Assessment of the impact of climate change on extreme precipitation and temperature events over the upper River Nile basin

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ABSTRACT
In river design application, design of hydraulic systems has traditionally been based on statistical analysis of historical records based on the assumption that the intensity and frequency of past events is statistically representative of what could happen in the future. Under the influence of climate change, this assumption may be null and void. Global and regional studies have shown that, for the upper River Nile basin, precipitation is projected to increase. However, it is not conspicuous how the changes in the precipitation extreme events and wet spells will be affected at catchment scale. In this study we assess the influence of climate change on precipitation and temperature data from several Global Climate Model simulations. The results showed significant increase in precipitation extreme events; a monotonic increase in the mean of the mean daily maximum temperature; and decreases in the seasonal wet spells for the periods 2046-2065 and 2081-2100. An ensemble analysis on the precipitation extremes indicates major shifts in the intensity-duration-frequency relationships, supporting the argument that under the influence of climate change the intensity and frequency of past events may not statistically be representative of what could happen in the future. This information is useful for many engineering applications; especially for river hydraulic infrastructure planning and design.

Key words: climate change, intensity-duration-frequency, precipitation extremes, quantile perturbation, upper Nile, wet-spell.

1.0 INTRODUCTION
Globally, wet extremes are projected to become more severe in many areas where mean precipitation is expected to increase, and dry extremes are projected to become more severe in areas where mean precipitation is projected to decrease (Wang, 2005; Burke *et al*., 2006). The increase in extreme events may be perceived most through the impacts of extremes (Kharin and Zwiers, 2005; Bernett *et al*. 2006). Regionally, analysis has shown that severe changes in precipitation will occur in the amount (Groisman *et al*., 2005) and such changes in precipitation may result in significant impacts on many sectors including urban drainage, dam design, farming and irrigation, etc. (Kunkel *et al*., 1999). In the case of river hydrology, the design of hydraulic systems, whose design period is comparable to the time scale associated to the induce climate change, has traditionally been based on statistical analysis of historical records. This is done based on the assumption that the intensity and frequency of past events are statistically representative of what could happen in the future. Under the influence of climate change this assumption must be reconsidered to account for the expected changes in the extreme precipitation events (Grum *et al*., 2006). Recent Global Climate Models (GCMs) continue to confirm the earlier results that the increase in precipitation extremes will be greater than the changes in the mean precipitation (Kharin and Zwiers, 2005; Barnet *et al*. 2006). Advances in climate modeling have grown to the extent that Regional Climate Models (RCMs) have been used (Fowler *et al*.

2005) at finer scales than GCMs but the applications of RCMs to regions in Africa are still limited. This means that impact studies are still largely based on GCM results. This study uses perturbation approach method (Harrold and Jones, 2003) through the extraction of the change signals from the GCMs. Such signals can then be applied to the observed data to obtain future times series. None of the few local studies carried out to assess the impact of climate change at catchment scale (Githui *et al*., 2009, Awange *et al*., 2008, Owor *et al*., 2009, Koutsouris *et al*., 2010) has addressed the implication of the change in extremes events (e.g. precipitation) in the Upper River Nile basin.

2.0 STUDY AREA

The upper Nile basin constitutes a huge part of the East African water body and forms the source of the River Nile.

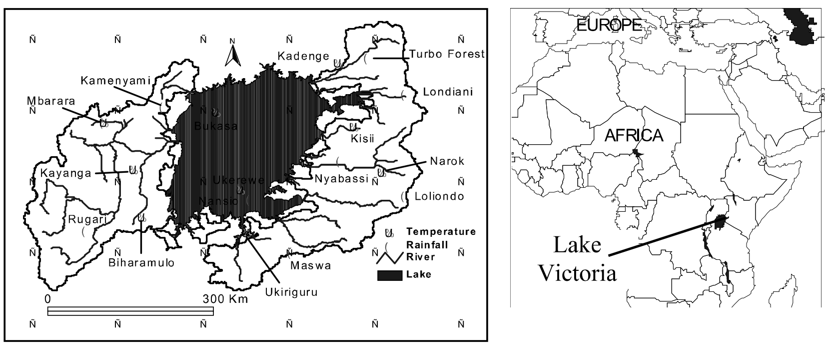


Figure 1: Dot (●) and full square (■) present the selected precipitation and temperature stations, respectively; plus (+) represent the mean grid size of the GCM simulation results used (left) and the location of the basin in Africa continent (right-top)

The lake basin is bounded by latitudes 0.5 N and 3 S and longitudes 29 E and 34 E. The major sub-catchments of the basin consist of Kagera, Katonga, Nzoia, Issanga, Mara, Nyando and Yala (Figure 1). The basin supports a huge population economically and understanding how the different sub-catchments will be affected by climate change influence is significant for adaptation strategy.

3.0 METHODOLOGY

3.1 Observed data

For each of the major sub-catchments in the Lake Victoria basin, a precipitation and a temperature station was each selected based on the availability of long term record. Areal Reduction Factor (ARF) in the range 0.6-0.9 for the respective sub-catchment was used to reduce the point precipitation into areal value so as to match the GCM area averaged projections. It is assumed that variation of temperature over the study area is not high and the point temperature measurement was taken as the catchment value.

3.2 GCM data

Eighteen GCMs' daily time series were obtained from the Program for Climate Model Diagnosis and Inter-comparison (PCMDI) database that were used for the Intergovernmental Panel on Climate Change Fourth Assessment Report, 2007. The GCMs reference period data was extracted from the series spanning 1961-2000, and for the periods 2049 -2065 (2050s) and 2081-2100 (2090s) were considered for the future simulations. The Projections are based on the SRES scenarios A1B, B2, and B1 which are linked to future greenhouse gas emission scenario trends (Nakicenovic *et al*., 2000). Using the GCM performance evaluation study results conducted over the Lake Victoria basin (Nyeko-Ogiramoi *et al,* 2010) fourteen GCM simulations were selected for the current study.

3.3 Climate change signals

The GCM outputs can not be used directly for impact assessment because of the huge difference in spatial scale and the high quantile bias between the GCM and the observed data. The climate change signals were instead extracted from the GCMs and used to construct future time series based on the different scenarios. The climate change signals are the changes in the statistical properties of the climate variable in the model scenario and control series. An important assumption in this study is that the bias in the future projection is similar to the bias in the reference simulation because of the same climate model structure. The climate change signals extracted and applied to the observation are: (i) the wet day frequency change, (ii) the wet day intensity perturbations (iii) the mean wet spell length change and (iv) the mean intensity change.

3.4. Independent precipitation extremes

In order to analysis the change in the precipitation extremes in the tail of the distribution of the perturbed series, independent precipitation extremes are required. An independent criteria, in which a threshold precipitation value in the ranked series, which makes all peaks above the threshold independent (Willems, 2009) of each other was used. All peaks above the threshold values are considered precipitation extremes. The intensity peaks were selected based on the principle of the Partial Duration Series (Willems, 2000) for aggregation levels 1, 2, 3, 5, 7, 10, 30 and 90 days.

3.4.1 Intensity-Duration-Frequency curves

To derive the IDF-relationships, the peaks of the intensity were fitted into Extreme Value Distribution (Lu & Stedinger, 1992), which combines three-component extreme distributions. The distribution parameters were calibrated using L-moment approach (Hosking and Wallis, 1997). The parameter/aggregation-level relationships, together with the analytical description of the extreme value distribution, then comprise the IDF-curves. The observed and the projected IDF-curves, for each of the scenarios and the selected stations, were plotted on the same chart to visualize the possible impact of climate change on the IDF-curves.

3.5 Change in temperature

The change in the mean daily maximum temperature was calculated as the different between the perturbed observed series and the observation. Instead of analyzing the extremes above a threshold, as was done with projected precipitation, the mean change about the mean of the mean daily maximum temperature, for each month, was considered and the changes were plotted on a chart.

4.0 RESULTS AND DISCUSSION

4.1 Percentage change in the peaks

Change in the precipitation extremes are expected to increase for the different catchments as indicated by the different models and for the different scenarios (Figure 1 – not all results shown).

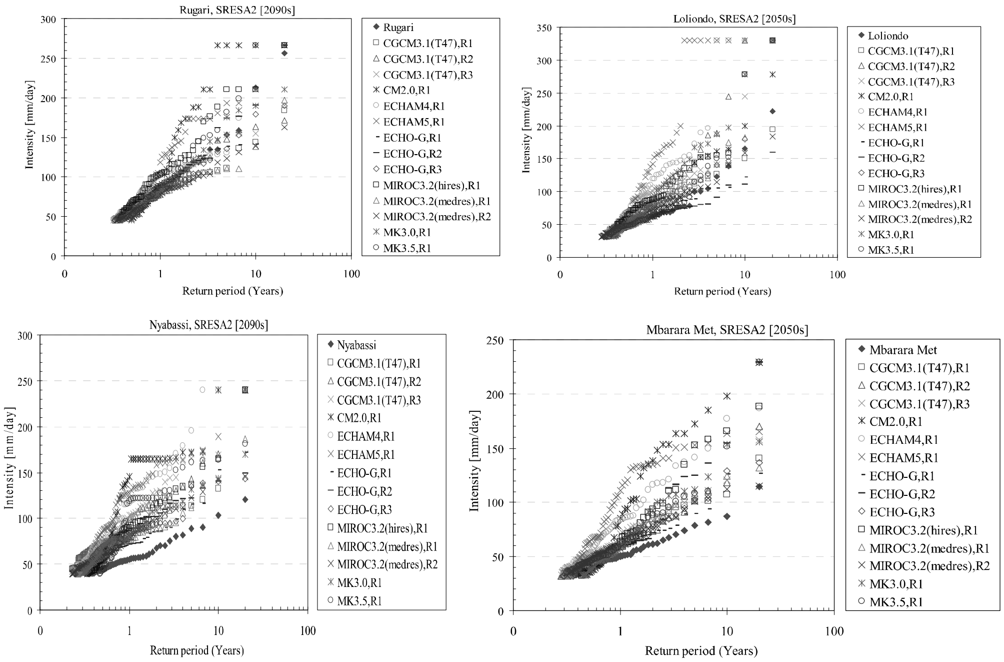
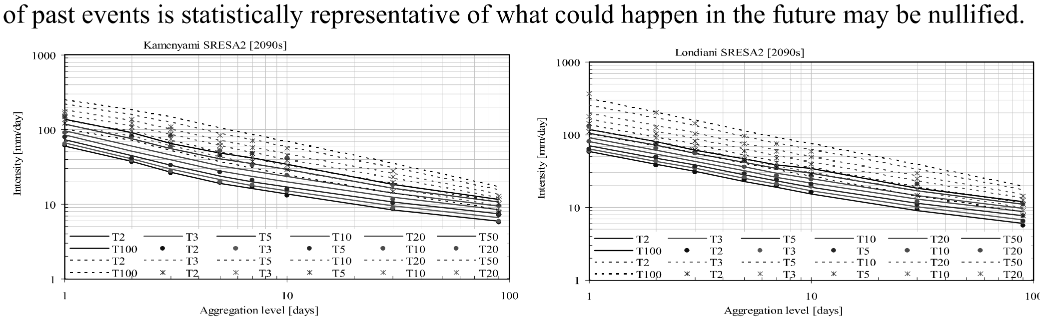


Figure 2: Projected peak intensity versus empirical return period for nine stations selected from the major sub-catchments in the Lake Victoria basin for the future period 2050s and 2090s.

This increase is in line with the finding of a regional study conducted by Anyaha and Semazzi (2007) on the variability of East African precipitation based on multiyear RegCM3 simulations. It is palpable from Figure 2 that the difference in change in the precipitation peaks for the periods 2050s and 2090s is not very clear but for the same return period the peak value for the period 2090 is higher than for the 2050s.

4.2 Intensity-Duration-Frequency

Figure 3 shows projected upward shift in the IDF, except for Rugari and the implication is that in the future, the frequency of reoccurrence of extreme events is projected to increase compared to the past record. Under climate change influence the assumption that the intensity and frequency of past events is statistically representative of what could happen in the future may be nullified.



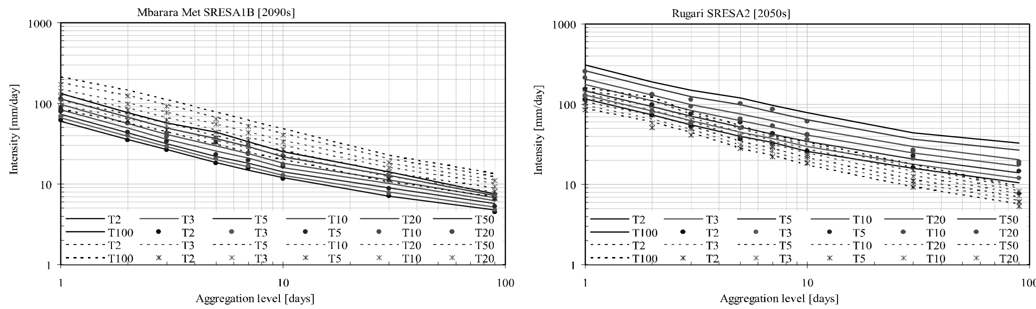


Figure 3: Selected IDF-relationships; Tx (x: 2, 3, 5, 10, 20, 50 & 100) are the selected return periods for the 2050s and 2090s. Continuous lines represent the observed IDF curves; dotted lines represent the ensemble mean IDF curves of 15 model simulations; full circle (•) represents the observed empirical points and star (∗) represents ensemble mean empirical points.

4.3 Change in the wet spell

Figure 4 shows that the mean wet spell lengths for the months of July-October will generally reduce and the reduction will be in the range of 10-30% for A2 and B1 scenarios. Results for A1B (20-60% increase) scenarios for all the months are significantly different from the other two scenarios implying that the direction of change is uncertain. Consistent results for the A2 and B1 shows decrease in wet spells for July, August, September and October. Extremes precipitation events will increase over the region but the dry spells for the different months will increase (A2 and B1).

The implication is that increases in the frequency of dry spells do not necessarily mean a decrease in the frequency of extreme precipitation events but the increase in the precipitation extremes is expected to be greater than the changes in the mean precipitation. This finding is consistent with the results of the recent studies conducted as macro scales (Kharin and Zwiers, 2005; Bernett *et al.*, 2006).

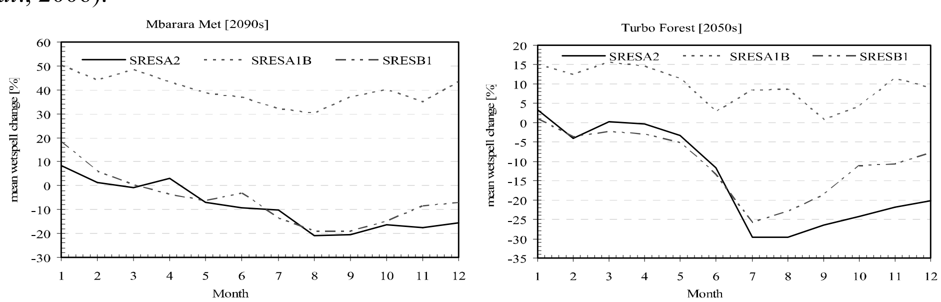


Figure 4: Selected charts for the percentage change in mean wet spell length for the 2050s and 2090s with respect to 1971 -1990 for SRES A2, A1B and B1

4.4 Change in temperature

The mean change in the mean daily maximum temperature for the 2050s and 2090s is projected to increase by 0.2-1.99 °C and 1.26 to 3.8 °C, respectively from the overall mean daily maximum temperature of 26.87 °C over the Lake Victoria basin (Figure 5).

The changes are amplified by A2 scenarios for both the time periods (2050s and 2090s) for all the stations. The difference in the changes projected by A1B and B1 scenarios is smaller compared with the difference either between A2 and A1B or A2 and B1. The difference between the lower value (projected by B1) and the higher value (projected by A2) is about 0.5°C for the month of January and about 3°C for the month of May.

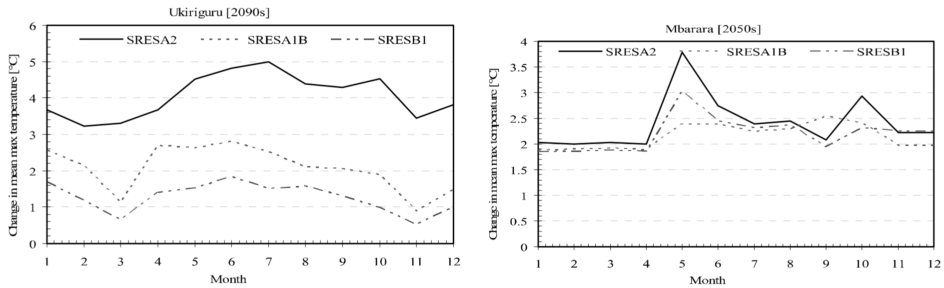


Figure 5: Selected charts for the percentage change in the mean of the mean daily maximum temperature for the 2050s and 2090s with respect to 1971-1990.

5.0 CONCLUSION

The impact of climate change on the Intensity and frequency of precipitation extremes and daily maximum temperature has been assessed and are projected to be significant by 2050s and 2090s. The wet-spell length for each of the seasons is expected to reduce implying longer dry spells for most of the months and this is related to the projected increase in the mean daily maximum temperature. Water professionals should take into account the expected impact of climate change on the precipitation extremes as it will significantly affect the storm design curves, which is very useful for many engineering applications. Water managers should properly plan for extreme precipitation events which are expected to result in floods and landslides; and thirdly farmers may be advise to take into consideration the changing climate and the expected influence of projected change climate on the frequency of extreme precipitation and change in the wet spells. It should be noted that there are sources of uncertainty in a study like this one which are associated with: (i) the climate change science (ii) the assumptions made (iii) spatial scale between the model and the observation and (iv) the internal structure of the models. Despite the different uncertainty sources, which are especially difficult to quantify in probabilistic projections (Tebaldi and Knutti, 2007), the use of multimodal ensemble may still give possible range of impacts.

6.0 ACKNOWLEDGEMENT

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