Evaluating the implications of future water resource development under current and projected climate in the Volta basin

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Abstract

This study combines climate change (CC), hydrological and water resource evaluation models to assess the impact of one downscaled mid-range CC scenario (A1B) on the performance of existing and planned irrigation and hydropower schemes in the Volta basin. The models were run (1983-2100) to simulate the CC scenario in combination with three development scenarios, each reflecting different levels of water resource development in the basin. Results indicate a general trend of declining rainfall and increasing potential evapotranspiration in the basin. This trend was found to have caused: i) a significant reduction in flows at key stream gauge locations; ii) an increase in average basin-wide per hectare irrigation requirement and iii) a significant reduction in the percentage of the potential hydropower that could be generated in the basin. This has the tendency to undermine the economic development of the riparian countries unless due consideration is given to these impacts and suitable adaptation measures introduced.

Introduction

The Volta basin is an important source of water for the inhabitants of the six riparian countries it drains. It plays a vital role in the economic prosperity of the people. Agriculture, which employs majority of the basin's inhabitant and generates about 40% of the basin's economic output, is heavily reliant on it (Biney, 2010). Water is also used to generate cheap hydropower which supports major industries (i.e. mining, aluminium, etc.) in Ghana and is also exported to neighbouring countries (Owusu et al. 2008). Other uses include livestock rearing, fisheries, recreation and tourism.

Water resources in the basin have come under increasing pressure in recent years. Massive population growth in the two main countries - Ghana and Burkina Faso – has resulted in larger abstractions to meet increasing demand (Van de Giesen et al., 2001). The basin's population is projected to reach 34million in 2025, up from 18.6 in 2000 (Biney, 2010).. Despite the existing pressure on the resource, there are plans to build more dams to increase electricity production and expand irrigation in the basin. In addition, CC and the uncertainty associated with it, will further complicate the management of the basin's water resources. Signs of a probable CC (i.e. shorter rainy seasons and increased temperature), which could have dire consequences for future development in the basin, have been reported (Jung and Kunstmann, 2007).

Previous studies have assessed the implications of CC and the ongoing development of dams/reservoirs on the water resources in the basin (e.g. Andah et al. 2004; de Condappa et al., 2009). It has been predicted that CC similar to that which has been observed in recent years will have a greater impact on Lake Volta than the continued construction of small reservoirs in the upstream portion of the basin (de Condappa et al., 2009).

This paper reports the findings of research conducted to determine the impact of one specific CC scenario on the performance of existing and planned irrigation and hydropower schemes in the Volta basin. The scenario selected for analyses was the IPCC SRES-AR4 A1B emissions scenario. This scenario is distinguished from other scenarios by the technological emphasis on a balance between fossil intensive and non-fossil energy sources (IPCC, 2000). The research was conducted by combining CC, hydrological and water resource evaluation models. Simulations were conducted between the period 1983 and 2100. In order to systematically assess the impact of growing water demand on the basin's water resources, three development scenarios were identified and modelled:

- Current Development – this simulated present water withdrawals/demand. Irrigation and hydropower schemes in this scenario were the ones that are currently operating.
- Intermediate Development – this simulated possible expansion of existing irrigation schemes as well as new hydropower and irrigation schemes that are likely to come on line by approximately 2025.
- Full Development – this simulated expansion of the near-future schemes and additional new schemes that may come on line by 2050.

Study Area

The Volta basin is drained by four major river systems: the Black (147,000km^2), White (106,000km^2), Oti (72,000km^2) and Lower Volta (73,000km^2) systems (Figure 1). The total annual runoff is estimated to be 40.4 Bm^3

(Andah et al. 2004). Climatically, the southern part of the basin is tropical, with a bi-modal rainfall distribution that reaches about 1500mmy^{-1}. The northern part has a semi-arid climate with a uni-modal distribution of about 500mmy^{-1}. The amount and distribution of rainfall varies significantly from year to year and also seasonally (van de Giesen et al. 2001).

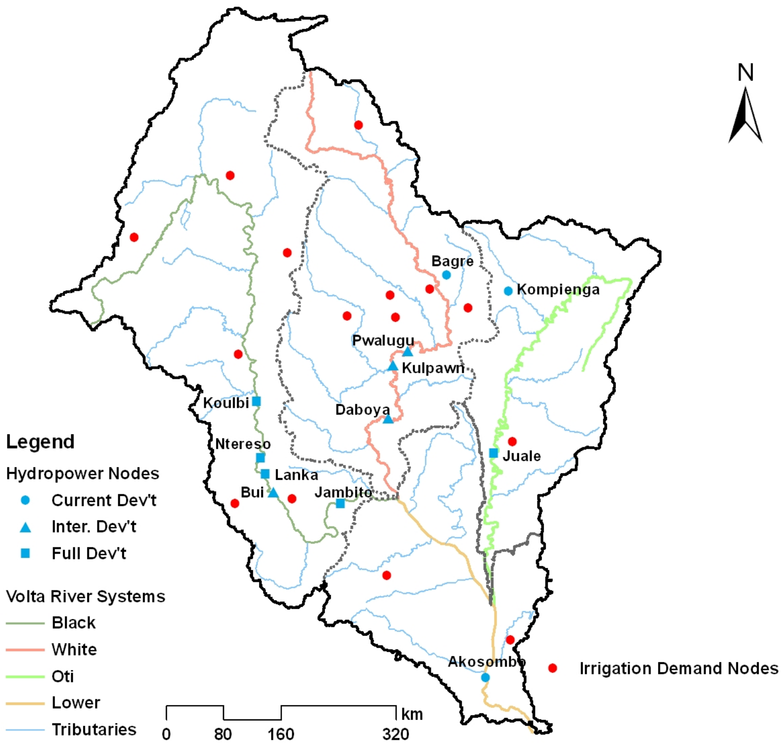


Figure 1: *Volta basin showing hydropower and irrigation demand points*

Current Water Resource Development

The most significant development in the basin so far is the construction of the Akosombo dam on Lake Volta primarily for hydropower production. The Lake reservoir has a surface area of 8,500km^{2}, an average depth of 18.8m and a storage capacity of 148 Bm^{3} (Barry et al. 2005). Current installed generating capacity is 1,020 MW. Other hydropower stations are Kompienga and Bagre in Burkina Faso which have total volumes of 2.03 Bm^{3} and 1.7 Bm^{3} and installed generating capacities of 14 MW and 10 MW respectively.

A number of small, medium and large reservoirs have been constructed in the basin primarily for irrigation. The total storage volume of these reservoirs (excluding the hydropower schemes) is about 1.4 Bm^{3}. These are mainly formal irrigation schemes. Total area under these formal schemes is 30,500 ha. Informal irrigation practice is widespread, but information on it is scanty despite attempts to compile it (Drechsel et al. 2006).

Future Water Resource Development

Major developments planned for the basin focus primarily on hydropower generation and irrigation development. In Ghana, for instance, the Volta River Authority has identified potential sites for hydropower generation in the Black and White Volta as well as the Oti (Figure 1). All together, these planned schemes, including the Bui scheme which is currently under construction, will have a generating capacity of approximately 900MW. At the time of writing, information on similar planned schemes in the other riparian countries were not available.

Expansion in the irrigated area of existing schemes and construction of new ones is expected to increase irrigated area in the basin by close to 33,000 ha. This includes 30,000 ha of irrigation under the Bui scheme. The Ghana Irrigation Development Authority (GIDA) plans to develop an additional 22,590 ha of small or micro scale irrigation and drainage schemes within five years in five regions of Ghana (including the three northern regions). Again, information on future irrigation development in Burkina Faso was not readily available.

Method

In this study, the Water Evaluation and Planning System (WEAP) was used to evaluate the effects of CC on water resources in the face of increasing water demand for irrigation, domestic and hydropower generation in the Volta basin. Modelling was performed in 18 sub-basins. The Soil and Water Assessment Tool (SWAT) was used to simulate flows (supply resources) in each sub-basin, with the downscaled CC (A1B) scenario as input. By using SWAT and WEAP in combination it was possible to simulate the amalgamated impacts of both increasing future demands and changed water availability resulting from CC. Table 1 below gives brief details about the models used.

Table 1: *Models used to evaluate the implications of climate change on existing and future water resource development in the Volta basin*

Climate modelling
COSMO-CLM (CCLM) is a dynamic, non-hydrostatic regional climate model (Davin et al. 2011). The data used for this study were taken from COSMO_4.0_CLM simulations, run for the African continent with grid dimension of 165 x 162 and grid spacing of 0.5°. It has 32 vertical layers and 10 soil layers. The simulations comprised 30 years of daily control runs using ECHAM5-OM (1971-2000) and 100 years of transient scenario runs using ECHAM5, A1B climate scenarios (2001-2100). The initial and boundary conditions were taken from the ECMWF Re-Analysis (ERA40)
Hydrological Modelling
The Soil and Water Assessment Tool (SWAT) is a rainfall-runoff model (Arnold et al., 1998). It operates on a daily time step on sub-basins identified using a digital elevation model. In this case 31 sub-basins were identified. Similar land-use, soil characteristics and topography (slope) within each sub-basin are lumped together into hydrological response units (HRUs). The model was first set up using observed daily climate data for the period 1968-1980 derived from fourteen meteorological stations located within the basin. Historic flow records at eight stations were used to calibrate and six were used to validate the model. Output from the model comprised, potential and actual evapotranspiration as well as flow and groundwater recharge for each sub-basin. Results were combined to provide data for the 18 sub-catchments used in WEAP.
Water Resource Modelling
The Water Evaluation and Planning (WEAP) model is used to evaluate planning and management issues associated with water resource development. It calculates a mass balance of flow sequentially down a river system, making allowance for human induced abstractions and inflows. It is typically used to simulate alternative scenarios comprising different development and management options. In this study the model was configured to simulate the 18 major sub-catchments of the basin. It was used with flows generated by the SWAT model for the period 1983-2100. Rainfall and evapotranspiration data, required for irrigation schemes and reservoirs, were also taken from the SWAT model output, and varied depending on which sub-basin they were located in. The WEAP model was calibrated and validated by simulating the recent past and comparing simulated and observed flows at Bamboi, Nawuni and Sabari, on the Black, White and Oti basins respectively.

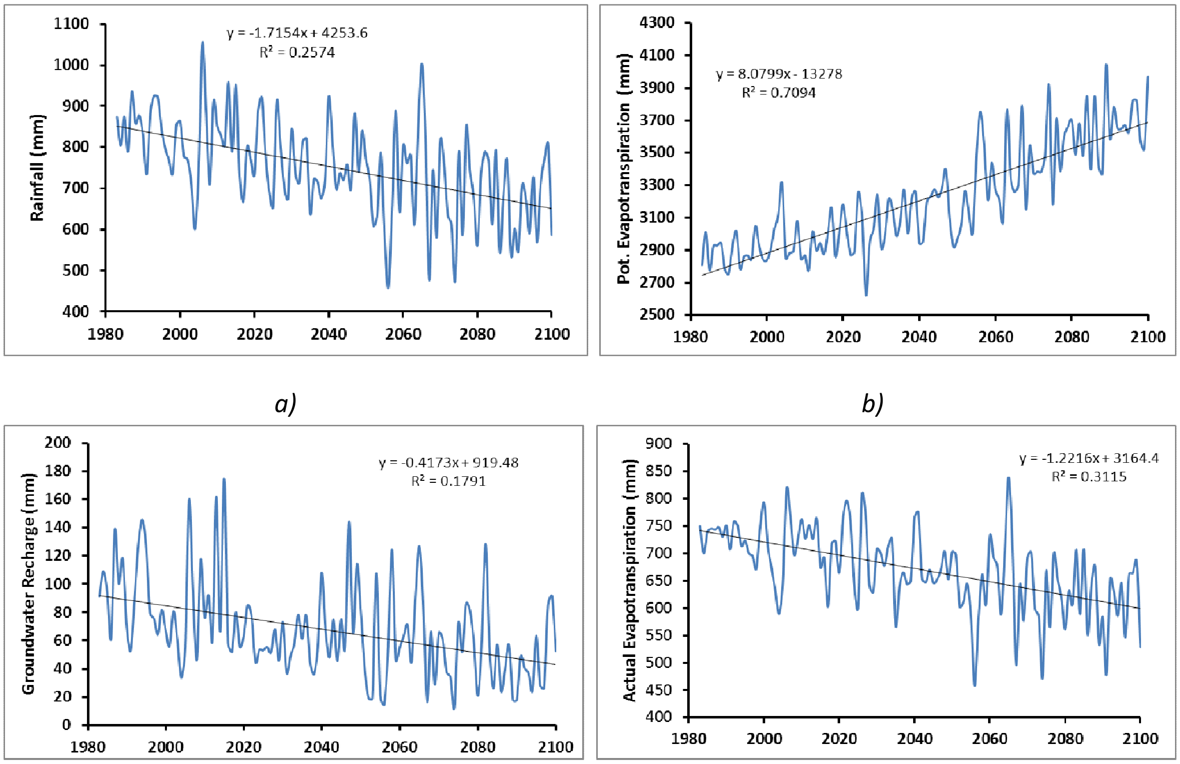
As earlier stated, three separate development scenarios were modelled. Table 2 compares total reservoir storage, irrigated area and installed hydropower generating capacity for the three scenarios. To facilitate comparison between the scenarios, results were summarized over three periods: 1983-2012, 2071-2050 and 2071-2100. Basin average results were computed from sub-basin results by computing the arithmetic mean of the results from individual basins.

Table 2: *Water resource development scenarios*

Scenario	**Total reservoir storage (Mm^3)**	**Irrigated Area (ha)**	**Installed hydroelectricity generating capacity (MW)**
Current Development	153,124	30,468	1,020
Intermediate Development	180,124	63,253	1,547
Full Development	203,437	65,207	1,916

Results

Figure 2 and Table 3 summarize changes in key hydrological variables (i.e. basin average rainfall, potential and actual evapotranspiration and groundwater recharge) over the period 1983 to 2100 as derived from the CCLM and SWAT models. Although there is some spatial variability, the models predict that for the A1B scenario, averaged across the basin, there will be: i) a decline in rainfall; ii) an increase in potential evapotranspiration iii) a decrease in actual evapotranspiration and iv) a decrease in groundwater recharge. Potential evapotranspiration increases mainly due to rising temperatures. Actual evapotranspiration, on the other hand, decrease because rainfall reduces, leading to drier conditions. Thus, although there's rise in temperatures, less water is available for evaporation due to the decline in rainfall.



a) *b)*

c) *d)*

Figure 2: *Basin average annual climate variables (1983-2100): a) rainfall; b) potential evapotranspiration; c) groundwater recharge and d) actual evapotranspiration*

Table 3: *Basin averaged hydrological variables for the periods: 1983-2012; 2021-2050 and 2071-2100*

	Rainfall (mm)	Potential Evapotranspiration (mm)	Actual Evapotranspiration (mm)	Groundwater Recharge (mm)
1983-2012	827	2915	722	88
2021-2050	767	3085	688	66
2071-2100	674	3623	614	50

Irrigation

Figure 3 and Table 4 compare irrigation water demand and unmet demand for the three development scenarios. Unmet demand shows an increasing trend due to (i) increase in irrigated areas, (2) decrease in rainfall and increase in evapotranspiration, and (3) increased per hectare water demand.

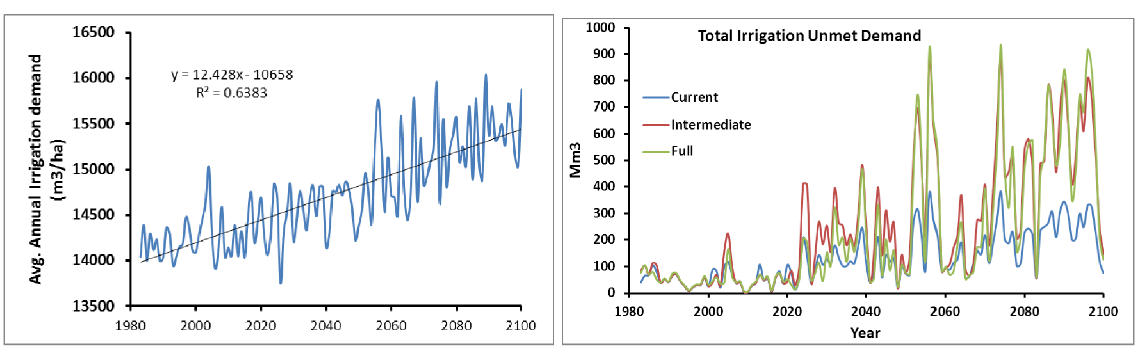


Figure 3: *a) Predicted average irrigation demand for the basin; b) Unmet irrigation demand for the three development scenarios*

Table 4: *Changes in total irrigation demand and unmet demand and in each of the three development scenarios*

		1983-2012	2021-2050	2071-2100
Basin avg. irrigation demand (m^3ha^{-1})		14234	14527	15328
Current Development	**Water Demand (Mm^3)**	356	376	394
	Unmet Demand (Mm^3)	51	113	227
	% demand delivered	86	70	42
Intermediate Development	**Water Demand (Mm^3)**	786	817	855
	Unmet Demand (Mm^3)	60	212	513
	% demand delivered	92	74	40
Full Development	**Water Demand (Mm^3)**	824	856	896
	Unmet Demand (Mm^3)	51	144	505
	% demand delivered	94	83	44

Hydropower

Figure 4 and Table 5 show the decreasing trend in hydroelectricity production and the reverse trend in total unmet potential in the basin for each of the scenarios. The results show a very significant increase in hydroelectricity produced as a consequence of the increased generating capacity between current and full development. They also show that reduced river flows, arising as a consequence of climate change, will significantly reduce the amount of power generated in comparison to the potential, particularly in the second half of the century. This could affect significantly the economic gains of the riparian countries, especially as they move towards industrialization.

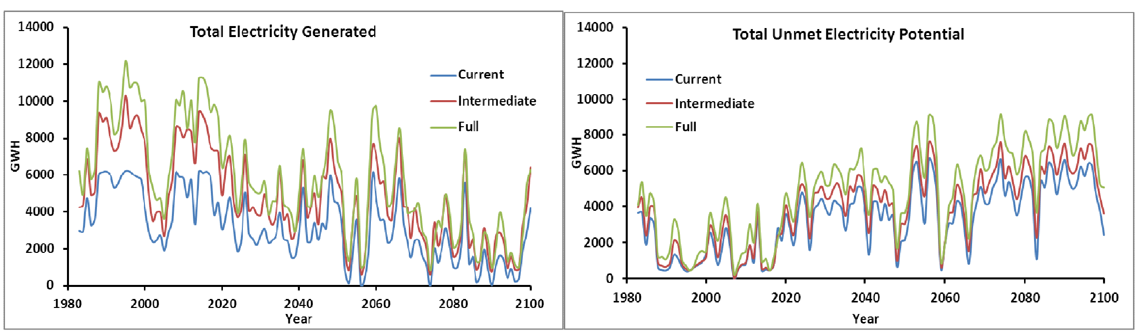


Figure 4: *a) Hydroelectricity generated; b) Unmet hydroelectricity potential in the Volta basin*

River Flow

Table 6 shows the impact of development and CC on the flows of key streams in the basin. All stations indicate significant changes in flow. The situation at Sabari is slightly different to the other locations because the change is driven solely by CC as there is relatively little water resource development on the Oti. Slight increases in flows at some stations between intermediate and full development (e.g. Nawuni) can be attributed to intensification of upstream storage, i.e. through the construction of reservoirs. The flow downstream of Akosombo is estimated to decline by 80% (i.e. from 1,207 to 290 m^3s^{-1}) as a consequence of the combined impact of CC and upstream development.

Table 5: *Changes in hydroelectricity generated and percentage of the total potential in each of the three development scenarios*

	Current Development		Intermediate Development		Full Development	
	Hydroelectricity generated ($GWhy^{-1}$)	% of total potential	Hydroelectricity generated ($GWhy^{-1}$)	% of total potential	Hydroelectricity generated ($GWhy^{-1}$)	% of total potential
1983-2012	4678	77	6975	80	8378	79
2021-2050	3159	48	4779	53	5684	53
2071-2100	1569	24	2599	30	2946	29

Table 6: *Changes in river flows (m^3s^{-1}) at four locations in the basin for the development scenarios.*

	River	1983-2012	2021-2050	2071-2100
Current Development	Bamboi	288	251	160
	Nawuni	218	155	140
	Sabari	300	173	167
	Akosombo	1,207	808	408
Intermediate Development	Bamboi	243	217	136
	Nawuni	182	111	94
	Sabari	300	173	167
	Akosombo	1,140	739	346
Full Development	Bamboi	229	202	120
	Nawuni	184	107	93
	Sabari	300	174	168
	Akosombo	1,096	676	290

Conclusion

Effective water resources management is critical for successful adaptation to climate change. Although there remains great uncertainty about how climate change will impact the water resources of the basin it is clear that even under a mid-range scenario, the performance of existing and planned irrigation and hydropower schemes in Ghana could be severely constrained. Efforts for economic development will be undermined unless due consideration is given to the possible impacts of climate change and suitable adaptation measures introduced.

References

Andah W., van de Giesen, N., Huber-Lee, A. & Biney, C. A. (2004) Can we maintain food production without losing hydropower? The Volta basin (West Africa). In: J.C.J.H. Aerts & P. Droogers (eds) Climate change in contrasting river basins. CABI Publ. Wallingford UK, pp 181-194.

Arnold, J. G., Srinivasan, R., Muttiah, R.S. & Williams, J. R. (1998) Large area hydrologic modeling and assessment part I: model development. *J. Am. Water Resour. Assoc*. **34**(1):73-89

Barry, B., Obuobie, E., Andreini, M., Andah, W. & Pluquet, M. (2005) Volta River Basin Synthesis. Comprehensive Assessment of Water Management in Agriculture, IWMI.

Biney, C. (2010) Connectivities and linkages within the Volta basin. Available online at: http://www.gwsp.org/fileadmin/GCI_conference/Products/Pres_-_Biney_-_Connectivities.pdf.

Davin, E. L., Stoeckli, R., Jaeger, E. B., Levis, S. & Seneviratne, S. I. (2011) COSMO-CLM2: A new version of the COSMO-CLM model coupled to the Community Land Model, Clim. Dyn., published online, doi: 10.1007/s00382-011-1019-z de Condappa, D., Chaponnière, A., Lemoalle, J. (2009) A decision-support tool for water allocation in the Volta basin. *Water International*, **34**(1): 71-87.

Drechsel, P., Graefe, S., Sonou, M. & Cofie, O. O. (2006) Informal irrigation in urban West Africa: An overview. Colombo: International Water Management Institute.

IPCC. (2000) IPCC Special Report Emission Scenarios. A special report of IPCC working group III. WMO: UNEP

Jung, G., & Kunstmann H. (2007) High-resolution Regional Climate Modelling for the Volta Basin of West Africa. *Journal of Geophysical Research*, **112**, 17 pages.

Owusu, K., Waylen, P. & Qiu, Y. (2008) Changing rainfall inputs in the Volta basin: implications for water sharing in Ghana. *GeoJournal*, **71**: 201-210

Van de Giesen, N., Andreini, M., van Edig, A. & Vlek, P. (2001) Competition for water resources of the Volta Basin. Proceedings of symposium: Regional Management of Water Resources, Maastricht, The Netherlands.

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