Proceedings of the 7th International Conference on HydroScience and Engineering

Philadelphia, USA September 10-13, 2006 (ICHE 2006)

ISBN: 0977447405

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APPLICATION OF HYDROLOGICAL CONCEPTUAL MODELS TO SIMULATE FUTURE RIVER FLOWS FEEDING LAKE VICTORIA, EAST AFRICA

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ABSTRACT

The Nile River receives its water primarily from Lake Victoria's catchment basin, and is a particularly vital source of potable water in that region. Since greenhouse gases induce climate change that will affect the water resources system, this necessitates a fundamental review of both the planning and management of water resources. This study delivers the range of plausible changes in flows of five rivers (tributaries) to Lake Victoria from the year 2010 to 2099. Two different hydrological conceptual models, namely IHACRES and SMAR, are used in establishing the daily rainfall-runoff relationships for the five sub-catchments (tributaries) within the Lake Victoria basin. The five catchment sites are – Nzoia, Yala, Sondu, Gucha and Mara.

A number of climate change scenarios from several General Circulation Models (GCMs), taking into account different CO2 emission forcings have been successfully used by these hydrological models in order to simulate the corresponding future river flows in the five sub-catchments. The results suggest an increase in mean annual flow in the 2020s period. However, the river flow trends in the 2050s and 2080s are inconclusive. The results show the potential for climate change to modify river flows, thus requiring a significant planning response. The results, amongst others also indicate the importance of considering hydrological impacts in potable water supply and flood/drought studies.

1. INTRODUCTION

The African Great Lakes are important sources of water for domestic use and avenues of transport. Lake Victoria, the largest of the African Great Lakes, is the primary source of water to the Nile River whose freshwater resources are widely shared and heavily used. The extensive use of the Nile River allows little water to eventually reach the Nile Delta and the Mediterranean Sea, and what does tends to be low-quality wastewater (Gleick, 1991). Furthermore, Egypt at the receiving end of the Nile river is almost entirely dependent upon the water that originates from the upstream Nile basin countries (Conway, 2005). The Nile water utilisation is further complicated by the catchment and riparian drainage area of this international river shared by ten nations.

Since the construction of the Owen Falls dam to maintain the basic flow of water from Lake Victoria down the White Nile, the Lake immediately became of great interest to hydrologists (Beadle, 1974). Other than being the source to the Nile, the significant fluctuations in the level of

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Lake Victoria and its anomalous hydrological behaviour have created particular interest in the context of water balance (e.g. IH, 1993; Kite, 1981; Tate et al., 2004; WMO, 1982; Yin and Nicholson, 1998). The variability of water balance feeds into the regulatory role for the annual Nile flows. Therefore any changes in the lake's water balance have significant consequences for the riparian countries dependent on the Nile River.

The natural variations caused in the Nile runoff may soon be aggravated by any global climate change which it is believed will alter regional hydrologic cycles and hence affect the quantity and quality of regional water resources. Hydrological research strongly suggests that plausible climatic changes will alter the timing and magnitude of runoff and soil moisture, lake levels and ground water availability, as well as affecting water quality (Gleick, 1989). Critical concerns in relation to the future climate change to Nile basin include water availability from possible altered rainfall patterns, frequencies of drought or flood, and changes in seasonality of rainfall and runoff. At the present time, climate change impact assessments are fairly common in the developed world, where resources and observational data are more extensive than in developing countries.

In the Nile basin, the certainty of increased water demand in the future and the uncertainty of future water availability, due to greenhouse gases induced climate changes in supply, makes it prudent to undertake a fundamental review of both the planning and management of water resources. There are not many literature published on the effects of climate change on regional river flows. And, there appears to be no literature published on the regional response under various future climate scenarios of different General Circulation Models (GCMs). This study is basically the first attempt aimed at predicting future flows in five rivers that feed Lake Victoria, a Lake that provides a large percentage of the Nile river flow

2. STUDY AREA

The study area consists of three semi-arid catchments at the Kenyan side (east) of Lake Victoria basin. These catchments are – Nzoia, Yala, Sondu, Gucha and Mara (see Figure 1). Based on the daily discharge data which were used in this study, that is, for the period 1970 to 1978, these five catchments contributed to more than 30% of the total annual inflow into Lake Victoria. They are also identified as rivers with the highest flows on the east of Lake Victoria basin.The annual average river flows recorded are 85.9 cumecs, 33.7 cumecs, 45.7 cumecs, 53.9 cumecs and 36.5 cumecs respectively for Nzoia, Yala, Sondu, Gucha and Mara.

Figure 1 Location of Nzoia, Yala, Sondu, Gucha and Mara river (Sutcliffe and Parks, 1999).

3. HYDROLOGICAL MODELS

Two conceptual models were used in establishing the rainfall-runoff relationships. Due to paucity of data in the study area, conceptual models were selected because they are not data-demanding as compared to physical-based distributed models. Conceptual models utilize the hydrological data for calibration (Evans and Schreider, 2002).. Conceptual models give a lumped response of the catchment which would be useful for the study of effects of climate change. The two models chosen for this study are IHACRES and SMAR. The two models were calibrated and validated to the five catchments with inflows to Lake Victoria. The two models show potential to be used in climate change assessment and other challenging problems facing the sustainable management of water resource (Phoon and Shamseldin, 2006).

4. CLIMATE SCENARIOS

The future evolution of future GreenHouse Gases' (GHG) emissions is highly uncertain as it would be determined by several driving forces, such as demographic development, socio-economic development and technological change (IPCC, 2000). Scenarios are plausible, coherent and consistent alternative representations of how the future might unfold, based on accounting both human-induced climate change and natural climate variability. Scenarios are then used in assisting climate change assessment of impacts, adaptation, vulnerability and mitigation measures to provide alternative views of future conditions considered likely to influence a given system or activity (IPCC, 2001). Climate scenarios are formed through a combination of observed data with the manipulation of the outputs from climate projection models; that is, a description of the modelled response of the climate system to scenarios of greenhouse gases and aerosol concentrations.

Climate change scenarios are taken from Hadley Centre (Britain), Canadian Centre for Climate modelling and Analysis (CCCma) (Canada) and Geophysical Fluids Dynamics Laboratory (GFDL) (America). The Special Report on Emissions Scenarios (SRES) A2 storyline scenario was used. For trend analysis, the climate change scenarios are divided into four periods to represent four plausible scenarios that is baseline, 2020s, 2050s and 2080s. A 30-year period control run were used to define a baseline climate (year 1960 to 1989 except for CCCma control run period of year 1961 to 1989). The three future periods are years 2010 to 2039 representing the 2020s, year 2040 to 2069 representing 2050s, and year 2070 to 2099 representing the 2080s.

5. RESULTS AND DISCUSSIONS

The GCM scenario results derived from HadCM3, CGCM2 and CM2.0 were directly used by the SMAR and IHACRES hydrological models. The daily future river flows are generated respectively for the five rivers. Statistical trends in the monthly and the total annual flows are examined and discussed.

5.1 Monthly trends

In the case of the monthly statistical trend, the estimated river flows tend to have a noticeable monthly trend, with the increment of flow being larger, particularly in the Lake Victoria rainy seasons, which are MAM and OND. The monthly trends of two rivers, Sondu and Gucha are discussed in as follows:-

The monthly changes in the Sondu river flows, corresponding to GCM experiments' scenarios used by both hydrological models, are shown in

Figure 2. Generally, all the graphs agree that there is an increase of river flows in most of the months in the 2020s. The simulated flows from both hydrological models have similar monthly trends and magnitudes in changes in flows in all the diagrams, indicating good agreement between both model simulations. However, HadCM3 has slight differences in monthly trends from the other GCMs. The flows for HadCM3 display a discrepancy between the IHACRES and SMAR. The SMAR simulated flows show an increase in the peak of the flow for the month of April and a smaller peak in the month of December. However, IHACRES estimated a prolonged increase from the current flows for December through to April. Furthermore, a smaller-than-current flows are estimated for the months of May-June for all three future periods, whereas SMAR shows virtually no variation from the current flows. In the case of CGCM2 A2, the 2020s flows are estimated to increase for all the months except January, and also to have a well defined peak in November,

coinciding with the local rainy season. The 2080s flows are estimated to be mainly less-than-current flows for nearly all months, except for the summer which are similar to the current flows.

The statistical trends estimated by CM2.0 is rather similar to the HadCM3, with nearly no variation in flows as compared to the current condition in the summer and early autumn. The CM2.0 has a double-peak trend in flow, coinciding with the local peak flow seasons in April-May and November-December.

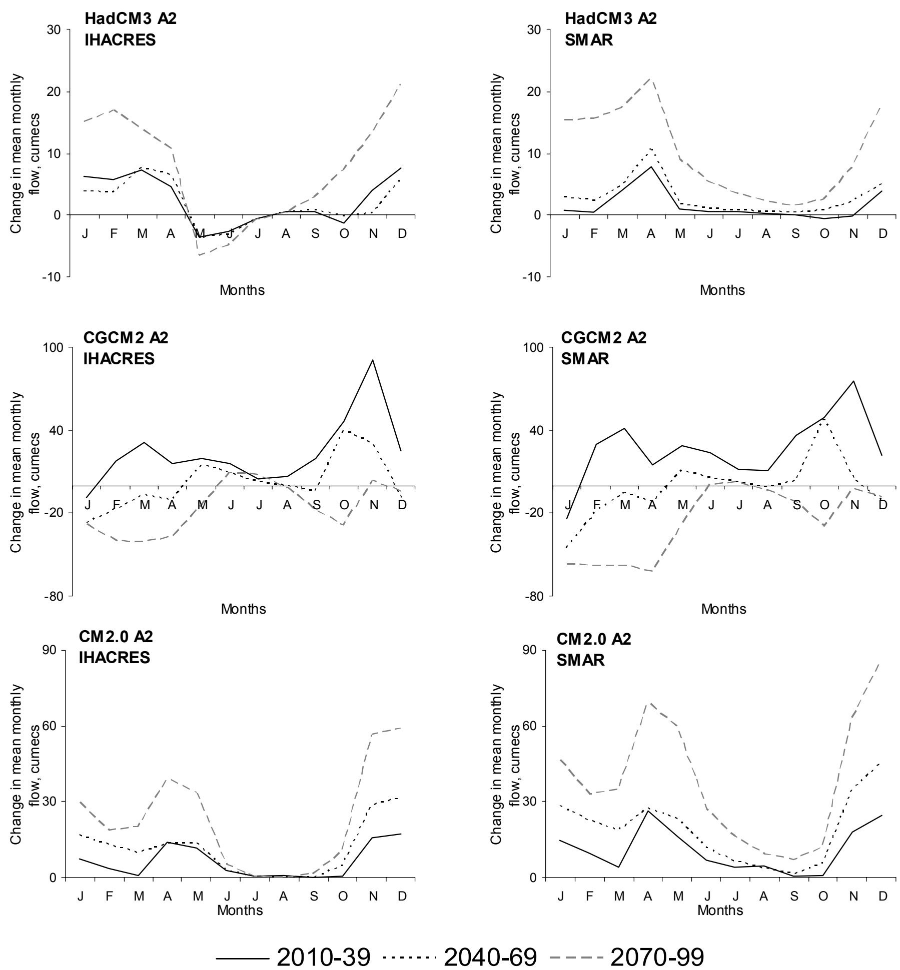

Figure 2 Simulated change in average monthly mean Sondu river flow corresponding to various scenarios and time periods.

The monthly changes in Gucha mean flows corresponding to HadCM3, CGCM A2 and CM2.0 scenarios are shown in Figure 3. The shapes of the plots are fairly similar to those estimated for Sondu though not exactly the same. The similarities are (1) all agree on an increase in current flows for nearly all months in the 2020s period, (2) comparatively minimal variation of flows to the current flows in the summer (3) CGCM A2 scenarios estimated an extreme decrease in flows in the 2080s, and (4) the CM2.0 estimated a large increase to flows in the 2080s. In the simulation of flows corresponding to HadCM3, though the shapes of both plots are somewhat similar, the changes in SMAR simulated flows are significantly lower than the changes in IHACRES flows. The 2020s and 2050s seemingly have similar changes, but the 2080s has a comparatively higher change in flows for the winter and spring seasons. Concurrent with these trend results, the change of flows in the summer months is nearly zero. CGCM A2 simulated very large increases in mean monthly flow for October and November, up to nearly 100 cumecs more than the current flows. For the CGCM A2 scenario, the flow in the spring season (FMA) has changed from an increase in the 2020s to a decrease in 2080s. Simulations of both IHACRES and SMAR are very similar in shape. However, SMAR generally predicts larger changes in future flows. Gucha river flows corresponding to GFDL CM2.0 A2 show a high increase in flows during the peak flow season in the local area, creating the typical double-peak, which has been noted before. Also, similar to CGCM2 corresponding flows, CM2.0 have smaller flow changes in the summer season. However, the SMAR model gave a relatively higher magnitude of change in the seemingly constant summer period, as compared to a nearly no-change result for the IHACRES model.

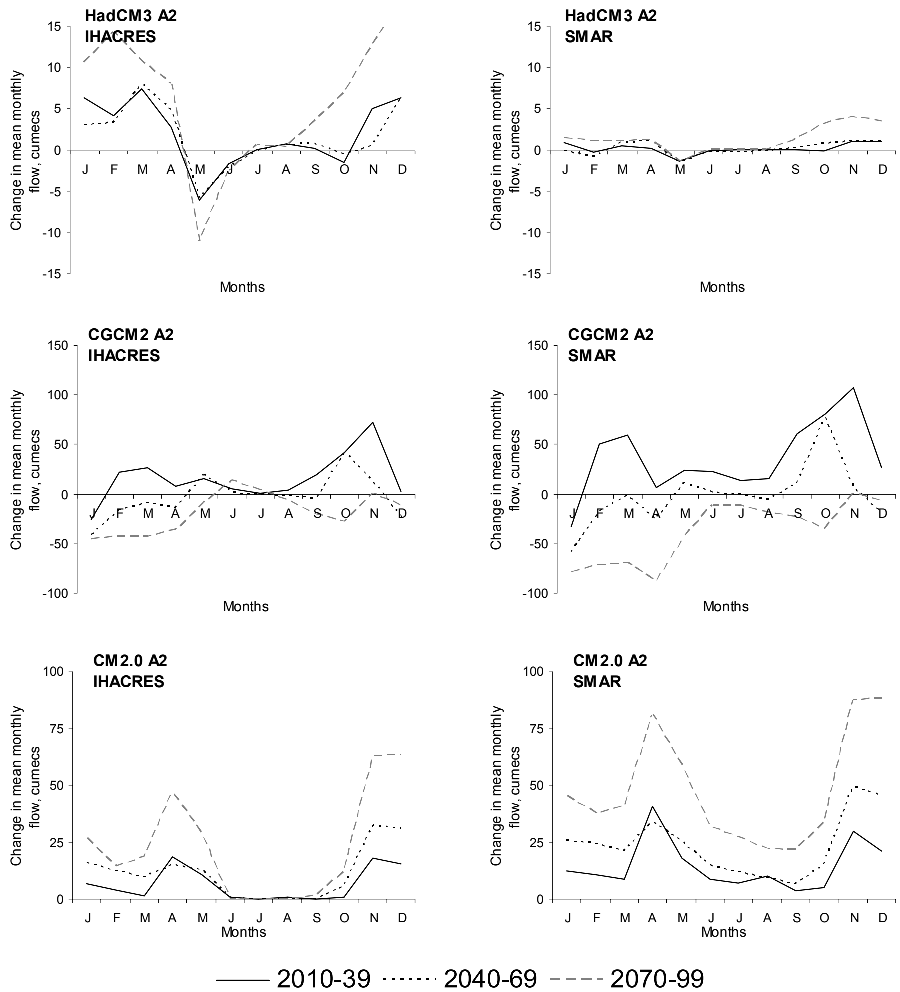

Figure 3 Simulated change in average monthly mean Gucha river flow corresponding to various scenarios and time periods

2.2 Annual Trends

Summary of the percentage changes in river flow changes for the future time periods are shown in Table 1. A minimum increase of 10% in total annual river flows for all catchments corresponding to the climate scenarios for the 2020s, while the 2050s and the 2080s are not confine to a particular trend.

Table 1 Percentage of increase/decrease of annual average flow corresponding to raw scenarios at different future time periods.

Scenarios		HadCM3			GFDL CM2.0			CGCM2		
Period		2020s	2050s	2080s	2020s	2050s	2080s	2020s	2050s	2080s
Nzoia	IH	9.3	4.6	30.8	47	72.7	194.1	17	-4.2	-27.4
	SMAR	26.7	77.6	243.2	75.9	120.1	340.3	18.7	-5.2	-34.1
Yala	IH	10.3	6.7	31.8	40.2	64.4	177.6	14.2	-5.5	-25.9
	SMAR	19.4	44.2	202.4	89.6	138	382.3	25.8	-4.3	-36.9
Sondu	IH	11.9	8.8	36.8	42.1	75.4	153.4	23.8	-1.1	-21.8
	SMAR	28.6	52.6	292.8	74.3	129.9	263.4	21.9	-4.7	-28.4
Gucha	IH	11.6	9.1	34.4	43	74.1	152.4	20.8	-3.3	-23.7
	SMAR	11.4	13.3	84.2	92.8	148.5	301.8	8.6	-16.4	-40.5
Mara	IH	6.2	1.9	22	41.5	72.1	147.5	23.3	-0.9	-22.5
	SMAR	-4.1	-14.3	41.2	98.9	166.4	339.6	31.7	-0.3	-30.1
average	IH	9.9	6.2	31.2	42.8	71.7	165	19.8	-3	-24.3
	SMAR	16.4	34.7	172.8	86.3	140.6	325.5	21.3	-6.2	-34

The suggested increases of river flows in the 2020s indicate a possible increase in the water level of Lake Victoria as well as possibility in abrupt increment. An increase in Lake level is good for hydropower, water supply and livelihood. However, the occurrence of larger incremental flows at concentrated at OND may imply extreme floods, similar to the extreme events in 1961 and 1997 event. The extreme OND rainfall received in 1961 and 1997 brought extensive flooding to lake shoreline settlements causing loss of homes and lives, and damage to crops. Both the 1961 and 1997 events show similarities in spatial characteristics and produced seasonal rainfall totals of approximately 200-500% above normal (Conway et al., 2005). It is suggested that this extreme OND rainfall suggested is associated with the periodic circulation dipole events in the Indian Ocean (Birkett et al., 1999; Webster et al., 1999). Future climate change induced increase in the Lake level would cause similar flood damage and decreases may affect hydroelectric power generation at the Owen Falls Dam, water supply and water quality. The large areas of wetland ecology in Lake Victoria basin may significantly be affected by the changes in lake level. Hence, a study of the impacts and response strategies associated with rainfall variability is essential in order to provide an insight into the region's vulnerability and adaptive capacity in relation to current climate variability and future climate change.

5. CONCLUSIONS

This study has attempted to understand the future river flows in relation to climate change for five rivers feeding Lake Victoria. Climate scenarios from GCMs are used as surrogates representing the future state. The results showed that the river flow reflect the rainfall distribution. The river flow pattern was accentuated by the rainfall pattern. Significant uncertainties remain about the likely impacts of climate change on rainfall intensity and patterns. However, particularly consistent results are, potential increase in river flows of over 10% in the 2020s period, increment of flows being larger during the local rainy seasons, and extreme river flows predictions in the 2080s.

The outcome of a hydrologic impact study, or impact study based on downscaled data, can be affected by the choice of a particular climate scenario, downscaling technique and hydrological model, as well as their combination. In conclusion, these results show the potential for climate change to bring about modification of river flows, thus requiring a significant planning response. The results, amongst others also indicate the importance of considering hydrological impacts in potable water supply and flood/drought studies.

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