CHAPTER 8: WATER RESOURCES AND ENVIRONMENTAL ENGINEERING

Climate Change and its Impacts on River Flows and Recharge in the Sezibwa Catchment, Uganda

Peace Abaho[3], Brenda Amanda[3] Max Kigobe[1], Micheal Kizza[2], Albert Rugumayo[4]

[1]Lecturer, Faculty of Technology, Makerere University, P.O. Box 7062 Kampala, Uganda
Corresponding author email: mkigobe@gmail.com
[2]Assistant Lecturer, Faculty of Technology, Makerere University, P.O. Box 7062 Kampala, Uganda
[3]Graduate Student, Faculty of Technology, Makerere University, P.O. Box 7062 Kampala, Uganda
[4] Senior Lecturer, Faculty of Engineering, Ndejje University, P.O.Box 7088 Kampala, Uganda

ABSTRACT

There is insufficient knowledge in Uganda about the effects of climate change on water resources in Uganda. To address this, a study was conducted for R. Sezibwa catchment of Mukono and Kayunga districts in Uganda, to assess the effects of climate change on the river flows and groundwater recharge. An uncalibrated Soil and Water Assessment Tool (SWAT) model was used in the hydrological modelling of the catchment for the baseline period of 1970-1990. A climate model MAGICC/SCENGEN was then used to simulate the expected changes in climate for the catchment for the future period of 2070-2100, for a set of SRES scenarios, for both precipitation and temperature. The results obtained were then used as inputs into the SWAT hydrological model, which was used to simulate the resulting hydrological changes.

The results showed the highest increase in temperature in the dry seasons of June – August as 2.6 – 3.0 ^{0}C and 2.3 – 2.4^{0}C in the December – February, respectively. The changes in precipitation showed an increase of 15 – 16% in March to May and a 10 – 11% and in September – November wet seasons, respectively. A 32% increase was observed in December - February and a 12 – 14% increase in the June – August dry seasons, respectively. These changes translated into approximately a 47% increase in average daily flows, which is significant and could occur by the year 2070. With respect to recharge, increments of between 15-40% were observed in the wet seasons of March – May and September – October-November, while higher increments of 60-100% were observed in the dry seasons of December-January-February. These results will contribute to the discussion on the effect of climate change on water resources in Uganda. However, the uncertainty associated with climate change scenarios and general circulation models and the limited data sets, means the outputs need to be carefully evaluated in regard to future water policies and strategies. There is therefore need for a more concerted effort in the collection of hydrological variables, in order to improve the accuracy of future model simulations.

Key words: Climate Change, Hydrology, Recharge, SWAT, MAGICC/SCENGEN

1.0 INTRODUCTION

Uganda is highly vulnerable to climate change and variability; its economy and the wellbeing of its people are tightly bound to climate as it is a predominantly agricultural country. Its climate is naturally variable causing it to be susceptible to flood and drought events which have had negative socio-economic impacts in the past. According to Hepworth (2008), human induced climate is likely to increase temperatures in Uganda by about 1.5^{0}C in the next ten years and by up to 4.3^{0}C by the 2080's with significant changes in rainfall patterns and total rainfall amounts. These changes will cause an alteration in the hydrological cycles resulting in an increase in evaporation and more intense rainfalls, severely affecting the availability quantity and quality of water (IPCC, 2001). Heavy rainfalls in the wet seasons are expected to damage agriculture and engineering structures as a result of increased runoff (Arnell, 1999). Uganda is more vulnerable to these climatic changes due to lack of institutional capacity and economic development Basalirwa et al (2008). Because of this deficiency, climate change problems have not been adequately dealt with in water resources analyses, management and policy formulation. This in effect has led to increased exploitation of groundwater resources as an alternative to rain-fed agriculture. Groundwater is a major source of water in Uganda because of its potable quality and inexpensive, easy- to- manage treatment systems. This advantage of groundwater over surface water has not only led to increased exploitation and dependence on groundwater in Uganda; but also questions about the sustainability of the presently available groundwater resources. Sustainability of the groundwater supplies can be ensured if the annual rate of abstraction of the available resources does not exceed the annual rate of recharge/ replenishment. This balance between abstraction and recharge can only be maintained if the quantity of water available in the aquifers is known and therefore properly planned for so as to avoid depletion of the resources.

The increased exploitation of Uganda's groundwater resources is being done with little knowledge of the quantity of water that is available in the aquifers, risking reduction in the quality and quantity of the available groundwater. This could ultimately lead to depletion of the resources, negatively affecting crop production in the affected areas. This calls for a better understanding of resources if sustainable development of the resources is to be done.

The study involved estimating the quantity of water available for both streamflow and recharge in the catchment for the baseline period (1970-1990), assessing the effect on climate change on mean temperature and precipitation for the future period (2070-2100) and then forecasting the impact of the change in mean temperature and precipitation on the quantity of water available in the period (2070-2100).

2.0 STUDY AREA

The catchment contributing to the flow of River Sezibwa is approximately 175 km^2. River Sezibwa is located in the southern central part of Uganda and is approximately 165 km long from the source to the point where the river enters L. Kyoga. The geology of the area is characterized by Precambrian rocks and the topography varies from 1353 m at the source to 1122 m at L. Kyoga (Nyenje and Batelaan, 2009).

3.0 METHODOLOGY

The Soil and Water Assessment Tool (SWAT), a physically based hydrological model, was used to relate the soil, land use and climatic data of the area. A climate model (MAGICC/SCENGEN) was used to simulate the significant changes of temperature and precipitation over the study area due to climate change. These changes were then used in the SWAT model to reflect the impact of climate change on the hydrologic processes in the catchment. The results were then compiled in geographical information systems (GIS).

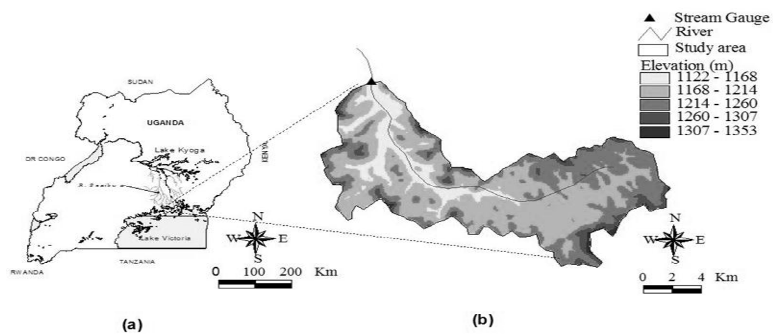

Figure 1: (a) Location map of study area (b) Topography and catchment boundary (Source: Nyenje and Batelaan, 2009)

Generally, a watershed for which a hydrological model has been developed can be assessed for climate change through climate change scenarios. According to Phoon et al. (2004), the assessment is evaluated by comparing specified climate change scenarios to the current climate or the baseline climate, which represents conditions in absence of climate change. The data used in this assessment included 90 m resolution grid map of elevation, land use and soil maps, as well as daily precipitation and potential evapotranspiration data. Meteorological data spanning from 1970 - 1990 was obtained from two weather stations from the Directorate of Water Resources Management Entebbe, Uganda.

Based on the Digital Elevation Model, Sezibwa catchment was then partitioned into 33 homogeneous watersheds, each with a spatial explicit location SWAT model simulations were conducted for the period 1970 – 1990 as the baseline and 2070 – 2100 as the future period. Climate change was simulated with SWAT by manipulating the climatic input that was read into the model (precipitation, temperature, solar radiation, relative humidity, wind speed, potential evapo-transpiration and weather generation parameters) using adjustment factors for precipitation and temperature in each sub basin.

Reference and policy scenarios for changes in climatic inputs were defined in MAGICC and their output used by the GCM'S in SCENGEN to produce spatially detailed information on changes in temperature, precipitation, changes in their variability, and a range of other statistics for the future period of 2070 – 2100.

The values of the percentage change in precipitation and change in mean temperature were obtained from MAGICC/SCENGEN, one of the global circulation models used to study how the global climate may change in response to increasing levels of greenhouse gases in the atmosphere (WRI, 1990). The model uses the four (A1, A2, B1 and B2) IPCC SRES (Special Report on Emissions Scenarios) storylines, which form the basis for many studies of projected climate change and water resources. The storylines consider a range of plausible changes in population and economic activity over the 21st Century, also putting into consideration global integration and regional emphasis. In this study, an average of the four scenarios was obtained and used.

4.0 RESULTS AND DISCUSSION

The precipitation data (1970-1990) and other data such as soil types, topography, vegetation types, land management practices for the Sezibwa catchment were used in the SWAT model to simulate the hydrological processes taking place in the catchment. Consequently, the amounts of soil water, potential evapotranspiration, evapotranspiration, recharge, surface run-off, groundwater flow, water yield, among others were obtained for the baseline period (1970-1990) for each of the sub-basins.

The resulting changes in mean temperature and precipitation from MAGICC/SCENGEN recorded in Tables 1 and 2 show that there is a general increase in temperature and precipitation in all sub-basins.

Table 1: Temperature changes in ^{o}C

	SCENARIOS				
SEASON	A1B-AIM	A2-ASF	B2-MES	B1-IMA	AVG
D-J-F	2.63	3.34	2.19	1.47	2.41
M-A-M	2.63	3.25	2.20	1.45	2.38
J-J-A	3.06	3.60	2.58	1.79	2.76
S-O-N	2.00	2.31	1.66	1.13	1.78

Table 2: Percentage precipitation changes

	SCENARIOS				
SEASON	A1B-AIM	A2-ASF	B2-MES	B1-IMA	AVG
D-J-F	34.30	39.07	30.33	24.00	31.93
M-A-M	14.60	39.10	14.67	7.53	18.98
J-J-A	10.17	31.17	15.90	-0.07	14.29
S-O-N	6.17	18.90	25.70	1.27	13.01

i) Recharge

Simulation with SWAT showed that these increments in precipitation in turn promise increments in recharge in all catchments over the 30-year period as shown in Figure 2 with variations in space and time. Increments of between 15-40% in recharge are observed in the wet seasons of March-April-May and September-October-November, while larger increments of 60-100% are observed in the dry seasons of December-January-February, a result of changed climatic conditions and patterns. While there is a decrease (negative percentage changes) in the amount of soil water in the March-April-May season, there is an increase in the amount of groundwater recharge as shown in Figure 3.

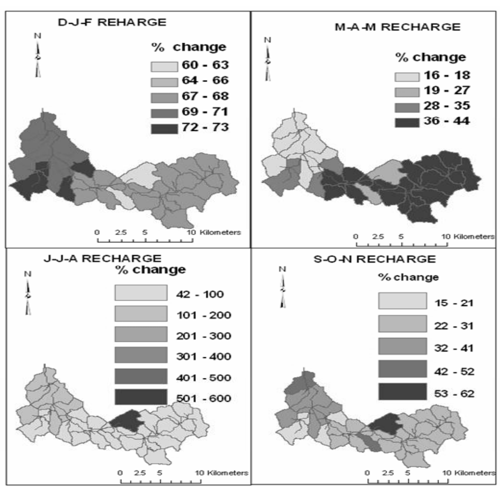

Figure 2: Maps showing percentage recharge increments for (2070-2100)

The increments in recharge are significant in some catchments, as high as 60% in the seasons of December- January-February and September-October-November. For catchments with such high predicted recharge increments, management policies could be put in place to make sure that the groundwater resources are allowed to increase so that sustainable abstraction can be done. The June-July-August recharge increments show an anomaly, rising up to 500%. The implication of such varied changes is that during the period when very little recharge is taking place in the month of June, the increased recharge in the following months of July and August can counteract the effects and therefore with the proper management policies and plans in place, controlled groundwater abstraction can still be done with no negative impact to the resources. It is important to study the hydrological processes using an integrated approach in order to better manage the resources; for example during this season, the farmers and agriculturalists in the catchment would have to rely more on irrigating their fields with water from other sources such as groundwater.

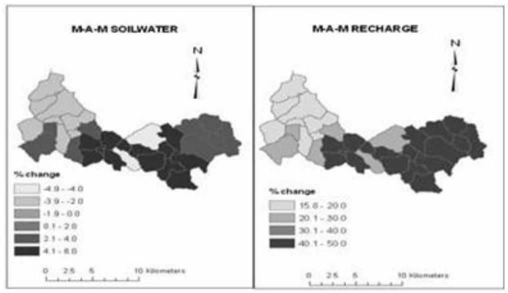

Figure 3: Map showing recharge and soil water changes for (2070 -2100)

ii) River Flows

Table 3 Comparison of flows between the baseline and future periods

Flow (1970-1990) in m^3/s	4	3	2	1.5	0.6	0.02
Flow (2070-2010) in m^3/s	6	4.5	3	2	0.9	0.02
% equalled or exceeded	10	20	40	60	80	100

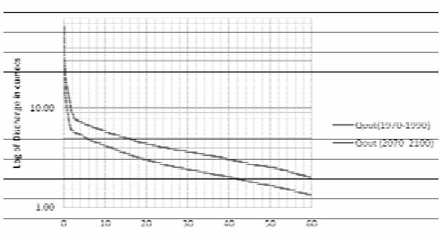

Figure 4 : A figure showing a high flow duration curve at the basin outlet

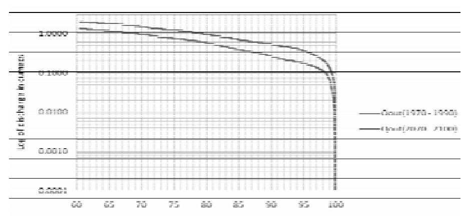

Figure 5: A figure showing a low flow duration curve at the basin outlet

The results show there is an increase in the volumes of flows in the period 2070 - 2100 as compared to the period 1970 – 1990. A comparison between results for the baseline and future flows showed on average a 47% change in the volume of flows as shown in Table 3. A high flow duration curve and low flow duration curve are shown in Figures 4 and 5 respectively. This increase in flows is likely to cause higher incidences of floods in the catchment. The spatial variation of both water yield and runoff from, which discharge results, is characterized by high changes with the highest changes in runoff of up to 707% being experienced in the season Jun – Aug as shown in Figure 6 (c)). In this period when high changes in runoff and water yield are realised, excess water may be collected and diverted to holding structures for subsequent use especially in the dry periods when low values of both runoff and water yield manifest but when runoff is very low as in Sep **-** Nov, it is important that the residents select and plant crop varieties resistant to adverse conditions such as this through sustainable agriculture.

5.0 CONCLUSION

Climate change is expected to occur in the Sezibwa catchment as in the rest of the world. The effect of climate change in the Sezibwa catchment is varied with different sub-basins in the different seasons. The climate change and hydrological models used show the predicted changes in the general hydrology of the catchment for the future period 2071-2100.

Future climate change scenarios generally show that precipitation will escalate with more heavy rains in the wet seasons of up to 3959 mm Mar-May and Sep - Nov while the dry months Dec – Feb, Jun – Aug will experience an increase in temperatures of up to 3^0C and up to 30% increase in precipitation are expected in the catchment as a result of climate change. This will in turn affect the hydrological processes such as soil water, evapotranspiration, recharge and streamflow

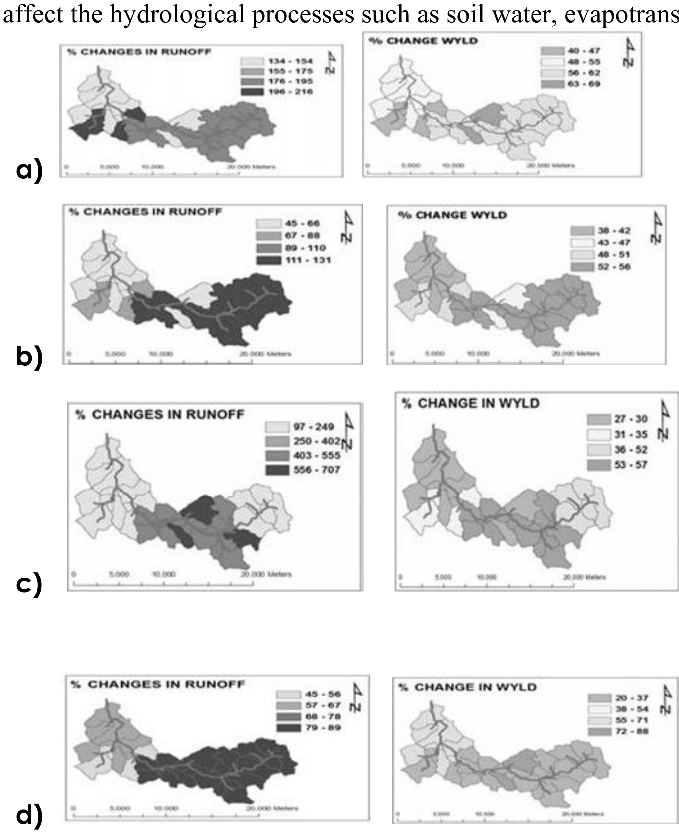

Figure 6: a) DEC – FEB   b) MAR – MAY c) JUN – AUG   d) SEPT – NOV

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-5-10% changes are expected in evapotranspiration during the dry season and 8% increase in the wet season. The soil water changes are widely varied in the dry seasons with a 1% increase estimated for the Dec - Feb season and 30% increase for Jun – Aug season while 3-5% increase in soil water is estimated for the wet season. Groundwater recharge increments range between 15-40% in the wet seasons and 60-100% in the dry season. The river is expected to flood in the wet months due to an increase in river flows of up to 47% while in the dry seasons; the results suggest that the river may experience significant reduction in flows due to the increased temperatures in these months. Therefore these results must be interpreted and with care and when these findings are translated to other catchments, this should be kept in mind. The results of this study will be useful in future studies and decision making in water resources management for the region.

6.0 RECOMMENDATIONS

Additional data should be collected (especially rainfall data) to improve the spatial distribution of the model results. It must also be noted that these results greatly depend upon the Global Circulation Models (GCMs) used for climate change projections. Further research is recommended in this area as regards uncertainties related to GCMs. Results from GCMs should also be downscaled to those of the catchment under investigation for a much more accurate prediction. It is however, important to note that the uncertainty of the model results was not investigated. Further research on the area regarding the use of hydrological models and calibration of model parameters must be done to ensure approximation of the model results to those observed for better accuracy.

The river flows obtained from this research could be used for further study on the area especially as regards flood mapping in order to determine which areas along the river would flood in case of heavy flows and subsequent planning of adaptation measures in such affected areas. Preferably this would consider use of a wider range of climatic data as compared to that used in this study.

In addition, other factors that are likely to affect groundwater recharge such as changing land cover and land use and soil water holding capacity were not considered .This should be put into consideration when using the obtained results. The results may also be compared with those obtained from the use of other hydrological models so as to get a better understanding of hydrological processes taking place in the catchment especially groundwater recharge.

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