Journal of Japan Society of Civil Engineers, Ser.
B1 (Hydraulic Engineering), Vol. 68, No. 4, I_205-I_210, 2012.

REGIONAL CLIMATE CHANGE AND ITS IMPACTS ON FUTURE DISCHARGES AND FLOW CHARACTERISTICS OF THE NYANDO BASIN, KENYA

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Using a physically-based distributed hydrological model (WEB-DHM), this study investigated the likely impacts of climate change on Nyando river basin in Kenya. Analysis of the East African regional climate indicates a weakening in the westerlies and a projected increase in precipitation. A simple statistical method was applied to downscale General Circulation Model (GCM) precipitation to the basin scale. At this scale the GCMs predict a relatively drier basin with two of the selected models projecting a 9% decrease in annual rainfall. The bias-corrected and downscaled GCM precipitation data was then used to drive the WEB-DHM to project future changes in streamflow. There's projected decrease in annual discharge with a likely increase of floods in the months of July and August.

Key Words: *WEB-DHM, Bias correction, Climate change, Nyando River Basin, Kenya*

1. INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC), global warming and associated climate change is going to have a major impact on the hydrological cycle at global and regional scales[1)]. Climate change and its variability will continue to exert additional pressure on the already strained water resources in the East African region. Previous analysis of climate change[2)] and its effect on water resources in the African region shows a likely increase in the number of people experiencing water scarcity by 2055. A recent study [3)] suggested an increase of 5% in streamflow above the 1961-1990 baseline.

How the local hydrologic cycle responds to climate change in a particular basin is very important not only for operational purposes like dam control and irrigation; but also for policy planning of disaster management and preparedness. The investigation of likely impacts of climate change at a basin scale is thus important, though there are limitations attributed to spatial resolution and uncertainties in the use of GCM projections. These uncertainties still remain to be a key limiting factor as well as the multiple future water uses that are not accounted for in future projections. Two downscaling approaches are typically available; statistical downscaling and dynamical downscaling. Dynamic downscaling involves the use of finer resolution numerical weather prediction models with GCM output as initial and boundary conditions. Statistical downscaling involves the use of statistical relationships to convert the large-scale projections from a GCM to finer spatial resolutions.

Watershed models are powerful tools for water resources planning and management. Models are used to predict how conditions are expected to change over time, to understand the nature and scope of a problem or to evaluate alternative management options. Flow modeling of the Nyando basin for flood forecasting and disaster management has been extensively done over the past years[4), 5), 6), 7)].

This study attempts to investigate regional climate change signal in the GCMs, downscale GCM precipitation output and investigate the likely future changes in discharge in the Nyando basin. Data from the Special Report on Emissions Scenarios (SRES) A1B model projections; Coupled Model Intercomparison Project (CMIP3) was used. SRES A1B scenario assumes a future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology[1)].

2. STUDY AREA

Nyando river basin (**Fig. 1**) is located on the western parts of Kenya and is within the greater Lake Victoria Basin. It's geographically located along the equator bounded by latitudes 0° 7' N and 0° 24' S; longitudes 34° 25' E and 35° 43' E. It covers an area of about 3,500 km^2.

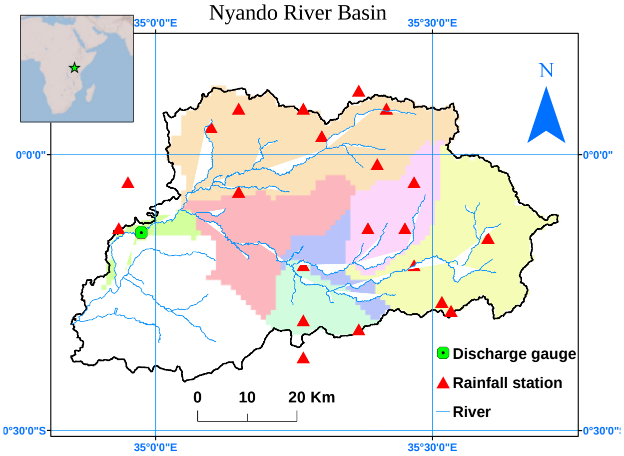

Fig. 1 Nyando River basin, Kenya

Rainfall in this region is mainly influenced by the migration of the Inter tropical Convergence zone (ITCZ) and exhibits a bi-modal pattern with peaks in March-April-May (MAM) and October-November-December (OND) known as long rains and short rains respectively[8), 9), 10)]. The mean annual rainfall ranges from 800 mm in the lowlands to about 1600 mm in the highlands. Other regional and synoptic scale phenomena like the Indian Ocean Dipole have been shown to influence the East African climate as whole[11), 12)]. Floods on the lower Kano plains occur frequently and this has affected the livelihoods of about 1.1 million people[4)].

3. METHODOLOGY

(1) SRES A1B model selection

The climate scenarios used in this study were obtained from the Data Integration and Analysis System (DIAS), University of Tokyo. In this study, 24 GCMs were available and only the "least biased" three were selected. Global Precipitation Climatology Project (GPCP) and Japanese 25-year Reanalysis Project (JRA25) datasets from the 20th century experiment were used as a reference. Four climate variables were considered in selecting the GCMs: precipitation, zonal wind, geopotential height and specific humidity.

Monthly spatial correlation factors and root mean square errors between the 20th century GCMs and reference datasets (1981-2000) were computed for these variables over the East African domain **(Fig.2).** Using MAM and OND months, the GCMs were ranked and the top three models with least mean RMSE and higher correlation coefficients were selected.

Table 1 Selected GCMs used in this study

Institute	GCM	Acronym
Istituto Nazionale di Geofisica e Vulcanologia	Ingv-echam4	ingv
Meteorological Research Institute (MRI) Japan	Mri-cgcm 2.3.2a	mri
Canadian Centre for Climate Modeling and Analysis	Cccma_cgcm 3_1_t63	cccm

(2) Regional climate change (East Africa)

Precipitation and zonal wind (U-850hPa) variables were analyzed from the three selected GCMs. Investigations were done at a regional scale to determine the qualitative future projected changes relative to the 1981-2000 baseline.

(3) GCM downscaling and bias correction

GCM outputs are usually produced at coarse resolutions. Without downscaling, these outputs are unsuitable for local-scale applications like hydrological modeling. Downscaling to finer resolutions thus becomes a necessity to achieve reasonable interpretations of climate change and its impacts at a basin scale.

In this study a bias correction method is used based on the assumption that both observed and simulated intensity distributions are well approximated by a common distribution function. It can be summarized as:

a) Correcting for "no-rain" using a threshold defined by observations
b) For normal rain days, a cumulative gamma

distribution function is used to map the GCMs to the observed

c) Extreme values are corrected by fitting to a ray of distribution functions

d) A "change" factor between 20th century and future GCMs is computed and applied to the corrected future GCM rainfall

(4) Hydrological model

The Water and Energy Budget–Based Distributed Hydrological Model (WEB-DHM) is a distributed biosphere hydrological model developed by coupling the Simple Biosphere Model 2(SiB2) with a based hydrological model (GBHM) [13). The model is capable of providing at a basin scale, the spatial description of water, energy and CO_2 fluxes. The main WEB-DHM components can be briefly described as: (1) the model, using the hydrologically-improved SiB2 simultaneously calculates heat, moisture, and CO_2 fluxes in the soil-vegetation-atmosphere transfer (SVAT) system; (2) the hydrological sub-model defines the overland, subsurface and groundwater flows using grid-hillslope discretization and then kinematic river routing. The model has been extensively evaluated[13), 14), 15), 16)] in different regions and applications.

(5) Data

The Shuttle Radar Topography Mission (SRTM) digital elevation dataset (DEM) at a resolution of 90m was obtained from the Consultative Group on International Agricultural Research (CGIAR) website. Meteorological forcing was obtained from the Japanese 25-year Reanalysis Project (JRA25)[17)]. Soil and soil-water parameters were subset from the FAO global harmonized dataset[18)].

Daily rainfall was obtained from the Kenya Meteorological department and daily discharge from the JICA office, Nyando river basin. Rainfall data gaps in all the stations were filled up using the Kriging geostatistical interpolation method. These forcing datasets were used to calibrate and validate the WEB-DHM.

4. RESULTS AND DISCUSSIONS

Fig. 2 shows annual mean precipitation (GPCP), zonal wind (JRA25) and the three GCMs for the period 1981–2000. The correlation factors for the three models are >0.8 with an average Root Mean Square Error (RMSE) <2.6. The three selected models represent the regional climatology well though the *cccm* model seems to overestimate precipitation over western Indian Ocean.

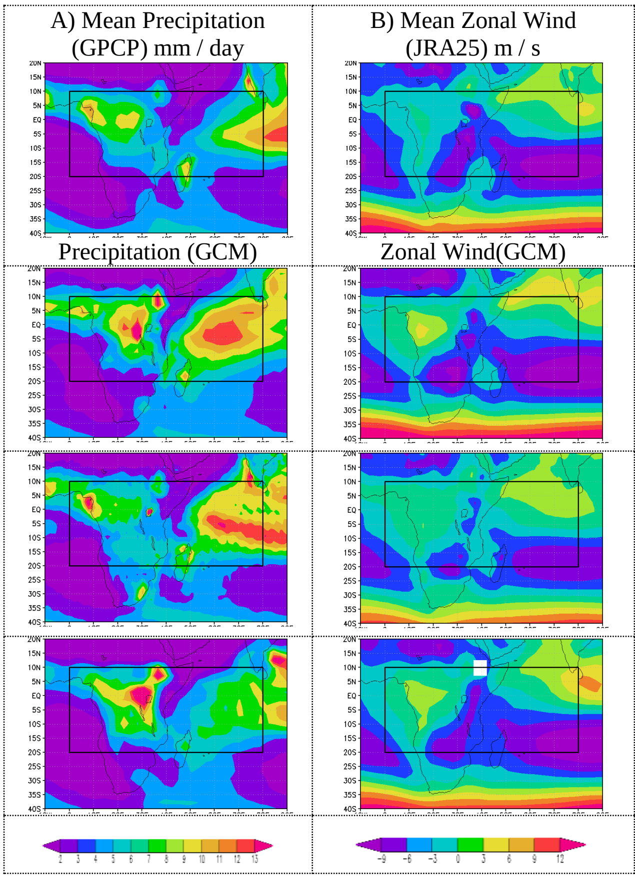

Fig.2 A) Annual mean precipitation for *GPCP*, *cccm* and *ingv* and *mri* (from upper to lower); and B) Same as A but for zonal wind with JRA25 (upper)

Over the East African region, the models show reasonable precipitation patterns similar to GPCP. Previous studies[20)] have identified a strong correlation between the zonal wind (westerlies) and precipitation over East Africa. Strengthening or weakening of these westerlies has a direct impact on precipitation. **Fig.2 B)** shows the mean zonal wind as represented by the three models and the JRA25 reanalysis. The selected GCMs show strong similarities to the JRA25 reanalysis.

(1) Projected regional changes in precipitation and zonal wind pattern

Fig. 3 and **Fig. 4** show the mean seasonal variation of precipitation, zonal wind, GCM baselines and projected future anomalies. There's a general agreement between the three GCMs favoring a slight increase in precipitation.

During the MAM season, the GCM ensemble mean projects positive anomalies over Lake Victoria region. Although a similar trend is observed during the OND season, it's more pronounced over the Indian Ocean.

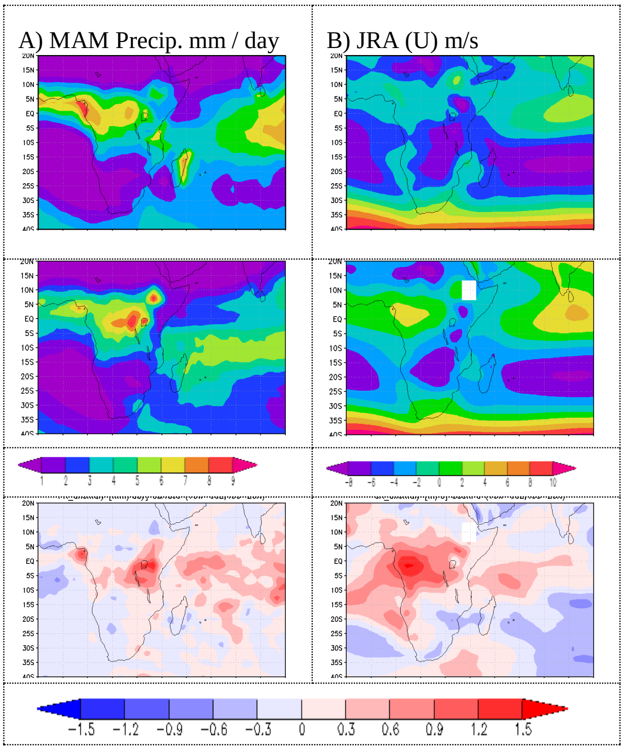

Fig. 3 A) Mean seasonal **(**MAM) precipitation for GPCP, GCM mean and future projection anomalies (from upper to lower); and B) same as A but for zonal wind with JRA25

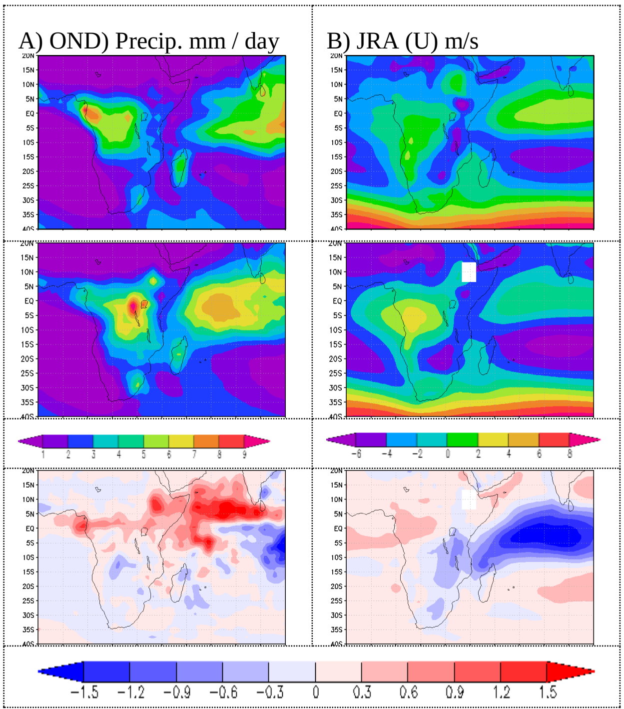

Fig. 4 Same as Fig. 3 but for OND season

These GCMs suggest weakening of the Westerlies south west of Indian Ocean during the OND season. This is strongly linked to precipitation anomalies.[20] In the MAM season, this does not occur implying that the OND rainfall season is most likely to be affected by climate change.

(2) Projected changes in precipitation and temperature at basin scale

The bias correction method reproduces a good match between the observed and the downscaled precipitation **(Fig. 5 b).** The method represents the bi-modal[8), 9), 10)] rainfall pattern in the basin very well.

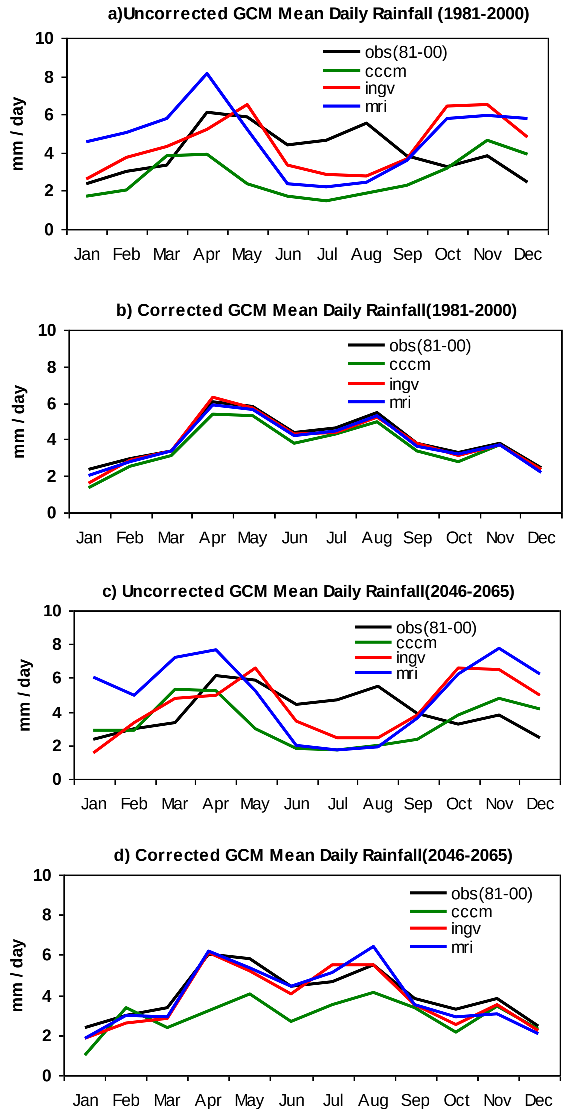

Fig. 5 a) and c) shows the basin-averaged rainfall from the raw data of GCM; b) and d) shows the corrected GCM rainfall for 1981-2000 and 2045-2065, respectively.

The three selected models project a 6% decrease (2046-2065) in annual precipitation over the basin with the largest annual reduction of 15% represented by the *cccm* model. The other two models project a decrease of 3% (*ingv*) and <1% (*mri*). On the seasonal scale, the *ingv* and *mri* models project an average increase of 16% and 17% in July and August respectively. Relative to the baseline (1981-2000), the three models agree on 10% decrease during the MAM and 14% decrease in the OND seasons.

There are shortcomings associated with this method of downscaling. The method uses a three step process in bias correction (no rain, normal rain and extreme correction). Normal rainfall is corrected by mapping to a monthly gamma function. A simple factor is then used to include climate change in the future. This factor may not be sufficient to address other changes that may occur. However, the method provides a robust qualitative approach in downscaling.

Due to unavailability of ground based temperature observations, the JRA25 reanalysis was used as a proxy and a simple monthly correction factor between the reference and future period was applied. The three models project an increase of 1~3^{o}C in the maximum daily temperature (*Tmax*) over the basin. For the two rainfall seasons, the models predict a modest increase of about 1.3^{0}C.

(3) Discharge simulations

The WEB-DHM model was calibrated for the year 1988 and validated for 1989-1990. These years were chosen because they had the least gaps in observations. Saturated hydraulic conductivity for soil surface (*Ks*), hydraulic conductivity anisotropy ratio (*anik*), and hydraulic conductivity decay factor (*f*), as well as the maximum surface water detention parameters were calibrated by matching simulated and observed discharges. Visual interpretation, percentage bias (PBIAS) and Nash[19)] coefficients were used in adjusting these parameters. Results presented here are for the upstream of the discharge gauge in **Fig. 1.**

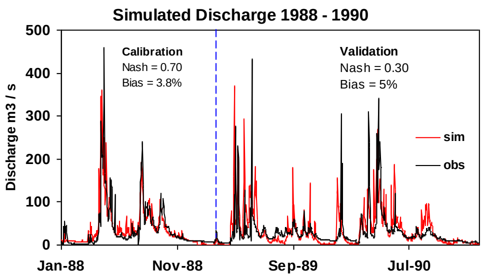

Fig. 6 Observed and simulated discharge

Fig. 6 shows the daily hydrograph for both the calibration and validation periods. Though calibration produced higher values of the Nash coefficient (0.7), the validation period produced a weaker measure (0.30) attributable to rainfall data gaps.

(4) Projected changes in streamflows

Evaluation for discharge is based on baseline simulated discharge using bias corrected GCM rainfall for 1981-2000 to eliminate any systematic model bias. Two of the selected models project an annual decrease of 36 %(*cccm*) and 25 %(*ingv*) respectively with the *mri* model predicting an increase of 15%. The highest rates of decrease are projected in March–May with *cccm* and *ingv* models predicting an average decrease of 47%. All the three models agree on a 40% decrease in March. Relative to the 1981-2000 observations, the models project an annual increase of 29 %(*ingv*), 84 %(*mri*) and 1 %(*cccm*) with *cccm* projecting an increase only in January – February and November - December.

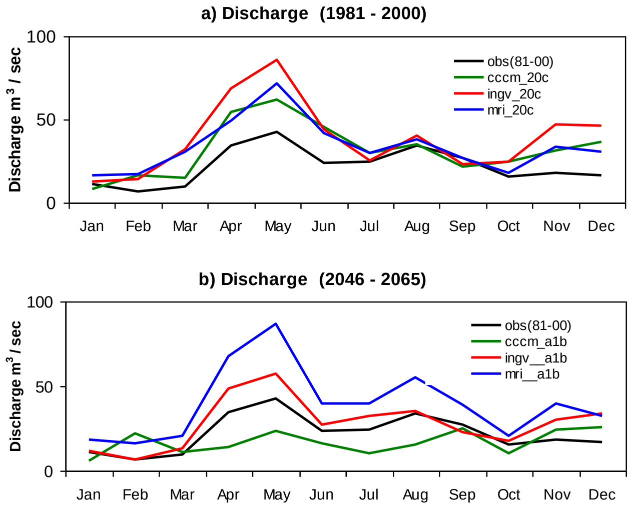

Fig. 7 Mean monthly discharge using GCM corrected rainfall for 1981-2000 (a) and 2046 -2065 (b).

(5) GCM and hydrological model uncertainties

The hydrological model used in this study performs well and produces reasonable discharge. However using downscaled GCM precipitation produces high peaks during May and August. This is because the GCM-based precipitation has higher frequency of rain days than observations during these months and this leads to flash floods. In addition, this method uses a factor method to transfer climate change signal and this partly introduces some degree of uncertainty. Though there's a general agreement between two of the models, their departures from the *mri* model is large and this adds to the uncertainty.

5. CONCLUSIONS

In this study, a preliminary climate change signal investigation was done; three GCMs predict a likely decrease in precipitation over the Nyando basin. Investigations in the regional climate system identified a weakening of the east African westerlies and thus a slight increase in precipitation is projected over the region in future. A simple downscaling and bias correction method was applied to three GCM precipitation outputs to produce gauge-based future projections. The downscaled precipitation was then used to drive the

WEB-DHM model. Though the GCMs project a relatively drier basin, hydrological simulations predict increased frequency of floods in the months of May, August and December. With the apparent disagreement between the selected models; a more inclusive study including more than three GCM outputs and different downscaling approaches is encouraged. This study serves as reasonable basis for further analysis of climate change impacts on the Nyando basin.

ACKNOWLEDGMENT: The study is supported by the grants from the Ministry of Education, Culture, Sports, Science and Technology of Japan. The authors would like to specifically appreciate the JICA Kenya office for the provision of discharge and rainfall data for the Nyando basin.

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(Received September 30, 2011)