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# The Nexus of Changing Climate and Impacts on Rainfed Water Supply and Fresh Water Availability for the Inhabitants of Densu Basin and Parts of Accra - Ghana, West Africa

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## Abstract

Hydrological modelling with downscaled climate data from a Regional Climate Model (RCM) was undertaken to determine the impact of climate change on the surface water resources of the Densu River Basin. This basin is largely a rural one that is the source of potable water supply to many parts of Accra and also provides life support for the communities living in and close to it. The aim of the study was to assess the resilience of the city of Accra to impacts of climate change on its water supplies. The adequacy of streamflows in the Lower Volta Basin as a source of water supply to Accra in the future under climate change was also ascertained. This river currently supplies about half of the water requirements of the Greater Accra Metropolitan Area (GAMA).Results of the study show that the Densu Basin streamflow is currently under stress conditions due to high water abstraction from the river for municipal and industrial water supplies. The climate change impact analysis indicates a reduction in streamflows in 2050 from the 1961-1990 baseline period as a result of general drying conditions projected for the basin. This future drying condition could result in rural agriculture in the basin shifting from largely rainfed at present to more irrigation. The result would be a substantially more upstream water abstraction from the Densu river system with dire consequences for downstream water supply to the city of Accra. However, the assessment of the streamflows of the Lower Volta River showed that these were adequate to meet the water supply requirements of GAMA even under climate change.It is recommended that an Integrated Water Resources Management (IWRM) plan be fully developed and implemented in the basin for the proper management of the water resources. In addition, the Lower Volta River, which has substantial flows, could be considered as a more reliable source of water supply to Accra.

**Keywords:** Densu Basin, Lower Volta, Streamflows, Rainfall and Climate Change

## 1. Introduction

The impact of climate change vulnerability varies globally. However, the adverse effect of climate change is particularly devastating in developing regions, especially Sub-Saharan Africa (SSA) (Kandji et al., 2006) as a result of rapidly declining precipitation levels, increasing temperatures, low adaptive capacity, high dependence on natural resources, inability to detect the occurrence of extreme hydrological and meteorological events due to low technology adoption (Kurukulasuriya and Mendelsohn, 2006), limited infrastructure, illiteracy, lack of skills, low management capabilities, weak institutions, and information (UNFCCC, 2007), and the absence of comprehensive national adaptation policy among others. While the direction of projected rainfall under climate change in SSA is not certain, an increase in the magnitude and frequency of occurrence of extreme rainfall events are envisaged (Kasei and Derbile, 2010; Mueller, 2009; Boko *et al*., 2007; TroFCCA, 2006; DFID 2004). Both urban and rural water supply will be under stress from these impacts.

Many cities in Africa are already under severe stress of inadequate water supply for livelihood support of their rapidly expanding populations. As cities and rural communities often share the same water resource such as a river basin, the potential for conflicts between them in the use of the resource exists and could be exacerbated by the impacts of climate change on water resources. To be able to manage these potential conflicts adequately and increase the resilience of particularly cities to the impacts of climate change on water resources, it is imperative that these impacts are properly investigated and understood. This would provide the necessary evidence and other information to facilitate the formulation, development and implementation of appropriate adaptation and conflict reduction measures.

To understand how water resources of a region are impacted upon by climate change, impact assessment and vulnerability studies are usually undertaken (Ringler et al., 2010; Mueller, 2009; Bates et al., 2008; Christensen et al., 2007). Such studies seek to provide answers to questions such as:

- How is the resource impacted upon and to what extent?
- What are the direct and indirect consequences of these impacts?
- Who and/or what is most exposed to these impacts and what is the exposure level?

- How vulnerable are the exposed groups?
- What adaptation measures can be implemented to increase the adaptive capacity and hence the resilience of those highly vulnerable?

Many climate change impact studies have been carried out or are on-going in Africa – in sectors such as agriculture, water resources, transport, fisheries and energy (Chinowsky *et al*., 2011; Ringler *et al*., 2010; Allison *et al*., 2009; Karekezi *et al*., 2009; EPA, 2008; Bates *et al*., 2008). For impacts on water resources, for example, studies in Ghana (Obuobie *et al*., 2010; CSIR-WRI, 2000), Burkina Faso (World Bank, 2011), Ethiopia (Kim *et al*., 2008; Tarekegn and Tadege, 2006), South Africa (Schulze *et* ***al***., 2005) and other Sub-Saharan Africa countries show that climate change has many adverse impacts on water resources and that most of the populations and natural systems are exposed to and are highly vulnerable to these impacts. Impact studies in Ghana showed increased temperatures and evapo-transpiration, decreased and highly variable rainfall patterns, and more frequent and pronounced dry spells in the selected representative river basins of the country (CSIR-WRI, 2000). However, what is not adequately articulated in these studies is the implications of the impacts on the urban-rural interface, i.e., how these impacts affect the level of dependence of urban centres on outlying rural areas, particularly where cities share water resources with these rural communities; and how they affect the potential for conflicts between cities and rural areas in the use of shared water resources under stress. Such an understanding is necessary for the design of measures to improve the resilience of such cities to the impacts on water resources from change in climate.

This study sought to investigate the impact of climate change on surface water resources of the Densu River Basin which provides about half of Accra and its immediate environs water supply which inhabits over 5 million people. Therefore, it was also the aim of the study to ascertain the level of vulnerability of the city to these impacts and to identify appropriate measures that could be adopted to improve the resilience of Accra to the impacts. The research included an assessment of the current (as at end of 2011) water availability and use in the Densu Basin; an assessment of the adequacy of the Lower Volta River flows to meet the current and future potable water supply requirements of Accra; and a hydrological modelling of the projected impact of climate change on the future surface water availability in the Densu River system using downscaled climate change data from a Regional Climate Model (RCM). The focus was on the surface water resources of the basin since in Ghana the bulk of water abstraction from river basins is from surface water sources.

## 2. The study area

### 2.1 The Densu Basin

The Densu Basin is one of the river basins in the Coastal River Basin System of Ghana. It extends from latitudes 5°30’ and 6°17’ N and longitudes 0°10’W and 0°37’ W (Figure 1). The basin spans 3 administrative Regions and 12 Metropolitan, Municipal and District Assemblies of the country. About 72% of the basin lies within the Eastern Region, 23 % in the Greater Accra Region and the remaining 5% in the Central Region. The Regions, Districts and the basin spans are indicated in Figure 1. It is a major source of water supply to over 540,000 people living in the urban settlements of Koforidua, Suhum, Nsawam and the western parts of Accra (WRC, 2010).

Nearly 40% of the economically active population in the basin is involved in agricultural activities which include cultivation of cash crops (cocoa, oil palm, papaya, pineapple, mangoes and citrus), food crops (cassava, maize, yam, plantain, banana and cocoyam) and vegetables. Fishing is also practised along the river (ADRA International, 2008).

The basin drains a total of about 2,600 km² to the Gulf of Guinea in the southern part of Ghana. The main Densu River flows a distance of nearly 120 km from its head waters at the Atwiredu range of hills in the north of the basin to the Gulf of Guinea. It enters the sea through the Densu Delta, a protected Ramsar site covering an area of around 50 $km^2$ and comprising the Sakumo lagoon, salt pans, sand dunes and flood plains of the river. The river is dammed at Weija, creating the Weija reservoir (Figure 1) that supplies about half of the potable water requirements of Accra. Agricultural, industrial and land use activities along the course of the river have significantly reduced its water quality (WRC, 2010). The main tributaries of the river include the Pompon, Kuia, Adaiso and Nsaki rivers.

The basin is influenced by two distinct climatic conditions; the dry equatorial climate of the south-eastern coastal plains and the wet semi-equatorial climate further north from the Gulf of Guinea forcing bimodal rainfall seasons with marked variations in the intensity, duration and seasonal distribution (WARM, 1998; WRC, 2007). Figure 2 shows the mean monthly rainfall distribution at Nsawam summarized from 1961-2009 obtained from the Ghana Meteorological Agency (GMet). The doubly peaked (bimodal) rainfall distribution shown in the figure is typical of the basin. The months of March to July and September to November are the major and minor rainfall seasons, respectively. The dry season from December to February is severe with negligible rainfall and high temperatures (WRC, 2007).

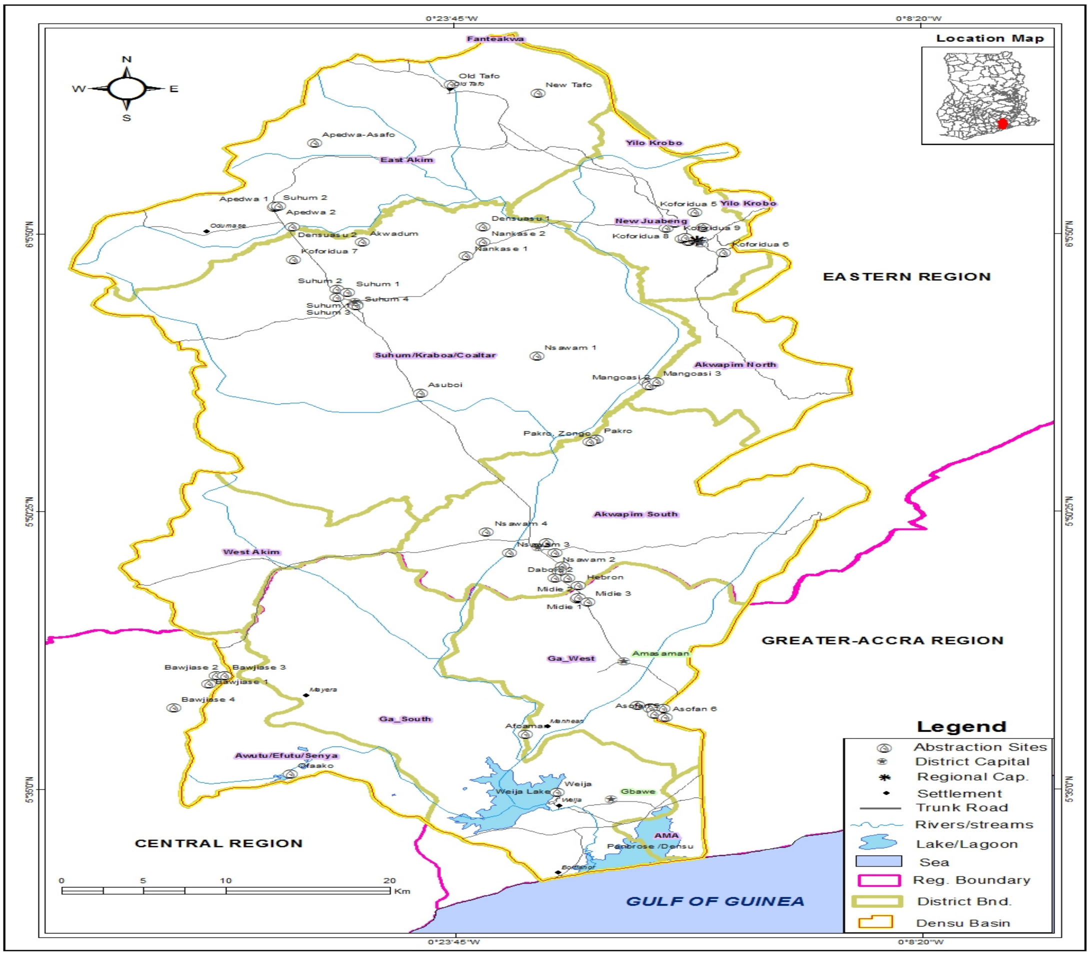


**Figure 1**. Location and drainage map of the Densu Basin

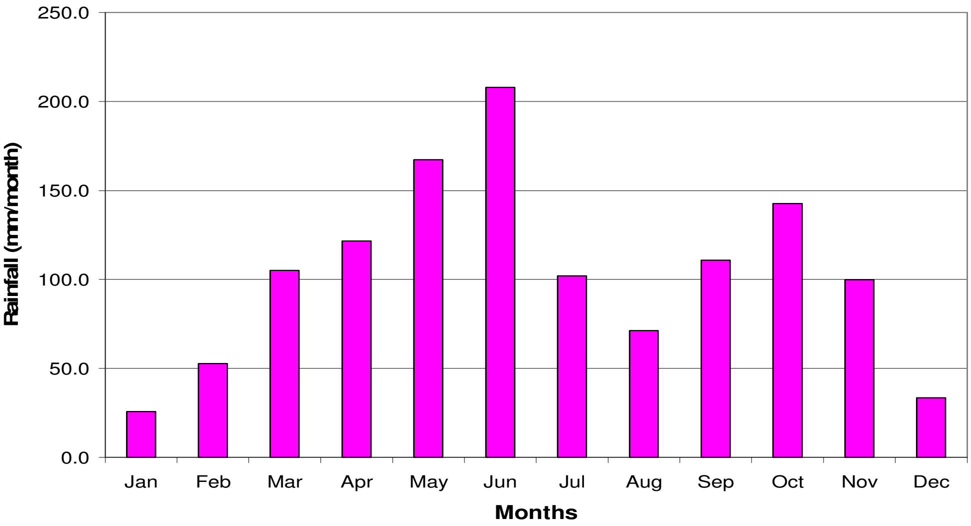


**Figure 2.** Mean monthly rainfall at Nsawam (see Figure 1 for location) from 1961-2009 showing bimodal rainfall distribution of the area typical of the basin (Source: GMet)

The mean annual rainfall varies between 800 mm near the coast to about 1,700 mm at the source of the river (Figure 1; Tay and Kortatsi, 2008). Temperatures in the basin are uniformly high throughout the year, with mean monthly temperature ranging from 23°C in August to 32°C in March and April (WRC, 2007).

The Densu river discharge is seasonal and follows the rainfall trend. The dry season flow ranges from 0.0 - 0.74 $m^3/s$, while the high flows occur during the rainy season with values ranging between 2.2 $m^3/s$ and 5.7

m³/s at Manhia (Nii Consult, 2001).

## 2.2 The Lower Volta River

The Lower Volta River is that reach of the Volta that is below the Akosombo hydroelectric dam (Figure 3). This river and the Densu are the two main sources of water supply to the city of Accra and the Greater Accra Metropolitan Area (GAMA) which extent is shown in Figure 4. There is a smaller hydroelectric facility on the river located at Kpong about 40 km downstream of Akosombo. This facility is operated in tandem with Akosombo because of the negligible storage behind it (VRA, 2011), so that the flow just downstream of Kpong is equivalent to the outflow (turbine water) from the Akosombo facility. Since water abstraction from the Volta Lake for consumptive use is very small, the Lower Volta annual streamflow is usually taken as the annual inflow to the lake.

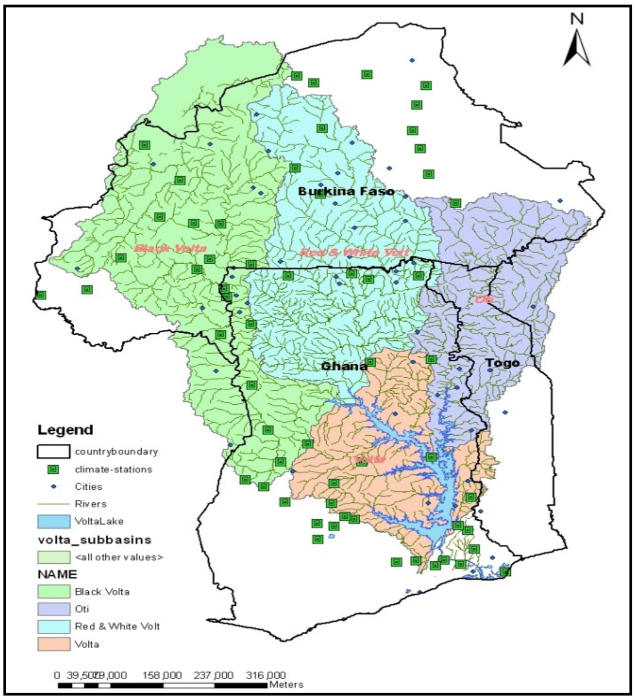


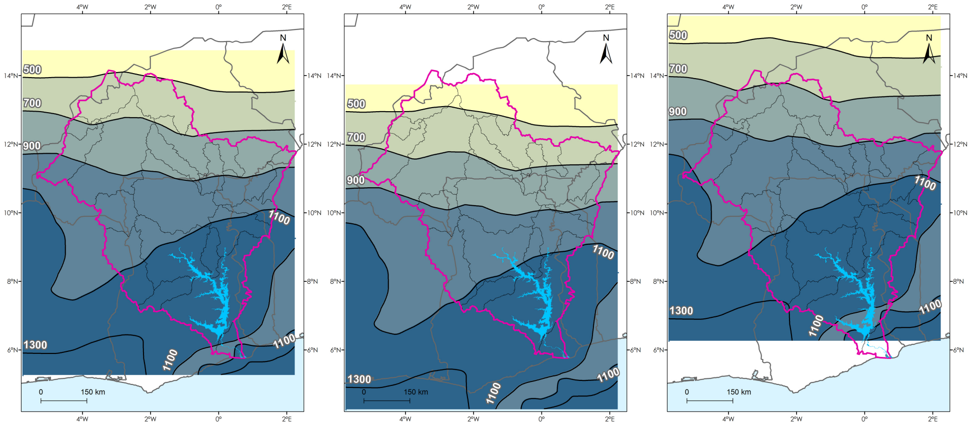
**Figure 3**. Map of the Volta Basin

**Figure 4**. Map of Greater Accra Metropolitan Area, GAMA

It has been shown that climate change has a much greater impact on inflows to the Volta Lake and hence the Lower Volta flows than the upper basin water abstractions such as through small reservoirs (de Condappa et *al*., 2008). The de Condappa *et al*. (2008) study used 1980-2000 as the baseline period and examined the impact of climate change on inflows to the Volta Lake relative to the estimated inflow of 29.1 x $10^9$ $m^3$ for the baseline. Two climate change scenarios were used: a dry and wet scenario. The dry scenario was simulated by shifting the isohyets for the basin $1^o$ southwards (Figure 5(b)) from the baseline distribution (Figure 5(a)) to mimic the dry conditions in the basin in the 1970s (the Sahelian drought). For the wet scenario, the isohyets were shifted $1^o$ northwards (Figure 5(c)) from the baseline distribution.

The study showed that for the dry scenario, the mean annual inflow to the Volta Lake reduces to 24.2 x $10^9$ $m^3$ from the baseline figure whilst for the wet scenario, mean annual inflow increases to 33.5 x $10^9$ $m^3$. The study points out that it is only in the wet climate change scenario that the level of hydropower generated at Akosombo in 1990 that resulted in a turbined-water of 31.5 x $10^9$ $m^3$ can be maintained. However, even under, the dry scenario, the projected Lower Volta mean annual streamflow (24.2 x $10^9$ $m^3$) is still large.

In this current study, the results from de Condappa *et al*. (2008) were used to assess the adequacy of the Lower Volta streamflows to support the Densu as a source of water supply to meet all the potable water requirements of GAMA into the future, even under climate change conditions.



a) b) c)

**Figure 5.** Spatial distribution of rainfall (1980-2000) for the climate change scenarios. Baseline (a), Dry scenario with isohyets shifted $1^o$ southwards (b) and Wet scenario with isohyets shifted $1^o$ northwards (c). Both shifts relative to the baseline - (adopted from de Condappa *et al*., 2008)

## 3. Methodology

### 3.1 Assessment of current Densu Basin water stress conditions

A list of water users with water abstraction licenses from the Water Resources Commission (WRC) of Ghana was compiled from the WRC. Field visits were then made to the basin to interview these users and those who didn't need permits to abstract water from the basin because their abstraction levels were too low. These interactions enabled us to obtain information on current annual water abstraction rates from the basin. WRC (2007) used a simple water balance analysis and sub-basin areas to determine the long term mean annual streamflow for various sub-basins of the Densu. These mean flows were used with the water abstraction rates obtained from the field visits to determine the vulnerability of the surface water resources of the basin.

### 3.2 Assessment of the Lower Volta River streamflows.

As indicated earlier, the Lower Volta River and the Densu are the two main sources of potable water supply to Accra. Figures on current and planned water supply to GAMA were obtained from the Ghana Urban Water Company Ltd (GUWCL) and compared to the flows of the Lower Volta River to determine the adequacy of the flows to meet the water supply requirements to GAMA. The streamflows as obtained by de Condappa et al. (2008) for climate change conditions were used.

### 3.3 Modelling the impact of climate change on Densu streamflows

The framework for modelling the impacts of climate change on the Densu streamflows is presented in Figure 6. GCM output data for the IPCC Special Report on Emission Scenarios (SRES) A1B and B1 were downscaled to a $0.5^o$ x $0.5^o$ (55 km x 55 km) grid for the Densu Basin using the Regional Climate Model (RCM) RegCM4. A deterministic semi-distributed model, the Hydrologic Engineering Centre Hydrological Modeling System (HEC-HMS), was then calibrated and validated with historical climate and streamflow data and run with the downscaled data to obtain simulated streamflows for the Densu River system for the scenario periods. These streamflows were then compared with observed historical streamflows of the river system to determine the impacts of climate change on surface water availability in the basin.

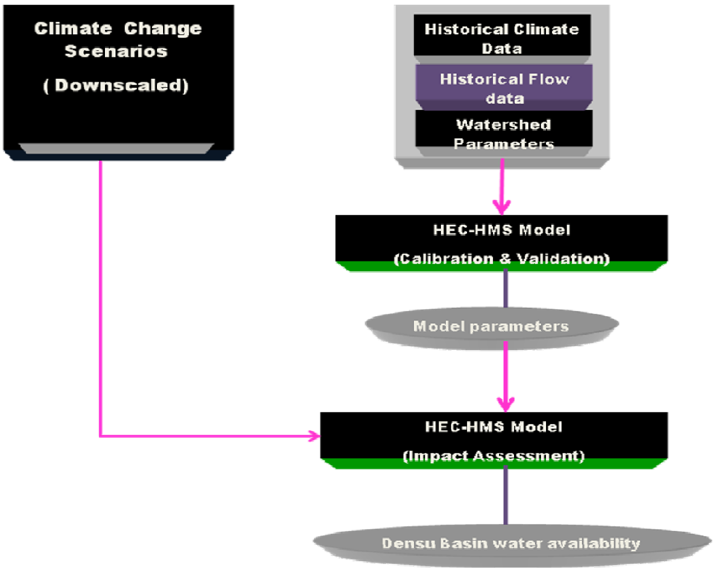


**Figure 6.** Hydro-climatic modelling framework for the Densu Basin water availability under climate change.

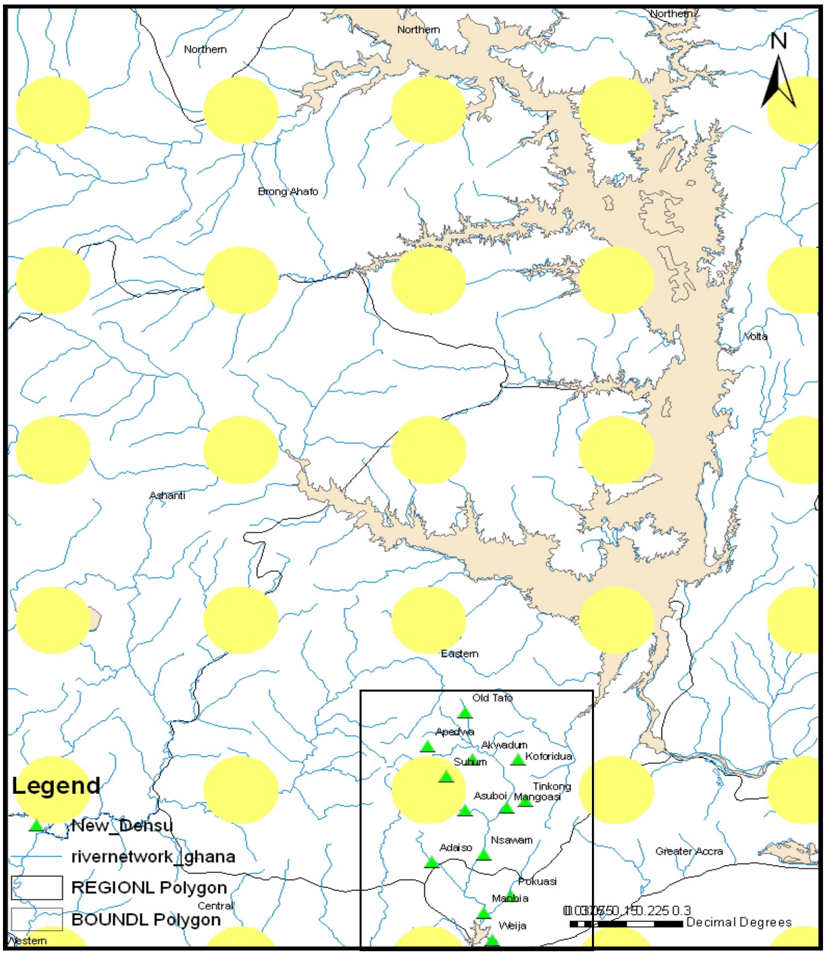


**Figure 7.** Locations of the meteorological stations and the grid points of the downscaled RegCM4 output at 55 km grid in the basin

The HEC-HMS software is a deterministic semi-distributed hydrologic model developed by the

Hydrologic Engineering Centre (HEC) of the US Corps of Engineers. The version used in this study (HEC-HMS Version 3.4) can be applied for both event-based precipitation-runoff simulation of surface hydrology and continuous simulation of dendritic watershed systems (HEC, 2009). It includes components for precipitation, potential evapo-transpiration, snow melt, canopy interception, surface storage, infiltration, surface runoff, baseflow, channel routing and channel losses. The continuous simulation mode is recommended for long-term runoff forecasting (McEnroe, 2010), as in the case of this study. HEC-HMS features a completely integrated work environment including a database, data entry utilities, computation engine, results reporting tools and is adaptable to a wide range of geographical regions, data availability, spatial and temporal scales. The output of the model can be used for water availability and streamflow forecasting (HEC, 2009).

### 3.3.1 Extraction of station meteorological data from output of regional climate model

Two different sets of simulated daily data on rainfall and minimum and maximum air temperatures at a high spatial resolution (55 km x 55 km) were obtained from the output of the 3-dimensional RCM (RegCM4) to assess the climate change impact on the surface water availability of the basin. These are:

- Gridded meteorological (meteo) data for the baseline period (1961-2000) and
- Gridded meteo data for the period 2001-2050 under the A1B and B1 scenarios.

In addition, observed daily rainfall and mean daily temperatures for the baseline period were available for 6 meteorological (meteo) stations in the basin. Figure 7 shows the locations of the meteo stations and the grid points of the downscaled RegCM4 output at 55 km grid in the basin. The HEC-HMS model was run on meteo and river gauging station data. Therefore, it was necessary to extract meteo station data from the RCM gridded data for the simulated baseline and climate scenario periods. The inverse distance weighting (IDW) method (Sluiter, 2008; Dudziak, 2007) was used to extract meteo station data from the nearest four grid points to the station. The procedure is presented in equation 1:

$$R_i = \frac{\left(\frac{R_{i1}}{d_{i1}} + \frac{R_{i2}}{d_{i2}} + \frac{R_{i3}}{d_{i3}} + \frac{R_{i4}}{d_{i4}}\right)}{\left(\frac{1}{d_{i1}} + \frac{1}{d_{i2}} + \frac{1}{d_{i3}} + \frac{1}{d_{i4}}\right)} \tag{1}$$

Where $R_i$ is the interpolated meteo data from the RegCM4 outputs at the meteo station i, $R_{i1}$, $R_{i2}$, $R_{i3}$, $R_{i4}$ are the respective values of the RegCM4 meteo data outputs at the four nearest grid points to the station and $d_{i1}$, $d_{i2}$, $d_{i3}$, $d_{i4}$ the corresponding distances of the grid points from the station.

### 3.3.2 Hydrological modeling with HEC-HMS

The basin was divided into five sub-basins, each sub-basin representing an area drained by one or more rivers (Figure 8). The Densu basin model was created and added to the HEC-HMS project by using the *basin model manager*. The hydrologic elements including sub-basins, reaches and junctions were added to the basin model by selecting and placing them at the desired location in the basin map. Each hydrologic element was connected from upstream to downstream to reflect the drainage of the real Densu watershed, represented by 5 sub-basins, 3 routing reaches and 4 junction elements (Figure 8). The global editor included in HEC-HMS was used to enter the parameters for all the hydrologic elements. Based on the number of meteo stations with data available in the basin, six new precipitation gauges were created in the hydrologic model using the time series data manager of HEC-HMS. These stations are Apedwa, Nsawam, Mangoase, Pokuase, Asuboi and Manhia (see Figure 7 for their locations). Similarly, a river discharge gauge was created for the observed hydrograph in the basin at Manhia from the time series data manager. Manhia is the gauging station on the main river just upstream of the Weija Dam. The observed flow at the gauge at Manhia was used for calibrating and validating the model.

Before making any model runs, a sensitivity analysis was first conducted to identify the most sensitive parameters of the hydrologic model. These were the parameters that were given more attention during model calibration. Next, a manual calibration was performed using observed meteo station daily rainfall and air temperature at the 6 meteo stations in the basin and observed daily streamflow at Manhia. The model was then allowed to automatically optimize the parameter values for mean daily stream flow. It was then validated with a different set of observed meteo station daily rainfall and air temperature at the 6 meteo stations and observed daily streamflow at Manhia.

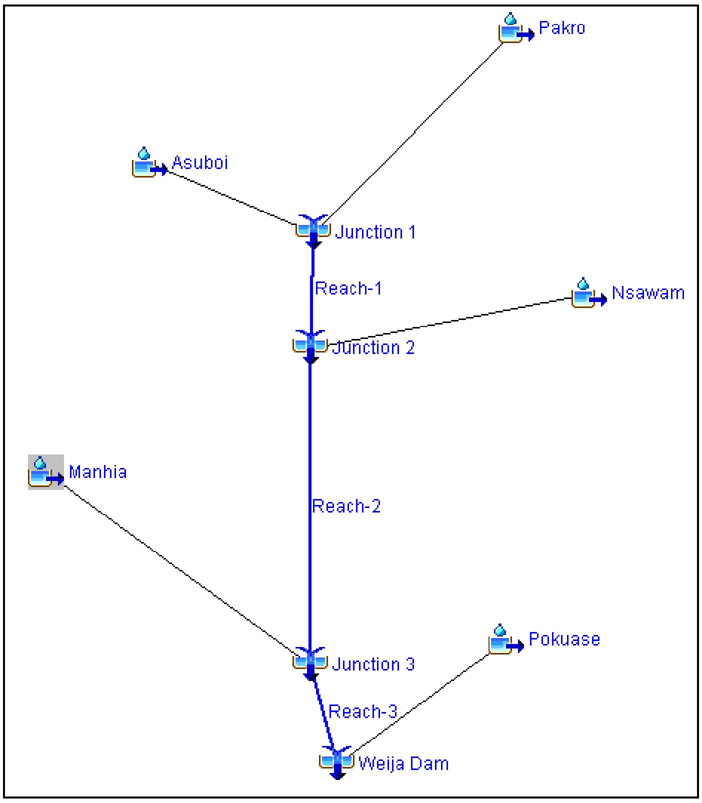


**Figure 8**. Densu Basin elements implemented in HEC-HMS

The validated model was then run in simulation mode driven by meteo station RCM data for the 6 stations in order to obtain predicted streamflows in the basin for the climate change scenario periods under the two SRES scenarios used.

It has been observed that output from RCMs exhibit biases when the simulations for the baseline period (control simulations) are compared to the observed baseline data (Lawrence and Hisdal, 2011; Sennikovs and Bethers, 2009; Schulze *et al.*, 2005). Therefore, the temperature and rainfall data extracted from RegCM4 were not used directly in HEC-HMS but were first bias-corrected using the perturbation of observed data (POD) version of the delta method. This method has been found to yield satisfactory results for predicted mean streamflows (van Roosmalen *et al.*, 2011; Ramirez-Villegas and Jarvis, 2010; Teutschbein and Seibert, 2010). Mean monthly changes in simulated climate output between the baseline period (1961-1990) and future (2001-2020, 2021-2050) periods were transferred to the observed baseline data to obtain the bias-corrected future climate data for the impact analysis. Equations 2 and 3 were used for deriving bias-corrected future meteo station daily mean temperature ($T_{f,daily}$) and daily rainfall ($P_{f,daily}$), respectively, from the observed baseline and RCM simulated data:

$$T_{f,daily} = T_{o,daily} + \left(\overline{T_{f,monthly}} - \overline{T_{p,monthly}}\right) \qquad (2)$$

$$P_{f,daily} = P_{o,daily} \frac{\overline{P_{f,monthly}}}{\overline{P_{p,monthly}}} \qquad (3)$$

where $T_{o,daily}$ is the observed daily temperature; $P_{o,daily}$ is the observed daily rainfall; $\overline{T_{f,monthly}}$ is the mean monthly simulated future temperature; $\overline{T_{p,monthly}}$ is the mean monthly simulated baseline temperature; $\overline{P_{f,monthly}}$ is the mean monthly simulated future rainfall; and $\overline{P_{p,monthly}}$ is the mean monthly simulated control rainfall.

### 3.3.3 Climate change impact assessment of future basin water availability

Impact assessment was made by comparing the mean annual simulated streamflows for the climate change scenario periods (1991-2020, 2021-2050) to observed mean flows or simulated flows with observed baseline meteo data. Both mean flows at Manhia (just upstream of the Weija Dam) and total mean inflows to the Weija Lake were used for the assessment.

## 4. Results and Discussion

### 4.1 Current Densu Basin water stress conditions

Table 1 summarizes the current water availability and use in the Desnsu basin. The water availability figures were estimated from field interviews of water abstraction license holders in the basin. The table shows that current water abstraction upstream of the Weija Dam is small; just 1% of annual flow of the river. The main reason for this low abstraction is that both spatial and temporal rainfall distributions are good in these parts of the basin so that agriculture is largely rainfed. In addition, local industries and businesses are still too small to abstract water in any appreciable quantities. Most of the communities upstream of the Weija dam are rural with small domestic water use. On the other hand, water abstraction from the Weija dam is mainly to supply the potable water needs of urban and peri-urban Accra which is considerably higher – about 33% of the annual streamflow of the Densu River. At a total basin water abstraction rate of 34% of total surface water availability, the Densu Basin can be described as being under water stress conditions already (Raskin *et al.*, 1997). Nevertheless, the situation is that at the moment upstream water abstraction levels (see Figure 1 for the location of water abstraction sites) pose no threat to water availability for the use of the city of Accra.

### 4.2 Adequacy of the Lower Volta River flows

Lower Volta streamflows under the dry and wet climate change scenarios of de Condappa *et al.* (2008) are shown in Table 2. Data from the Ghana Urban Water Company Ltd (GUWCL) shows that current annual potable water production from both the Weija Dam and the Lower Volta River for supply to GAMA is almost 127 x $10^6$ $m^3$.

**Table 1.** Surface water availability and use rate in the Densu Basin (as at December, 2011)

| **Point of Water abstraction** | **Rate of abstraction ($10^6$ $m^3$/yr)** | **Estimated basin streamflow (WRC, 2007) ($10^6$ $m^3$/yr)** | **Percent abstraction** |
|---|---|---|---|
| Weija water supply scheme | 93.1 | | 33.2 |
| Weija Irrigation Project | 0.0 | | 0.0 |
| Other points | 3.6 | | 1.3 |
| **Basin Total** | **96.7** | **280.0** | **34.5** |

**Table 2.** Lower Volta streamflows under the dry and wet climate change scenarios of de Condappa *et al.* (2008) and percentage levels of abstraction for GAMA water supply.

| **Climate change scenario** | **Annual renewable water for the Lower Volta ($10^9$ $m^3$)** | **Water withdrawals for GAMA** | | | |
|---|---|---|---|---|---|
| | | **2011** | | **2015** | |
| | | **Volume ($10^9$ $m^3$)** | **Percent of Lower Volta Flows** | **Volume ($10^9$ $m^3$)** | **Percent of Lower Volta Flows** |
| Baseline | 29.1 | 0.127 | 0.44 | 0.223 | 0.77 |
| **Dry scenario** | **24.2** | **0.127** | **0.52** | **0.223** | **0.92** |
| Wet scenario | 33.5 | 0.127 | 0.38 | 0.223 | 0.67 |

There are plans to increase the water supply to GAMA from both sources to nearly 223 million $m^3$ annually by 2015. As indicated in Table 1, both the current and planned near future water abstractions constitute a tiny fraction of the available Lower Volta streamflow, even under the dry climate change scenario. Therefore, the Lower Volta flows are adequate to meet all current and future potable water demands of Accra.

### 4.3 Impact of climate change on River Volta streamflows

The spatial dynamics and distribution of the period 1961-1970 was simulated for the Volta Basin using the calibrated and validated WaSiM Volta model (Figure 9). Maximum discharge is simulated for most of the southern parts of the basin conforming to the maximum rainfall within that area with a large gradient. Daily mean evaporation is also high in the south compared to the dryer north driven by availability of moisture in the south compared to the north. The soil water content is relatively lower in the north and this trend could be due to many factors such as rainfall and potential evapotranspiration, vegetation cover, soil properties among others. The general gradient in the temporal and spatial distribution of the basin is strongly influenced by the spatial distribution of rainfall, discharge and evapotranspiration which vary widely between the north and south of the basin; such gradient is not however visible between the east and west of the basin.

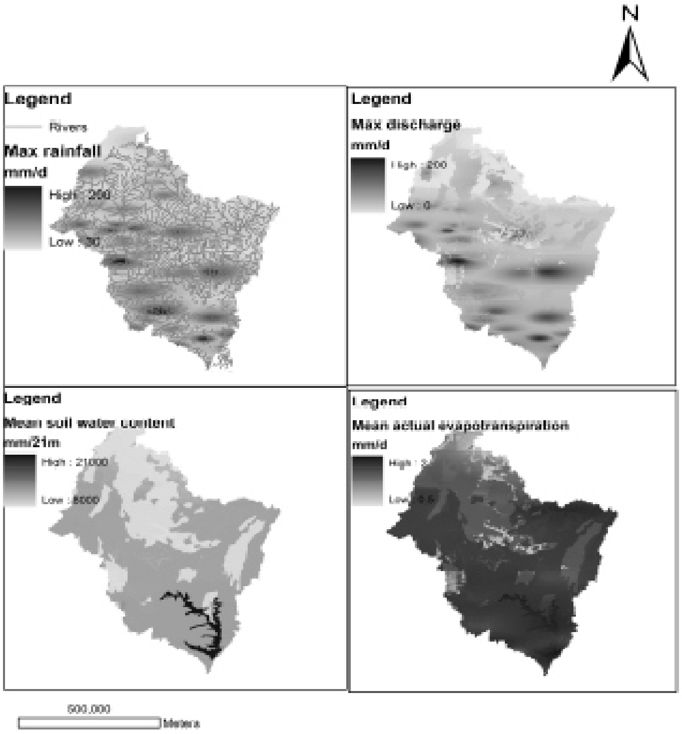


**Figure 9**. WaSiM Volta-simulated dynamics of the Volta Basin for the period 1961-1970 (Kasei, 2009).

The combined transpiration from vegetation and evaporation from surfaces follows the same trend as the rainfall (Figure 10), with slight increases over time. Generally, annual mean evaporation in the north has increase from 823 mm (past) to a little over 900 mm from the present to expected future. The south records a relatively low evapotranspiration compared to the north, mainly due to lower temperatures in the south, but has also realized a general increase in annual mean of 872 mm (past) to 893 mm (future).

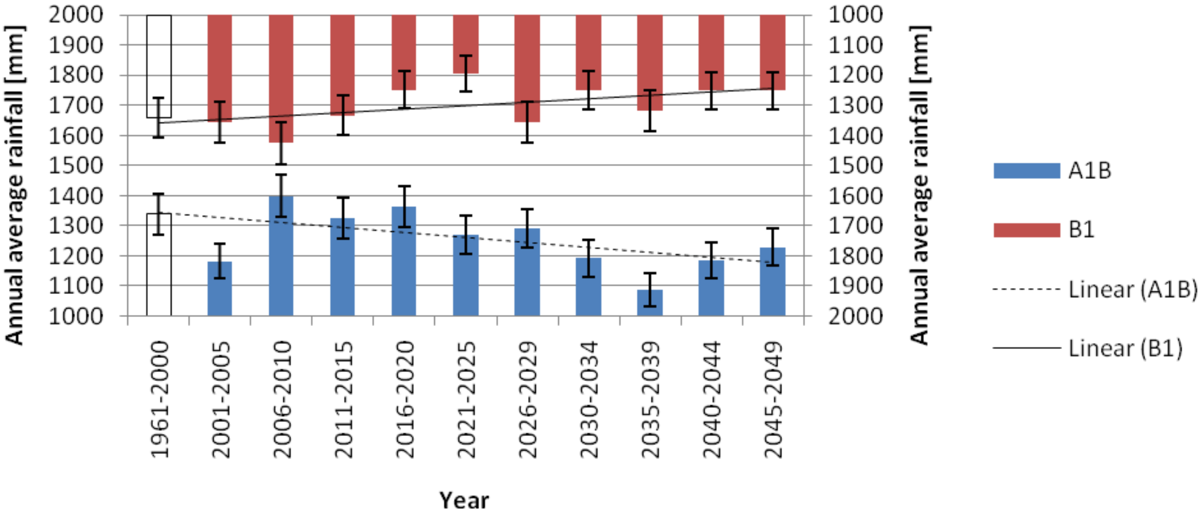


**Figure 10**. RegCM4-simulated compared to observed (mean over 4 years) rainfall including standard deviation (over the period) and trend lines of rainfall at the north of the catchment of the Volta Basin

Total annual discharge is expected to reduce between 2 % to 4 % for the northern part of the basin, with an increase of between 30 % and 35 % of potential evapotranspiration and an increase of about 3 % in actual evapotranspiration. For the south of the basin, REGCM4's A1B scenarios project a 3 % increase in discharge whiles the B1 scenarios project a 9 % decrease in discharge. Both scenarios however project between 8 % and 10

% increase in evapotranspiration. Potential evapotranspiration is expected to decrease under the A1B scenarios but an increase of about 8 % is expected under the B1 scenarios.

## 5. Conclusions

The science of the future climate is plagued by uncertainties. Most climate change scenarios predict for the region of West Africa a decline in precipitation in the range of 0.5–40 % with an average of 10–20 % by 2025. Though other scenarios predict the contrary, many scenarios portray a more pronounced downtrend in flow regimes. As a result of the recent major droughts and a number of floods with unusual magnitudes, climate specialists expect exacerbated extreme climate events in some parts of West Africa (IUCN, 2004). In the wake of all these predictions, it is important to point out that the climate change scenarios do not consist of definite predictions, but rather present plausible future conditions. According to Carter and La Rovere (2001), within climate change studies, high uncertainty requires the use of scenarios that are plausible but usually have no probability attached to them.

Considering the many possible future scenarios, what matters is the ability to manage the uncertainty. This includes reducing current vulnerability of society and communities to climate variability and extreme events as well as improving and updating management options to deal with the worst-case scenarios and also take advantage of opportunities that may arise.

A comparison of wet and dry years in the Volta basin shows that the ratio of direct runoff and base flow is at an average of 30 %, being high in the wet years and a sharp decline in the dry years. It is observed that total percentage discharge and surface flow have increased in the north which might be good for dugouts and streams; the opposite is true for the south. The probability of daily average discharge falling below 1 mm is expected to increase from 0.47 in the “past” to 0.75 for the “future” time slice of 2030 to 2039 in the south of the basin, thus increasing the frequency of low flow occurrences. Temperature is rising over the years, which cause increases in evapotranspiration, and hence annulling any surplus that might have been gained with the increase of rainfall amounts. With increase in population; increasing demand for food and water use, coupled with poor water management practices and increasing risk of climate change, the resultant impacts could reach undefined proportions for over 5million inhabitants of the Densu Basin**.**

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