ASSESSING THE IMPACTS OF CLIMATE CHANGE ON STREAMFLOW IN MALABA RIVER CATCHMENT, UGANDA

Charity Kangume, Deogratias M.M. Mulungu
Masters Student, University of Dar Es Salaam, College of Engineering and Technology
Kangumecharity@ymail.com
Senior Lecturer, University of Dar Es Salaam, College of Engineering and Technology
deorgm@yahoo.co.uk

Abstract

Malaba River in Uganda a focal area to the Lake Kyoga basin is prone to climate change because of its heavy reliance on rainfall as its major flow contributor. The impacts of climate change on streamflow in Malaba River were assessed using LARS-WG downscaling model and Soil and Water Assessment Tool (SWAT) model. This was achieved by downscaling the future (2020-2050) precipitation and temperature variables for A1B and A2 scenarios and simulating the projected climate with calibrated LARS-WG and SWAT models for the two scenarios. The SWAT calibration (1992 - 1999) and validation (2000 - 2004) NSE results were respectively 0.55 and 0.35. Results indicated that the projected areal rainfall will increase by 0.34 mm per year for A1B which is averagely 1% less than the baseline period. Areal rainfall for A2 scenario will increase by 0.41 mm per year which is averagely 9% more than the baseline period. The Flow Duration Curve analyses indicated that the A2 scenario displayed higher flows for all the percentiles as compared to the baseline flows while A1B scenario has lower flows for percentiles less than 50, and equal or slightly higher flows for percentiles greater than 50 as compared to the baseline flows.

Keywords: climate change, LARS-WG downscaling model, Malaba River, SWAT

1. Introduction

About 65% of the African population will be at risk of water stress by 2025 (Gunasekara 2014, 169-184). Climate change is most likely to have an effect on developing countries like Uganda whose major economy relies heavily on water. There were registered low flows in Malaba River in January and February in 2015 which led to a substantial water deficit to the surrounding irrigation and town water supply schemes. Therefore the general objective of this study is to assess the impacts of future climate change (2020-2050) on streamflow in Malaba river and this was achieved by; projecting the climate change variables 2020-2050 period for the Malaba river catchment based on the selected climate scenarios, simulate streamflow of the catchment using SWAT Model and finally assessing the impacts of climate change on streamflow.

SWAT model that simulates the hydrological processes in a catchment was used because its inputs are readily available, thus the least data is required to make a run and also it is efficient computationally. LAR-WG downscaling model was used because it’s readily available on the internet and also easy to use. It has also been applied successfully in several similar case studies (Mwiturubani 2010).

2. Methods

2.1 Analysis of Hydroclimatic data sets

The trend analysis for the observed, projected climate and simulated flow was done by Mann-Kendall test and its magnitude was estimated using Theil-Sen approach. Change analysis of the projected climate and simulated flow was determined against a baseline period of 1980-2004 (for climate) and 1986-2015 (for flow) respectively. Two different periods were used for the baseline because of insufficient data for the same period. Areal rainfall of the catchment was determined using Thiessen polygon method.

The simulated flow was also analyzed using Flow Duration Curve (FDC) to determine the percent of time during which specified discharges were equaled or exceeded in a given period. Therefore, FDC was used for flow variation assessment with daily flows for simulated flow (2020-2050) which was compared to the one in the baseline flow period (1980-2015).

2.2 LARS-WG Model Calibration and Validation

A1B and A2 scenarios which predict a future (2020-2050) with homogenous and heterogeneous development path were selected for this study because they explain the most “likely to happen” development paths i.e. medium and high development path respectively. LARS-WG model was calibrated (site analysis) using the historical observed data i.e. precipitation, maximum and minimum temperature of all the three stations for 1980-2010 time period. Q-test (validation) was carried out to confirm the performance of the model. The Kolmogorov-Smirnov (K-S) test indicates equality of the seasonal distributions for daily rainfall and temperature data determined from observed and downscaled data and a p-value, based on which the modeler uses to accept or reject the hypothesis. Therefore the modeler is able to determine the difference between the observed and simulated variable if any.

2.3 SWAT model calibration and validation

The first step was to delineate the watershed using the DEM. This created 15 sub-basins as well as the drainage system of the study area. From the land cover, soil spatial data, slope and soil maps, 85 hydrologic response units (HRUs) were generated. The meteorological input data were: maximum temperature, minimum temperature, and precipitation. Three rainfall stations were used i.e. Bungoma, Tororo and SWAT station. Mbale station was used for only temperature. Tororo flow gauging station was used. Due to availability of only rainfall and temperature data in the study area, the SWAT model was set to compute potential evapotranspiration using Hargreaves method. The SWAT model was then set to simulate streamflow of Malaba River from 1992 to 2004. During the simulation period, the model warm up period was 4 years (1988-1991) and the calibration period was from 1992 to 1999 and the validation period was from 2000 to 2004. According to Moriasi (2007), the model performance in simulating streamflow was evaluated using the commonly used optimization objective functions: Nash-Sutcliffe Efficiency (NSE), Root Means Square Error (RMSE) and Percentage bias (PBias) and coefficient of determination (R2). Moriasi (2007) proposed NSE be above 0.5 for hydrologic and pollutant evaluations on both daily and monthly time step. Then, the calibrated and validated SWAT model for Malaba River catchment was used for future streamflow simulation for the period 2020-2050 for both A1B and A2 scenarios.

3. Results and discussion

3.1 LARS-WG Model Calibration and Validation

The results from statistical tests at a significant level of 5% showed that LARS-WG generated climate that is most likely to be the same as the ‘true’ climate. This is an indication of the suitability of LARS-WG for the climate downscaling in Malaba River catchment

3.2 Projected Data Analysis;

3.2.1 Trend Analysis; Trend in areal rainfall displayed an increasing trend with magnitude of 0.34 mm per year and scenario displayed an increasing trend with magnitude of 0.408 mm per year for A1B and A2 scenarios respectively. For maximum temperature, both A1B and A2 scenarios displayed a non significant decreasing trend with magnitude of 0.004^{0}C. For minimum temperature A1B scenario displayed a non significant increasing trend with magnitude of 0.001^{0}C per year and A2 scenario displayed a non significant increasing trend with a magnitude of 0.002^{0}C per year.

3.2.2 Projected Change Analysis; For A1B scenario, areal rainfall will increase by an average of 8% of the baseline monthly rainfall. For A2 scenario, areal rainfall will increase by an average of 18% of the baseline monthly rainfall. For A1B scenario, maximum temperature will increase by at least 0.2^{0}C monthly and for A2 scenario, maximum temperature will increase by at least 0.3^{0}C monthly. For A1B scenario, minimum temperature will increase by 0.1^{0}C monthly and for A2 scenario, minimum temperature will increase by atleast 0.2^{0}C monthly. Therefore areal rainfall in the catchment will increase significantly by approximately 2% of the baseline monthly areal rainfall and maximum and minimum temperature will not increase significantly. These results are supported by (Niang 2014, 1199-1265) which shows that precipitation will decrease in the months of June and July by the end of the 21st century, this is as a result of weakening Somali jet and Indian monsoon. Jassogne (2013) also stated an increasing trend in maximum and minimum temperature over the next 50 years starting from 2015.

3.3 SWAT calibration and validation

A given set of calibration parameter values were found to give a good simulated stream flow at subbasin 14 which is the gauging station by SWAT model. The optimum calibration parameters are presented in Table 1.

Table 1: Calibration parameters

No	Parameter name	Fitted value	Min value	Max value
1	r_CN2	-0.247	-0.25	-0.17
2	v_SURLAG	30.75	30.30	38.20
3	v_ESCO	1.28	1.10	1.30
4	v_APLHA_BF	0.22	0.18	0.24
5	v_CH_K2	191.43	138.50	219.40
“v” means Replacement of the default parameter “r” means multiplication to default parameter				

The calibration was obtained with NSE of 55%, R2 of 0.59, p-factor of 44% and r-factor of 0.57. The results for the validation period (2000-2004) were: NSE = 35%, p-factor = 40% and r-factor = 59%. The NSE for the calibration was better than the one for validation period and this could be attributed to some factors such as the spatial distribution of the rainfall stations and also the change in rainfall for the two periods.

3.4 Analysis of simulated streamflow

Simulated streamflow for A1B scenario has an increasing annual trend of 0.243 m^3/s and A2 scenario also has an increasing annual trend of 0.264 m^3/s.

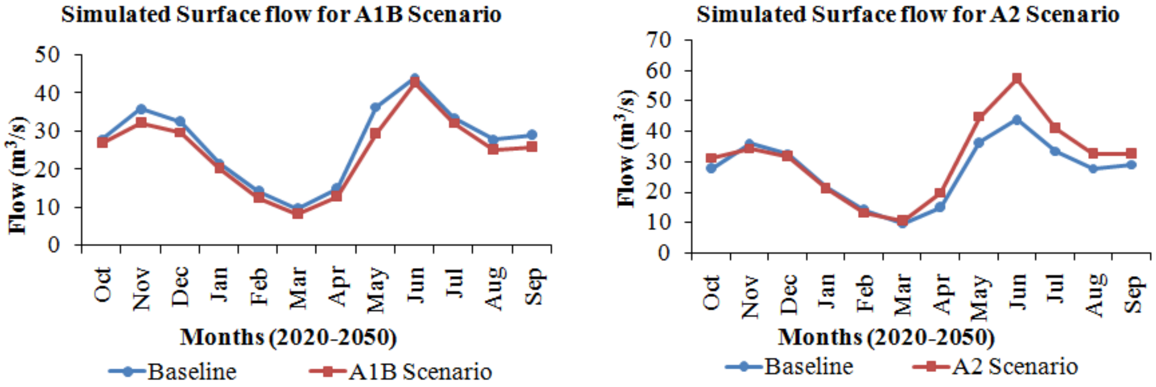

Figure 2: Change analysis of simulated flow for A1B and A2 Scenarios

From Figure 2, simulated stream flow for A1B scenario follows the trend of the baseline period with the high flows being in June and low flows being in March. But the A1B displays monthly low flows as compared to the baseline with an average of 2.3m3/s. For the A2 scenario, the simulated surface flow follows the trend of the baseline period. The simulated surface flow has highest flows in the month of June and the lowest flows in the month of March. However, the simulated surface flow is higher than the baseline period by an average of 3.5m3/s monthly

Simulated Flow Variation Assessment

The FDC was developed for both the observed (1980-2010) and SWAT simulated flow (2020-2050 for both A1B and A2 scenarios) for comparison purposes (Figure 2)

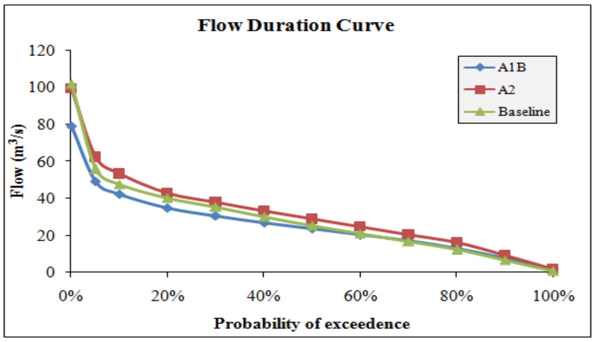

Figure 2: Simulated flow variations by flow duration curve

From Figure 2 above, A1B scenario has lower flows for percentiles less than 50 and equal or slightly higher flows for percentiles greater than 50 as compared to the baseline flows. A2 scenario has higher flows for all the percentiles as compared to the baseline flows. Therefore this means that higher floods are to occur and the lower flows will increase in A2 scenario as compared to the baseline period. Higher median flows are to also occur in the A2 scenario.

4. Conclusions

Irrespective of insufficient observed data, the SWAT model proved to be applicable in Malaba River catchment. From an analysis on the hydroclimatic variables in the study area, results showed that fluctuations in rainfall have an impact on streamflow. Therefore the historic climate change has contributed to fluctuations in stream flow. The climate of the catchment was projected and both the areal precipitation and temperature trends showed an insignificant increase for A1B and A2 scenarios. The change analysis showed that monthly areal rainfall for A1B scenario is 1% less than the one for baseline period while for the A2 scenario it is 9% more than the value for baseline period. The SWAT model was successfully calibrated during 1992-1999 with a NSE of 55%, R^2 of 0.59, p-factor of 44% and r-factor of 0.57. The validation period was 2000-2004 with NS of 35%, p-factor of 40% and r-factor of 59%. The simulated streamflow for A1B scenario is averagely 2.3m^3/s less than the one for baseline period per month whereas for the A2 scenario, it is averagely 0.1m^3/s more than the value for the baseline period per month.

It is therefore concluded that the A2 scenario is most likely going to be experienced which will impact on the streamflow of Malaba River. The simulated flow will start to increase from April and reach its peak in June which is 13.3m^3/s higher than the value for the baseline period and gradually decrease till it intersects with the baseline period in November. The flow from November to March is similar to the baseline period with March having the lowest flows. Hence the streamflow is most likely to increase in Malaba River for the two scenarios

5. References

Gunasekara, Nilendra., Analysing Regional Aspects of Climate Change and Water Resources. Journal of Water Resources Management vol 28, no.1 (2014): 169–184.

Jassogne, Laurence. 2013. *The impact of Climate Change on Coffee in Uganda*: Lessons from a case study in the Rwenzori Mountains. Oxfam Research Reports.

Moriasi, Daniel. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations, 2007.

Mwiturubani, Donald. Climate change and access to water resources in the Lake Victoria basin. Institute for Security Studies: 2010.

Niang, I. 2014. *Climate Change Impacts, Adaptation, and Vulnerability*. Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 1199-1265. Cambridge University Press.