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Modelling in the Semi Arid Volta Basin of West Africa

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1. Introduction

A region is said to be semi-arid when it receive precipitation below potential evapotranspiration thus insufficient water in the soil (excess to the wilting point) which to the extent support less growth and development of plant and animal life as compared to arid region which is characterized by a severe lack of available water, to the extent of hindering or even preventing the growth of primary life. The arid and semi-arid regions are fairly distributed within the earth's surface (Figure 1)



Fig. 1. Spatial distribution of arid and semi-arid regions of the earth (Shaded)

Semi-arid climates tend to support short or scrubby vegetation, with areas usually being dominated by either grasses or shrubs which can be called xeric. The climate of West Africa, particularly in the Sahelian zone has been undergoing recurrent variations of significant magnitude, particularly since the early 1970's.

Countries in Africa boarded with arid and semi-arid zones extend to north and south of the equator including, Senegal, Upper Volta and Chad Morocco, Algeria, Libya, and Egypt,

Lesotho, parts of the Cape, Botswana; Namibia The zones extend southeast through Somalia and Northern Kenya and parts of Zimbabwe. Semi-arid zones also extend to the northern part of Ghana and Burkina Faso of the Volta Basin in West Africa (Figure 2).



Fig. 2. Extension of arid areas in Africa

According to reports, these regions have experienced a marked decline in rainfall and hydrometric series around 1968–1972, with 1970 as a transitional year ((Ajayi (2004) and Kasei (2009)). Research also found a decline in average rainfall, before and after 1970, ranging from 15 % to over 30 % depending on the area. This situation resulted in a 200 km southward shift in isohyets. Statistically, significant changes have been realized in the last century. Climatologically, Precipitation in semi-arid zones results largely from convective cloud mechanisms producing storms typically of short duration.

2. The Volta Basin

The Volta River Basin is located between latitudes 5°N and 14°N and longitudes 2°E and 5°W (Figure 3). It has a surface area of about 414 000 km2 covering areas in six riparian West African countries (Benin to the east, Burkina Faso to the north, Côte d'Ivoire to the west, Mali, Togo and Ghana to the south). The total basin population is estimated at a little over 19 million inhabitants, with an annual growth rate estimated at 2.9% (Green Cross International, 2001). The hydrographical network of the basin is delineated into three main subcatchments: the Mouhoun (Black Volta), the Nakambé (White Volta) and the Oti River. Apart from the huge network of rivers, the basin is dotted with a number of reservoirs, ponds and dugouts. In areas where surface water is inadequate, groundwater



Fig. 3. Volta River Basin of West Africa (Source: GLOWA Volta project and Google map)

resources are used by those small communities for domestic and irrigation purposes; and since the communities depend on rainfed agriculture which have recently failed due to poor rains, irrigation has become the best alternative to food production. According to the World Bank report (1992), groundwater resources are relatively of good quality and usually need minimum treatment. Many communities, both rural and urban, within the basin depend largely on groundwater for their water needs. Data is scarce on groundwater level fluctuation and recharge, but in some areas a high recharge is observed. Runoff is essential for hydropower generation which is a major source of energy for the countries within the Basin. Reduction in flows has rendered the hydropower systems vulnerable and shows no sign of ending any time soon. Since the Akosombo hydroelectric dam was constructed in 1964, discharge has barely reached 1000 m3 s-1 and recent records show a further decline.

The semi-arid regions have variable rainfall pattern with extreme cases of drought and sporadic flood and has an annual average rainfall between 1,150 mm in the north and 1,380 mm in the south, According to Ajayi (2004), the semi-arid regions have one rainy season which begins from April and peaks up in July, August, and September and gradually end with some showers in October and part rainfall distribution in the northern part of the basin spatially variable with the intensity ranging between 2 mm/hr to 240 mm/hr and a median intensity of about 70 mm/hr. Rainfall duration is generally short with an average of about 30 to 50 minutes, but some events are longer especially the monsoon rainfall which is also common in the study area. In contrasting, other regions in the basin such as the humid forest have bimodal rainy seasons with a mean annual rainfall between 1500 mm and 2000 mm. Generally, a good amount of rainfall normally occurs and measured during the wet season which is influenced by the South-West Monsoons. The wet season is characterized by two main rainfall regimes with two distict modes, The first occuring from March to July with a peak in June, and the second from September to November with its peak in September/October.

The dry season in semi-arid region starts from November to April with dry hamattan winds with low humidity mostly in January and February and high sunshine in part of February, March and April suitable for the growing of horticultural crops like tomatoes, pepper, onions, watermelons, okro and other leafy vegetables. Most of the rains in the region fall as thunderstorm. The temperature is between 27°C and 36°C. Potential evapotranspiration in the northern part of the basin is high compared to the southern part. According to Amisigo (2005), it varies both spatially and temporally with an annual mean varying from 2500 mm in the north to 1800 mm in the coastal zone. In other words, evaporation in this semi-arid climate exceeds precipitation for 6-9 months, in the sharply contrasting, sub-humid climate precipitation exceeding potential evaporation in 6-9 months of a year (Hayward and Oguntoyinbo, 1987).

Remote sensing information of the land surface is important in solving and managing water resource problems in arid and semi-arid regions. It is important that regional water and energy balance models developed most especially in arid and semi-arid regions of West Africa in the Volta Basin. The uncertainty involved in both remote sensing information and regional water and energy balance models, it is crucial that data assimilation methods are applied to improve the accuracy of these management tools

A thorough literature review on models used on large watersheds that incorporated landuse changes, runoff and soil characteristics of watersheds and basins explains that hydrological models are inherently imperfect in many ways because they abstract and simplify "real" hydrological patterns and processes. This imperfection is partly due to the scale of the catchment against the backdrop that most hydrological modeling is based on regionalization of hydrologic variables, with constituent process and theories essentially derived at the laboratory or other small scales (Blöschel, 1996, Brown and Heuvelink 2005). The underpinned assumption of catchment homogeneity and uniformity and time invariance of various flow paths over watersheds and through soils and vegetation underscores the embedded processes such as channel hydraulics, soil physics and chemistry, groundwater flow, crop micrometeorology, plant physiology, boundary layer meteorology, etc.(Brown and Heuvelink, 2005). All the flaws of hydrological modeling notwithstanding, process-based distributed models have proven to simulate fairly well the spatial variability of the water balance among other processes when the main hydrological parameters and processes are known (Schellekens, 2000). Until recently, there has not been an alternative to hydrological simulation of watersheds that incorporate spatial scenarios such as land use changes. A typical hydrological model follows the protocols of figure 4

3. Regional climate modelling

Given the discernable evidences of climate change due to natural or/and human activity, there is a growing demand for the reliable climate change scenario in response to future carbon dioxide emission forcing climate viriables. One of the most significant impacts of climate change can be that on the hydrological process. Changes in the seasonality and the low and high rainfall extremes can influence the water balance of river basins, with several consequences for cities and ecosystems. In fact, recent studies have reported that West Africa is regarded to be a highly vulnerable region under global warming, especially for water resources; coupled with population rises in communities. Given the discernible evidences of climate change due to natural or/and human activity, there is a growing

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Fig. 4. Common protocol of hydrological modelling

demand for the reliable climate change scenario in response to future carbon dioxide emission forcing climate variables downscaling system using the Regional climate models with mosaic-type parameterization of subgrid-scale topography and land use are preferred.

Downscaling climate data is a strategy for generating locally relevant data from Global Circulation Models (GCMs). The overarching strategy is to connect global scale predictions and regional dynamics to generate regionally specific forecasts. Downscaling can be done in several ways. The two most prefered methods are: i) Nesting a regional climate model into an existing GCM is one way to downscale data. To do this, a specific location is defined and certain driving factors from the GCM are applied to the regional climate model. A regional

climate model is a dynamic model, like a GCM, but it can be thought of as being composed of three layers. One layer is largely driven by the GCM, another layer builds on some locally specific data, and the third layer uses its own physics based equations to resolve the model based on data from the other two. The results are comparatively local predictions that are informed by both local specifics and global models. This process requires significant computational resources because it is dependent on the use of complex models. Currently Canada has just one Regional Climate Model (CRCM). ii) the use of statistical regressions which has a variety of such methods ranging from multiple regressions that link local variables to particular drivers in GCMs, to more complex methods using statistics designed for neural networks. The general strategy of these methods is to establish the relationship between large scale variables, such as the driving factors derived from GCMs, to local level climate conditions. Once these relationships have been developed for existing conditions, they can be used to predict what might happen under the different conditions indicated by GCMs.

Derived from the atmospheric global circulation models (AGCMs) and the atmosphereocean coupled GCMs (AOGCMs) are the HADCM, GFDL, CM2.X, ECHAM, among others, used for the study and simulation of the present climate and for the projections of the future climate. In the simulation of the hydrology of a watershed, credible input parameters of climate are essential for good results. Outputs of GCMs, however, have a spatial resolution of 250 km, offering only very coarse data for the study of small watersheds. According to Sintondji (2005) and Busche et al. (2005), GCMs have flaws for events of heavy rainfall in respect to their exceeding thresholds and frequencies. It is also evident that local or regional climates are influenced not only by the atmospheric processes, but are also greatly influenced by land-sea interaction, land use and the topography, which are poorly presented in GCMs due to their coarse spatial resolutions (Storch et al. 1993)

Regional Climate Models (RCMs) have been derived from the coarse GCMs to much higher resolutions. The process of downscaling of GCMs to meso-scales or regional scales enables the downscaled regional climate model to adequately simulate the physical processes consistently with GCMs on a large scale (Mearns et al. 2004). Since parameters of land use and topography are crucial in the efficiency of the RCMs, the higher the resolution of the RCMs, the better the simulation of the climate and ultimately, a better hydrological simulation is achieved. Some of the RCMs that have been popular in West Africa are REMO, MM5 and PRECIS.

4. Regional climate scenarios – MM5

The regional climate model MM5 is a meso-scale model derived from the GCM-ECHAM4 recently developed for the assessments of the impacts of environmental and climate change on water resources on the Volta Basin of West Africa. The MM5 is a brain child of the cooperation of the Pennsylvania State University (PSU) and the National Center for Atmospheric Research (NCAR) of the USA. According to Grell et al. (1995), the MM5 non-hydrostatic or hydrostatic (available only in version 2) is designed with the initial and lateral boundary conditions of a region to simulate or predict meso-scale and regional-scale atmospheric circulation.

The GLOWA-Volta project (GVP) executed by the Center for Development Research (ZEF), Germany, ran MM5 with the initial and lateral boundary conditions derived from the

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ECHAM4 runs of the time slice 1860-2100, and based on IPCC's IS92a (assuming an annual increase in CO₂ of 1 %, and doubling of CO2 in 90 years (May and Rockner, 2001; cited in Jung, 2006). Using future climate scenario and girded monthly observational dataset from the East Anglia Climate Research Unit (CRU), UK, the model was calibrated to $0.5^{\circ} \times 0.5^{\circ}$ resolution. GVP further down-scaled the MM5 model for the Volta Basin to finer resolutions of 9 km x9 km, and for some watersheds within the basin to 3 km x 3 km. Details of the setup, coupling and simulation are available in Kunstmann and Jung (2005) and Jung (2006).

A good agreement was reported between the ECHAM4-MM5 simulated climate and the CRU data sets for 1961-1990. According to Jung (2006), simulated temperature was slightly higher in the Sahara during the wet seasons and for the humid south during the dry season, while rainfall was generally comparable except for higher rainfall events that were underestimated. Between ECHAM4 and MM5, 1990-2000 simulations revealed that temperature was generally over estimated and rainfall under estimated by the latter even though the spatial representation was relatively good. However, the future simulations of the models were almost the same. Generally, MM5-Volta estimated an increase in rainfall in the Sahel zone (10-30 %), an increase mean annual rainfall of 45 mm (5 %) between 1990-2000 and 2030-2039, and a 1.2°C mean temperature rise (Jung, 2006).

GVP produced two 10-year simulated time slices of MM5 (1991-2000 and 2030-2039). For this section of the study, the 1991-2000 outputs were considered as the present climate and the time slice 2030-2039 as the future climate.

Changes in the hydrological cycle of a basin hinge largely on, among others, changes in climate. 10-year time slices were used to represent three windows of the past, present and future conditions. Climatic inputs for the past are data obtained from the meteorological agencies of Ghana and Burkina Faso through the GLOWA Volta project for the period 1961-1970. The present and future climate conditions are outputs of the MM5-Volta after Jung (2006) and Kunstmann and Jung (2005); these are 1991-2000 and 2030-2039, respectively. For these analyses, the Pwalugu watershed (Savannah) represents the north of the basin and the Bui watershed (transition zone) represents the south.

5. Highlights of MM5 on the Volta Basin Rainfall

Results of the GLOWA-Volta climate studies showed some significant changes, most especially in rainfall over the entire basin across the periods (Figure 5. In general, average monthly rainfall decreased in the period 1991-2000 for the whole of the rainy season (May-September) compared to the previous climate years.

The Frequency Distribution Curves (FDCs) of 1991-2000 and 2030-2039 do not differ significantly except for the extremely high and low rainfall events. However, both simulated time slices differ considerably from those of the 1961-1970 data records. This accounts in particular for the high percentiles in the high rainfall range. For example, the extreme daily precipitation amounts of two locations of the basin, Pwalugu in the north and Bui in the south will nearly double from the past to the future (80 mm-160 mm) and (52 mm-78 mm), respectively. The frequency of the daily mean of 10 mm of rainfall, for example, is expected to reduce from 17 % to 8 % in the north, and from 14 % to 7 % in the south.



Fig. 5. Spatially averaged, simulated mean monthly precipitation (1991-2000) versus observed long-term means [mm] for the Volta Basin area (Jung, 2006)



Fig. 6. Frequency distribution curves of rainfall for the north of the Volta Basin at the Pwalugu (56,760 km²) catchment for the time slices 1961-1970 (observed), 1991-2000 and 2030-2039 (both MM5 simulated)

6. Evapotranspiration

Actual evapotranspiration and temperature are closely related in the basin. As predicted by almost all climatic models and the IPCC, increases in the global and the basin mean temperature are eminent. Jung (2006) reported that monthly mean temperatures will increase in the Volta Basin by an average of 1.3°C by 2030-2039 compared to the present

1991-2000 data sets (Table 1) conforming to the assumptions of IPCC's IS92a of an annual increase in CO_2 of 1 %, and doubling of CO_2 in 90 years (May and Rockner, 2001).



Fig. 7. Frequency distribution curves of rainfall for the south of the Volta Basin at the Bui (99,360 km²) catchment for the time slices 1961-1970 (observed), 1991-2000 and 2030-2039 (both MM5 simulated).

	Average(1991-2000)°C	Average(2030-2039)°C	Temperature Change °C
January	28.10	28.90	0.80
February	30.10	31.30	1.20
March	32.40	33.60	1.20
April	32.20	34.30	2.10
May	30.10	32.20	2.00
June	28.80	30.10	1.30
July	28.40	29.60	1.20
August	28.20	29.30	1.10
September	29.10	29.80	0.70
October	30.90	31.90	1.00
November	30.40	32.00	1.60
December	27.90	29.60	1.60

Table 1. Mean monthly and annual temperatures (1991-2000 and 2030-2039) for the Volta Basin (after Jung, 2006)

Many reports on the Volta Basin estimated evapotranspiration between 70 % - 90 % of total rainfall (e.g., Andreini et al. 2000, Martin, 2005). According to Jung (2006), significant increases are expected based on the use of the MM5-Volta model for the 2030-2039 periods for nearly all the months of the rainy seasons except May. Increases range from an average 64 mm to 79 mm per month (Figure 8).



Fig. 8. Spatially averaged monthly mean real evapotranspiration [mm], (1991-2000 and 2030-2039) and evapotranspiration change [%] for the Volta Basin (Jung, 2006))

Calculating evapotranspiration using the Penman-Montheith method requires temperature, wind run, radiation and humidity data. An analysis carried out on the Basin based on archived data from the metrological agencies of Ghana and Burkina Faso, indicated that this was not adequately a representative of the entire basin. Nevertheless, the trend and amounts of increase in evapotranspiration of the time slices is phenomenal. The dryer north is expected to experience much higher increases in evaporation and transpiration e.g., the probability of 3 mm of water lost to evapotranspiration per day is increased from 0.07 in 1961-1970 to 0.21 in 2030-2039. The transition zone (south) is expected to lose less water compared to the north but with similar trends, while the frequency of higher evapotranspiration days will increase. The spatial distribution of evapotranspiration shows a general increase over nearly the whole basin, with only the south showing little or no increase in evapotranspiration for the period from the 1990s to the 2030s.

7. Runoff

Runoff in the Volta Basin is closely associated with the pattern of local precipitation, and changes in runoff frequency can reflect changes in climate, vegetation, or land use. An analysis of a stream in the Pwalugu catchment north of the basin showed an increase in the frequency of extreme high flows, but more profound are the expected increase in low flow events that will ultimately have severe impacts on the water resources of the basin in terms of drought frequencies. Jung (2006) attributed the higher values in the future climate scenario run (Figure 11) to the increase in direct runoff especially in the rainfall-intense month of September. Discharge in the south of the basin shows a similar pattern (Figure 13), but differences are more pronounced between the past and future time slices. While the



Fig. 9. Frequency distribution curves of evapotranspiration for the north of the Volta Basin at the Pwalugu (56,760 km²) catchment for the time slices 1961-1970 (gauged), 1991-2000 and 2030-2039 (both MM5 simulations).



Fig. 10. Frequency distribution curves of evapotranspiration for the south of the Volta Basin at the Bui (99,360 km²) catchment for the time slices 1961-1970 (gauged), 1991-2000 and 2030-2039 (both MM5 simulations)

probability of daily discharge exceeding 15 mm increases in the future, there is also an equally significant increase in low flow events. For example, the probability of daily discharge exceeding 1 mm in south for the past time slice was 0.4, but is expected to rise sharply to 0.8 for the future time slice of 2030-2039.



Fig. 11. Normalized frequency distribution of daily runoff values [mm] (1991-2000 and (2030-2039), Pwalugu, Volta Basin (Jung, 2006)



Fig. 12. Frequency distribution curves of discharge for the north of the Volta Basin at the Pwalugu (56,760 km²) catchment for the time slices 1961-1970 (observed), 1991-2000 and 2030-2039 (both MM5 simulations).



Fig. 13. Frequency distribution curves of discharge for the south of the Volta Basin at the Bui (99,360 km²) catchment for the time slices 1961-1970 (observed), 1991-2000 and 2030-2039 (both MM5 simulated).

8. Regional climate scenarios – REMO

REMO is a hydrostatic regional climate model, initially developed at the Max-Planck-Institute for Meteorology (MPI) in Hamburg, Germany, on the foundation of the operational weather forecast model Europa-Modell of the German Weather Service (DWD) (Majewski 1991). According to Jacob et al. (2001) cited in Paeth (2005), the dynamical kernel is based on primitive equations with temperature, horizontal wind components, surface pressure, water vapor content and cloud water content as prognostic variables.

REMO simulations are driven according to Roeckner et al. (2003) by recent global coupled climate model simulations of ECHAM5/MPI-OM, which are known to be forced by enhanced greenhouse and sulphate aerosol conditions and are synonymous with the modeling approaches of the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC).

The simulation outputs used for this study are those produced and used in the GLOWA IMPETUS project whose focus was on western and northern Africa. The horizontal resolution is 0.5°, equivalent to about 55-km grid spacing at the equator, and 20 hybrid vertical levels are resolved. These levels follow the orography near the surface and correspond to pressure levels in the upper troposphere (Paeth, 2005).

The global climate model ECHAM4 (Roeckner et al. 1996) was adjusted to the 0.5° model grid scale of REMO to account for atmospheric processes like deep convection, cloud formation, convective rainfall, radiation and microphysics from the sub grid scale of

ECHAM4. Similarly, land surface parameters such as soil characteristics, orography, vegetation, roughness length, and albedo are derived from the GTOPO30 and NOAA data sets (Hagemann et al. 1999) and partly modified according to the scenarios of land degradation. Underlying an idealized seasonal cycle over West Africa, the same daily interpolated surface parameters are prescribed each year using a model output statistics (MOS) system (Paeth, 2005).

The IMPETUS project made some changes to the default parameter of REMO to adapt to the tropical-subtropical West African region. The focus is on the key region of the West African monsoon system of which the Volta Basin is part. Some results of the adopted REMO correlated well with observed extreme climate year For example, the driest years derived from simulated rainfall in the basin were 1981, 1983, 1990, 1992 and 1998, whereas 1979, 1984, 1988, 1989, and 1991 were characterized by abundant monsoon rainfall. Parker and Alexander (2002) basically confirm that the CRU time series data set reveals almost the same composite years.

9. Highlights of REMO on Volta Basin area

Data on the West African region have large gaps, hence the CRU data set is deficient in regions with low data coverage. This problem applies to all available gridded rainfall data sets. REMO, in an attempt to resolve the handicap of data gaps, uses two statistical post processing steps:

- 1. Monthly rainfall is adjusted to the observations by constructing a model output statistics (MOS) system.
- 2. Daily rainfall intensity is corrected from grids by fitting Γ distributions to the simulated and observed time series, and then taking the ratios between both distributions as weighting factors in the combined correction algorithm. The MOS system is a stepwise multiple linear regression analysis.

The MOS-corrected precipitation by the REMO model reveals a good performance according to Paeth et al. (2005) of the model in terms of the basic features of African climate, including the complex mid-tropospheric jet and wave dynamics and the climate seasonality of the Volta Basin area.

Available scenario runs of REMO (Jacob et al. 2001, 2007) in 0.5° resolution over tropical Africa (Paeth et al. 2005) consider three scenarios of GHG (Figure 14) and emissions and land-cover changes in order to evaluate the range of options given by different achievements in mitigation policy and to quantify the relative contribution of land degradation in line with IPCC projections.

The 2007 report of the IPCC lacks new information on the African climate change but highlights model uncertainties, particularly over tropical Africa. The inconsistency of different model projections reflects in the low values of the regional climate change index in Giorgi (2006), which relies on regional temperature and precipitation changes in the IPCC multi-model ensemble framework. This model discrepancy clouds the interpretation of the results of uncertain model parameters, which may impact specifically on the simulation of African climate.

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Fig. 14. Multi-model means of surface warming for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulation. Values beyond 2100 are for the stabilization scenarios. Linear trends from the corresponding control runs have been removed from these time series. Lines show the multi model means, shading denotes the plus minus one standard deviation range. (Source: http://ipcc-wg1.ucar.edu/wg1/wg1-report.html)

Within the adopted REMO, the spatial mean of the change of forest to agricultural land under the A2, B1 and A1B scenarios have been considered. For example, under the A1B (all)¹ scenario the estimate of the FAO (2006), assumes a decrease in forest coverage of about 30 % until 2050 for the entire Africa region. Associated albedo changes between 2000 and 2050 are in the order of 5-10 %. Forests transformation into grasslands and agricultural areas in the order of 10-15 % were incorporated. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resourceefficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives, whereas the A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines. The available REMO outputs from the IMPETUS project have three ensemble runs for the various scenarios and time slices. These are for the periods 1961-2000; the A1B scenarios with land-use changes are for 2001-2050 time periods; and for the B1 scenarios are for 2001-2050 periods.

¹ All ensemble scenarios of IPCC considered

10. Regional climate model performance of MM5 and REMO

Regional models share similar problems but differ in magnitude. Notable are MM5, MAR and REMO (Vizy and Cook, 2002; Gallée et al., (2004); Paeth et al., 2005). However, Schnitzler et al. (2001) suggest that integrating the interaction with vegetation cover and albedo considerably improves the simulation of rainfall over the Sahel in the global ECHAM4 model.

For the hydrological modeling for which these regional climate models are required, rainfall is a very important input parameter apart from temperature because it is the major driver of moisture input to the hydrological cycle. Hence it is important to ascertain that the annual, monthly and daily distributions of the data represent the amounts and the frequency statistics of the data, e.g., the exceedance of extremes are consistent with the long-term mean observed. It is important to assress the reliability of the MM5 and REMO future climate scenario for the evaluation of the impacts of climate change on water resources in the Volta Basin, for instance, the REMO-simulated and MM5-simulated mean rainfall for the time slice 1991-1997 were obtained from the basin weather stations and compared to the mean observed rainfall for the same area and periods (Figure 15) From the outcome, the comparison for the station, for example, show a good correlation between the observed and MM5-simulated and REMO-simulated monthly rainfall (Figure 15). Pearson correlation of gauged 1991-1997 and REMO 1991-1997 = 0.823; P-Value = 0.001; for gauged 1991-1997 and MM5 1991-1997 = 0.957; P-Value < 0.0001 On average, MM5 and REMO overestimate rainfall for this selected time slice of 1,203 mm and 1,322 mm per annum, respectively, against the measured1,101 mm per annum. MM5 overestimates the rainfall from April through July and September and underestimates for August and October. REMO, on the other hand, overestimates rainfall for February through April, July, October and November and underestimates for August. The strongest overestimation for MM5 is for the month of July, while for REMO, this is March and April (Figure 16).



Fig. 15. MM5-simulated and REMO-simulated compared to observed monthly rainfall at Pwalugu (56,760 km²) catchment of the Volta Basin



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Fig. 16. MM5-simulated (mean over 7 years) and REMO-simulated (mean over 7 years) compared to observed (mean over 7 years) rainfall including standard deviation (error bars) rainfall at Pwalugu (56,760 km²) catchment of the Volta Basin

The resultant impacts on the hydrology are similar in most of the rainy seasons, apart from isolated extreme runoffs generated as a result of overestimations of some days and months of the season (Figures 17 and 18).



Fig. 17. MM5-simulated (over 4 years) and REMO-simulated (over 4 years) compared to observed (over 4 years) discharge with trend lines at Pwalugu (56,760 km²) catchment of the Volta Basin

Statistically, the Pearson correlation of MM5 and gauged = 0.181 with a P-Value = 0.108; Pearson correlation of REMO and gauged = 0.677 with a P-Value < 0.0001. The general trend for both MM5 and REMO for the period 1991-1997 is similar in pattern, and they simulate dry and wet years fairly well, with REMO better for hydrological simulations. Available daily gauged runoff exist data for 1994-1997 (Figures 17 and 18).



Fig. 18. MM5-simulated and REMO-simulated compared to aggregated observed discharge at Pwalugu (56,760 km²) catchment of the Volta Basin

11. Comparison of past, present and future hydrological dynamics of the Volta Basin

The 2001-2050 time slices representing the future period with increasing GHGs and changing land cover, according to the business-as-usual and a mitigation scenario from the IPCC SRES A1B and B1 scenarios (Nakicenovic and Swart 2000) are considered by REMO. The relative contribution of the land-use changes to total climate change in Africa was carried out using the A1B and B1 emission scenarios between 2001 and 2050. An annual growth rate of 2 %, land-use changes comprising of mainly prevailing cities and currently



Fig. 19. Exceedance probability of daily rainfall simulated by MM5, REMO-A1B and REMO-B1 with average total rainfall of 1,287 mm, 1291 mm, and 1,391 mm, respectively, for the Pwalugu catchment of the Volta Basin for 2030-2039.

existing agricultural areas were some assumptions adopted (Paeth et al., 2005). MM5, on the other hand, did not consider land-use change scenarios and was based on IPCC's IS92a scenarios (May and Rockner, 2001), which are known to overestimate the CO₂ projections compared to the A1B and B1 emission scenarios.

A simulation by MM5 and REMO-B1 predicts high rainfall events compared to the scenarios of REMO-A1B. The resultant discharge in these scenario simulations shows a very high discharge for MM5 with a sharp gradient and larger amplitudes, closely followed by REMO-B1, and REMO-A1B. This is explained by the number of very low and rainy day event counts that are higher with MM5 than those of both scenarios of REMO (Figure 19).



Daily rainfall class [mm]

Fig. 20. Rainfall distribution simulated by MM5, REMO-A1B and REMO-B1 with average total rainfall of 1,287 mm, 1291 mm, and 1,391 mm, respectively, for the Pwalugu catchment of the Volta Basin for 2030-2039.

12. Climate change projections and Policy implications

The regional climate models MM5 and REMO have demonstrated that they are able to simulate the observed main characteristics of African climate to some extent, with varied accuracy. For the resultant hydrological simulation with respect to discharge, the regional climate model REMO provides reliable and consistent high-resolution data for hydrological application of WaSiM-ETH for the Volta Basin Nevertheless, both climate models have divergent projections for the future climate and hence the hydrology of the basin.

There is evidence from models that the world's climate is changing and this change will impact regional development in various ways. According to climate scientists, increases in global temperatures are largely the result of increased greenhouse gas concentrations and that the continued increases in these concentrations will cause future climate warming. Climate variability and change present risks relating to vulnerabilities that potentially undermine global efforts at poverty reduction and meeting the Millennium Development Goals (MDGs) of most countries. Semi-arid regions are vulnerable especially in Africa to this projected climate variability and change and the related impacts. These include projected temperature increases, changes in precipitation, projected change in cropping systems and food security etc.

Given the history of climatic variability, climate specialists predict a mix of droughts and floods of unusual magnitudes for West Africa that will threaten human security (IUCN, 2004; IPCC, 2007). Some climate change projections predict a decline in precipitation in the range of 0.5- 40% with an average of 10-20% by 2025. Others predict increases in precipitation. This will cause extreme climatic events such as floods and droughts - impacting on agriculture negatively (Houghton et al., 2001; Smith and Mendelsohn, 2006).in a similar case, a greater drought risks due to higher evapotranspiration and decrease in precipitation. In this case, it is high time every region will need to adapt policy implication to climate change by examining the nature of regional impact

Although there has been increased recognition of and global policy support for adaption, there is still the lack of policy commitment to adaptation at the sub-regional and national levels especially in developing countries. The incidence of dry spells and drought over the past two decades in the semi-arid region and the projected drying trends expose the sub-region to more drought related hazards and livelihood vulnerabilities among the human population. If the exposures to drying related hazards are not managed through concerted policy support, this potentially undermines the attainment of the Millennium Development Goals (MDGs) in the sub region. With increase in population; increasing demand for food and water use, coupled with poor water management practices and increasing risk of climate change, resultant impacts could reach undefined proportions for inhabitants of the semi arid regions.

Rainfall variability, land degradation and desertification are some of the factors that combine to make life extremely difficult in this part of the world.

Simi-arid regions which in recent times due to climate variability and change experienced massive losses of agricultural production and livestock; loss of human lives to hunger, malnutrition and diseases; massive displacements of people and shattered economies. Yet, most climate models predict that these regions will be drier in the 21st century. Even slight increases in rainfall are unlikely to reverse the situation since a hotter climate means that evapotranspiration will be more intense, exacerbating the already arid conditions.

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Hydrology is the science that deals with the processes governing the depletion and replenishment of water resources of the earth's land areas. The purpose of this book is to put together recent developments on hydrology and water resources engineering. First section covers surface water modeling and second section deals with groundwater modeling. The aim of this book is to focus attention on the management of surface water and groundwater resources. Meeting the challenges and the impact of climate change on water resources is also discussed in the book. Most chapters give insights into the interpretation of field information, development of models, the use of computational models based on analytical and numerical techniques, assessment of model performance and the use of these models for predictive purposes. It is written for the practicing professionals and students, mathematical modelers, hydrogeologists and water resources specialists.

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