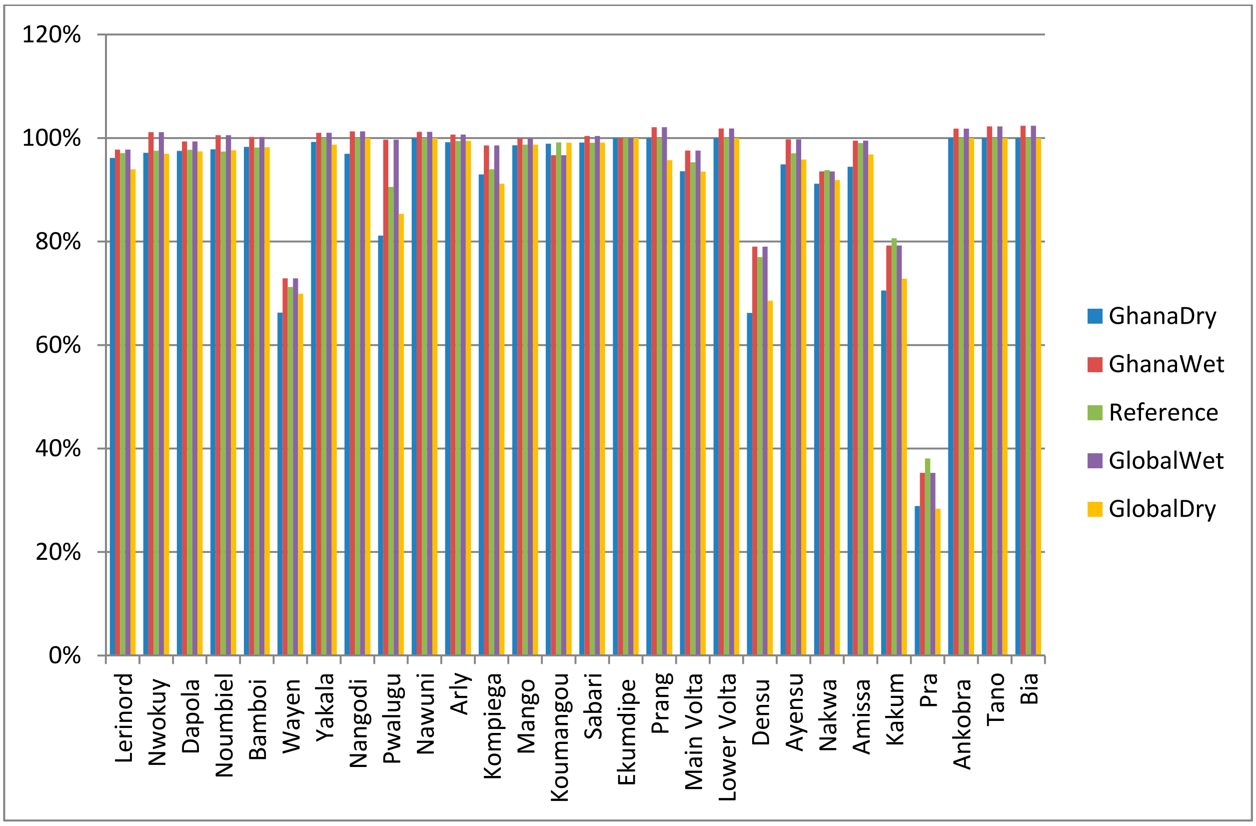


Figure 8. Agricultural water demand coverage (Source Authors' Compilation).

4.3. Impact of Climate Change on Municipal Demand Coverage

The municipal water demand coverage for the basins averaged over the entire 2011–2050 period is shown in Figure 9. Overall, the coverages are high except for a few cases, particularly the small catchments in the more arid northern part of the Volta Basin such as Wayen and Yakala. Densu is the only sub-basin in the SWC basin system with poor demand coverage.

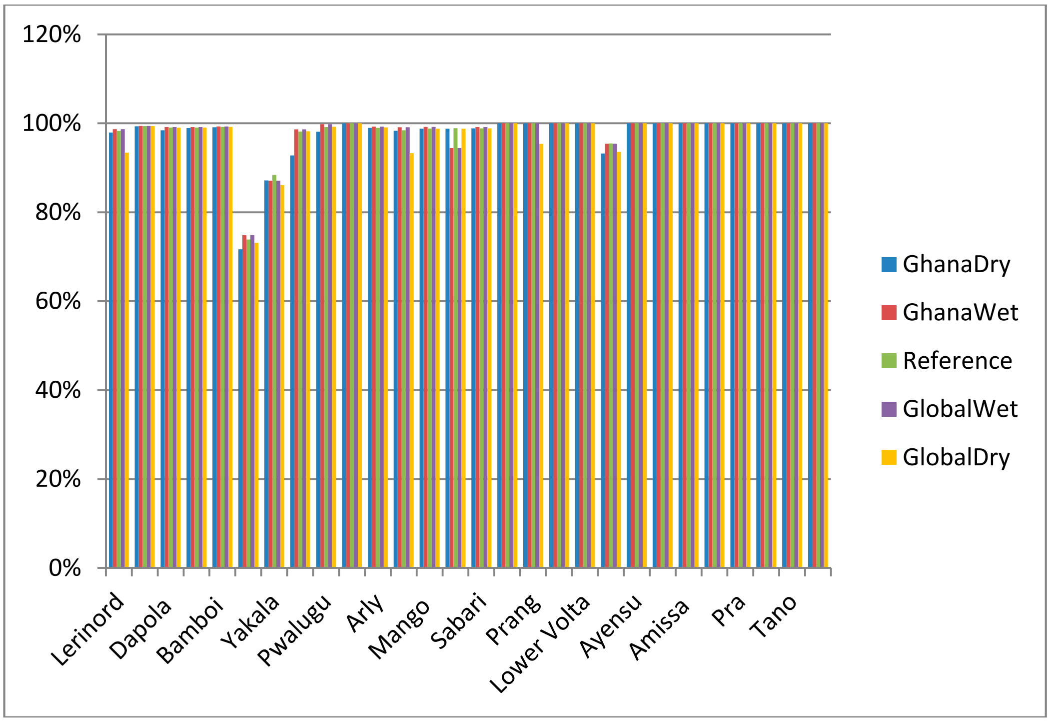


Figure 9. Municipal water demand coverage.

The municipal demand for Densu includes half of the demand for the Greater Accra Metropolitan Area (GAMA) covering the city of Accra and the surrounding communities. Currently, GAMA obtains half its water requirements from the Weija water supply facility on the Densu River; the other half is sourced from the Lower Volta below the Akosombo dam. The high population in the GAMA (highest in Ghana) thus puts great pressure on the water resources of the sub-basin.

4.4. Impact of Climate Change on Hydropower Production

The climate change impacts on hydropower generation potential are summarized in Figure 9. The percentage coverage was computed from means taken over the entire 2011–2050 period for the Bagre, Kompienga, and Akosombo facilities, 2014–2050 for Bui and 2025–2050 for Juale on the Oti, Pwalugu on the White Volta, and Hermang on the Pra Rivers. The coverages are potential since they can exceed 100 percent. The potential hydropower generation is based on flow availability only.

Figure 10 shows that there is variability in demand coverage at the facilities for the study period. The coverage for the Hermang facility in the Pra sub-basin is rather low. Again, this points to inadequate basin runoff generated by CliRun. The percentage coverages are generally higher for the global scenarios than for the Ghana scenarios, in agreement with the latter scenarios being generally drier than the former as pointed out earlier. The results also show that on the average, the demands for the two largest facilities, Akosombo and Bui, are not fully met under any of the scenarios.

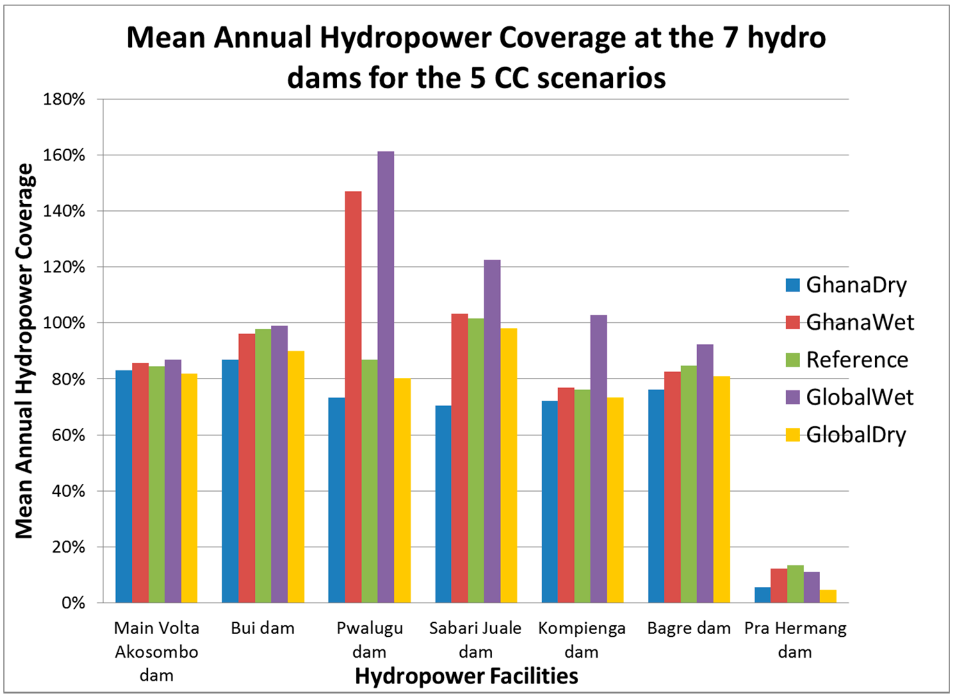


Figure 10. Mean annual hydropower coverage for the seven plants under all four climate change scenarios generated from WEAP.

5. Conclusions

A WEAP model for the entire Volta Basin and all of Ghana has been setup. The model runs with input data on simulated sub-basin runoffs from the water balance model CliRun, expected municipal water demand, hydropower demand, and simulated agricultural water demand from AquaCrop. It has been successfully used to model the impact of climate change on the availability of water resources to meet various demands in the study area using four climate change scenarios.

The CliRun catchment runoff predictions for input to WEAP underestimate mean runoffs for the catchments but appropriate adjustments were applied to enable WEAP to run satisfactorily. The simulated runoffs show that the global climate scenarios used tend to be wetter on the whole than the Ghana climate change scenarios. Runoffs in the Volta Basin are very sensitive to rainfall because of the basin being largely semi-arid to arid.

Rainfed agriculture is especially vulnerable. This analysis has shown the variability of different regions and crops in their susceptibility to different climate scenarios moving forward. Some regions and crops may be significantly impacted, while others are less so. However, the overall trend is clear: higher temperatures and lower precipitation mean diminished crop productivity. Irrigation water demand is expected to rise in response to climate change, most significantly under the "Ghana Dry" scenario.

Results from the modeling exercise also show that the basins studied would not have enough surface water resources to fully satisfy all three water demands (municipal, agriculture, hydropower) simultaneously, even for the wet scenarios. This calls for an assessment of groundwater resources and integrated water resources management in the basins to ensure that both the resources that are under great pressure and the future demands on them are prudently managed. It should be noted that the large turbine flow at Akosombo means quite a lot of streamflow in the Lower Volta. This could be mobilized with the necessary infrastructure to further meet the water demands in the coastal regions of Ghana, in particular.

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Author Contributions

Barnabas A. Amisigo performed the data collection and main modeling of the WEAP model. Alyssa McCluskey aided in the WEAP modeling. Richard Swanson performed the AquaCrop analysis.

Conflicts of Interest

The authors declare no conflict of interest.

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