Application of SWAT in Natural Wetland Catchments. A Case of Rugezi Catchment in Rwanda

P.M. Ndomba[1]*, D. Magoma[1], F. W. Mtalo[1], and J. Nobert[1]

[1]University of Dar es Salaam (UDSM), Tanzania; *Email*: pmndomba2002@yahoo.co.uk*

Abstract

Hydrologic models are increasingly used to support decisions at various levels and guide water resources policy formulation, management and regulations. In this study the Soil and Water Assessment Tool (SWAT) was examined for its applicability in wetland catchment of Rugezi in Rwanda covering an area of, approximately to, 197 Km^2. The study adopted SWAT model as recommended by others workers in the region in order to extend its testing. The application of SWAT model entailed setting up the model using readily available data, sensitivity analysis and calibration. In this study wetland model physical parameters such as width, depth, length, slope and area were generated by GIS based SWAT interface. The ground photos available from literature supplemented and validated the GIS data. An independent simulation was also conducted without implementing the wetlands in order to study its impacts on the hydrology. Sensitivity analysis indicated that Channel effective hydraulic conductivity (CH_K2), Surface runoff lag time (Surlag), SCS runoff curve number under moderate moisture condition (CN2), and Manning's n value for main channel (Ch_n) are the most sensitive parameters. Comparable results between simulated and observed streamflows at the catchment outlet, Rusumo gauging station, were obtained. The Nash and Sutcliffe coefficient values (CE) and Index of Volumetric Fit (IVF) were 49.15% and 95.6% for calibration and 51.4% and 98.6% for validation periods, respectively, indicating a satisfactory simulation. It was evident from this study that the wetland was a major hydrological controlling feature in the basin and should be safeguarded. These results suggest that SWAT model is potentially useful in studying the hydrology of natural wetland catchments with limited data. Besides, the authors would like to recommend extensive testing of the model in other wetland catchments in the region.

Keywords: Hydrology, Modelling, Natural Wetland, Rugezi Catchment, SWAT

1. INTRODUCTION

Hydrologists and water managers are facing a number of challenges prime among of them is the scarcity and misuse of fresh water which poses a serious and growing threat to sustainable development and protection of the environment (ICWE, 1992). In turn, human health and welfare, food security, industrial development and the ecosystems on which they depend, are all at risk (ICWE, 1992). Nevertheless, the rational and efficient management policies of land and water resources require decision support system tools in order to evaluate available resources, secure water supply for domestic use and industries, share resources and information, protect and restore water resources, and create awareness for possible threats such as floods and droughts. Modeling is one of these decision support tools. However, it has been much difficult in developing countries where inadequacy of appropriate tools and personnel to develop and maintain water resources model are evident, but also their catchments experiences insufficient data to build, calibrate and validate models (Ndomba et al., 2005). Therefore, before adoption of any model, model testing is highly required in catchments different from that of invention. For the circumstances, documentation of the necessary modification to the model is of high interest.

The adoption of SWAT model in this study is built on the premise that the model has already been tested in some catchments in Nilotic Countries' catchments (Ndomba and Birhanu, 2008). The results suggest that the model can be applied in tropic regions characterized by data scarce (Ndomba, et al., 2005; Ndomba and Neeven, 2004; Mulungu and Munishi, 2007; Ndomba, 2007, Ndomba et al. 2008). However, the results can not be generalised in the entire region and for all applications unless more catchments controlled by different hydrological features in the tropics have been studied and therefore calling for its application in Rugezi wetland catchment. When compared SWAT with other models, Borah and Bera (2003, 2004) concluded that the model has been applied in data rich catchments and has said to be a promising model for continuous simulations at catchment scale.

Rugezi catchment is characterized by extensive marshes occupying 42% of the wetland area. Hydrologically, these features are expected to control rainfall-runoff process in the catchments.

The marshlands modify the movement of water in the channel network by lowering the peak flow and volume of flood discharges. Currently, a little or none of previous researches have reported the influence of marshland on Rugezi catchment hydrology. SWAT 2005 model offers a possibility to simulate reservoirs, ponds and wetlands in the catchment. The simulation is based on one wetland per sub catchment which is assumed to capture discharges and pollutants loads from a user-specified percentage of the overall sub catchment (Neitsch et al., 2005). As peak discharge is expected to decrease in the wetland, Schuol et al., (2006) suggested two approaches to deal with reservoirs and wetlands in calibration procedure. The first is to exclude the gauging stations affected by the reservoirs and wetlands from the calibration procedure, the other is to include reservoirs, wetlands and water uses as far as possible, even though detailed information on the management of the reservoirs and also on stored water in the wetland are not yet available.

Therefore, in this study the Soil and Water Assessment Tool (SWAT) was examined for its applicability in wetland catchment of Rugezi in Rwanda.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

Rugezi catchment dominated by swamps is located in the Northern part of Rwanda and covers an area of about 196 km^2 (Figs. 1 and 2). It extends between latitudes $1^0 21' 30''$ and $1^0 36' 11''$ South and between longitudes $29^0 49' 59''$ and $29^0 59' 50''$ East. The Rugezi catchment is made up of two sub catchments: The Rugezi main catchment (164 km^2) and Kamiranzovu catchment (32 km^2). The Rugezi main catchment located in high altitude is situated immediately east of Lakes Bulera and Luhondo below the high peaks of the Virunga volcanoes. It drains via the Hondo River, from its north-western end, over two waterfalls, into Lake Bulera. The swamp is embedded between mountains. The hillsides are very steep because many of them have a slope up to 35 %. Formerly, this swamp, originated from the trapping of runoff in a synclinal depression behind a quartzitic ridge that led formation of a vast waterlogged valley (Hategekimana and Twarabamenye, 2005). The outlet is located at "Rusumo" flow gauging station at latitude 1º25´03" South and longitude 29º49´59" East.

Basing on the National Population Census carried out in 2002 and an annual growth rate of 2.8 %, the population around Rugezi catchment is estimated to be about 120,000 people. Of these 90% are involved in agriculture and depend heavily on natural resources for livelihoods (REMA, 2005). Population pressure combined with land degradation is considered the major reasons that prompted people to invade Rugezi wetland for agricultural purposes (REMA, 2005).

The Mean Annual Rainfall (MAR) on the hillsides is 1200 mm/yr at 'Rwerere- Colline' rainfall station whereas at the marsh surface it is 1050 mm/yr at Rwerere-Marais rainfall station. The long term mean annual temperature ranges between 14.2°C and 25.9°C for minimum and maximum, respectively. The total water flows from Rugezi catchment and the Volcano National Park are of international importance because they are water sources for both Lake Victoria and the White Nile and have been the main sources of hydro power generated electricity in Rwanda (REMA, 2005). The Nile River Basin claims 67% of Rwanda's national territory and drains 90% of its national waters through the Nyabarongo and Akagera Rivers. Water flows out of Rwanda into Lake Victoria and thus contributes roughly 8-10% to the White Nile waters (Willetts *et al.,* 2008)

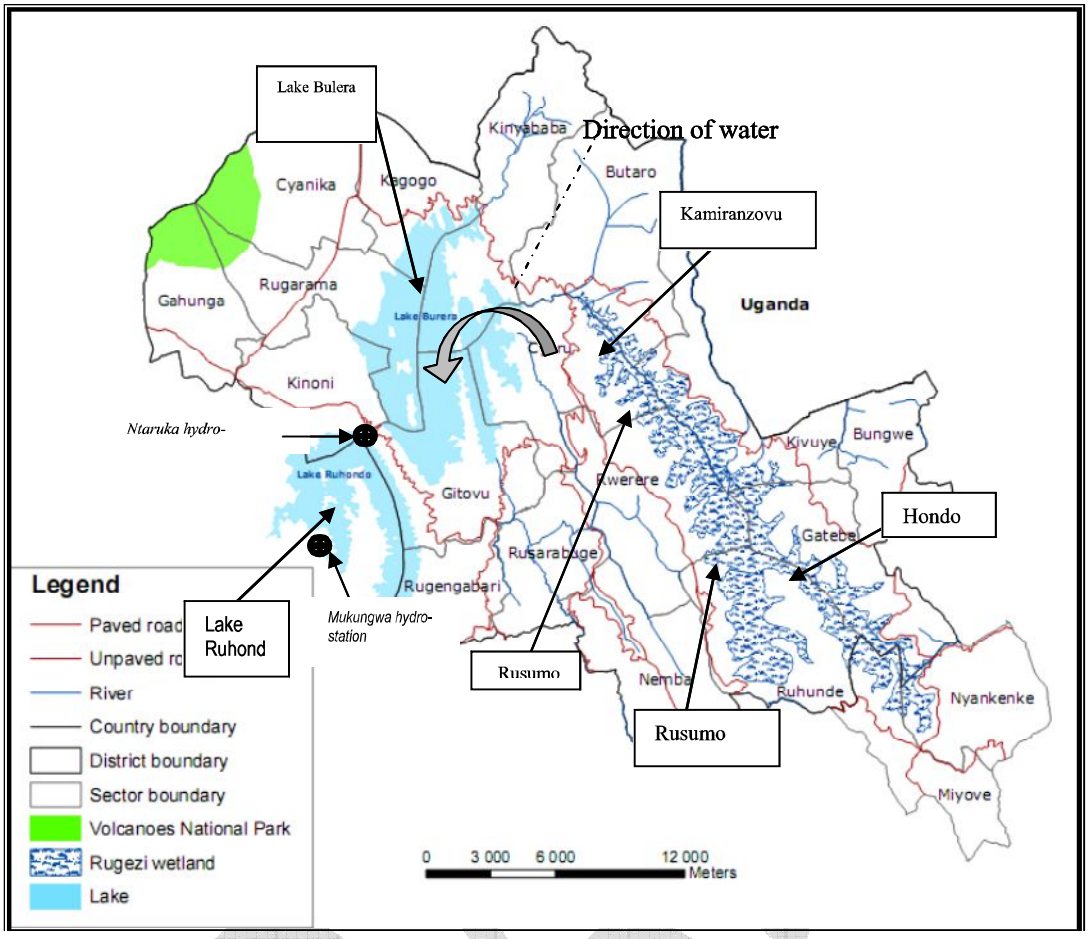


Figure 1: A location map of Rugezi catchment (as adopted from Willetts, 2008)

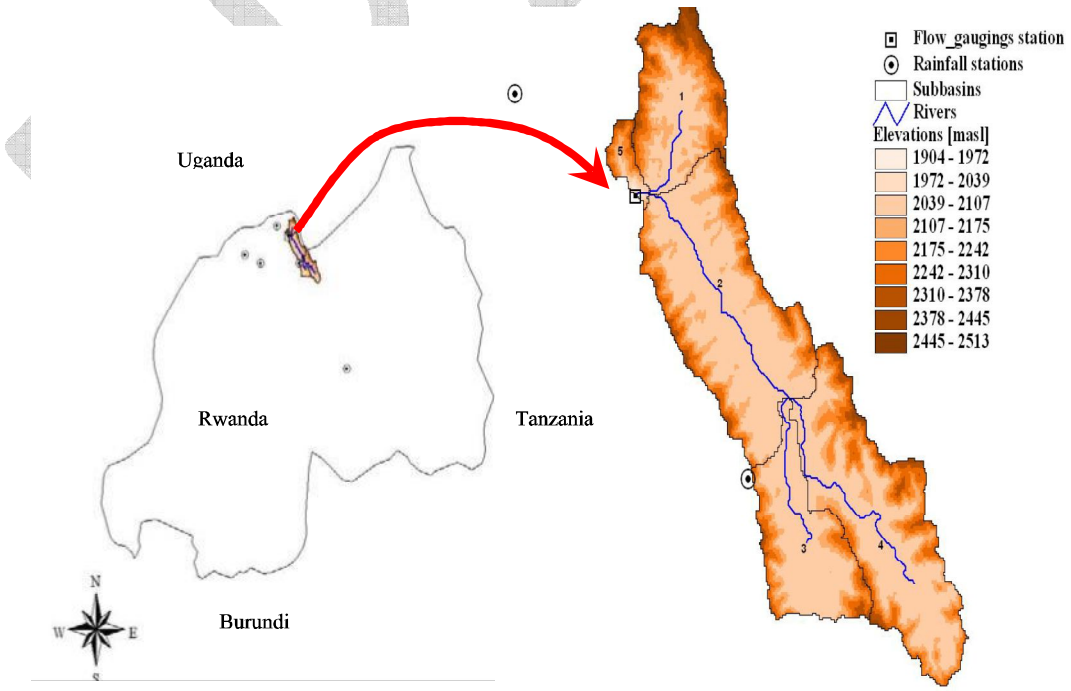


Figure 2: A location map of regular hydro-meteorological monitoring stations in Rugezi catchment (NBCBN, 2005)

2.2. Data Types and Sources

In this study, the data collected were meteorological, spatial, wetland parameters and streamflows data (Tables 1, 2 & 3). The meteorological data included daily precipitation and maximum & minimum air temperature. The records of meteorological and streamflows data mismatch in terms of length and in starting and ending dates.

Table 1: Summary of data used for model setting up and sources

No	Data	Description	Source
1	Spatial	Digital Elevation Model	Shuttle Radar Topography Mission (SRTM); 90 m resolution; 300 ha minimum flow accumulation drainage Area as Arc GIS interface delineation threshold used
		Soil map	Food and Agriculture Organization of the United Nations (FAO, 1995); 5000 soil types; spatial resolution of 10 km; two soil layers 0–30 cm and 30–100cm depth
		Land use/Land cover map	USGS Global Land Cover Characterization (GLCC) database; spatial resolution of 1 km; 24 classes of land use representation
2	Meteorologic l	Daily precipitation	Rainfall Stations: Kigali Aero com Kanombe, Bulera-lac com Kidaho, Ruhengeri-aero com Kigombe, Rwaza com Ruhondo and Rwerere colline com Cyeru; Division of the water and cleansing of the MINITERE
		Minimum and maximum daily temperature	Temperature stations: Kigali aero com Kanombe and Ruhengeri-aero com Kigombe; Division of the water and cleansing of the MINITERE
3	Streamflows	Daily streamflows	Stream flow: Rusumo; Division of the water and cleansing of the MINITERE
4	Wetland parameters	Rugezi wetland drainage parameters	Five subbasins identified: Kamiranzovu, Rugezi North, Rugezi Central, Rugezi South West and rugezi South East

Climatic data are necessary as they provide moisture and energy that derive all other processes simulated in the watershed. These data were used as the weather generator input data in SWAT. Other information was also supplemented from previous studies conducted in the catchment. In selection of the climatic station to be used by the model, SWAT has a built-in capability of selecting the appropriate station and this is based on relative distances. In this study a number of 5 rainfall stations were considered. Of the five stations, only one station is located near to the border of the catchment (Fig. 2). The rest four stations are located outside of the study area under consideration.

Table 2: Details of rainfall data from regular monitoring network

No	Station name	Lat.	Long.	Elevation	Period		% Missing
				Masl	Start	End	
1	Kigali aero com Kanombe	01° 58	30° 08	1490	1971	2005	1.7
2	Bulera-lac com Kidaho	01° 23	029° 46	1862	1970	1993	10.0
3	Ruhengeri-aero com Kigombe	01° 30	29° 36	1878	1977	2002	36.5
4	Rwaza com.Ruhondo	01° 32	029° 41	1800	1916	1991	32.4
5	Rwerere-Colline	01° 32	029° 53	2312	1962	1980	0.0

Table 3: Details of temperature data from regular climatic data monitoring network temperature

No	Station name	Lat.	Long.	Elevation	Period		% Missing
				Masl	Start	End	
1	Kigali aero com Kanombe	01° 58	30° 08	1490	1971	2003	5.5
2	Ruhengeri-aero com Kigombe	01° 30	29° 36	1878	1977	2003	40.0

Other data of interest were the wetland physical parameters in the catchment (Table 1). The Africa DEM was downloaded from the Shuttle Radar Topography Mission (SRTM). SRTM 90 m (3 arc second) data is distributed by continent and is available in 1 degree tiles on the SRTM FTP server, ftp://e0srp01u.ecs.nasa.gov/srtm/version2/). The digital stream network was also downloaded from SRTM FTP server. It is derived from the flow accumulation layer for areas with an upstream drainage greater than 300 ha (i.e. 3 km^2). Soil map was obtained from Food and Agriculture Organization of the United Nations (FAO, 1995). The map has a scale of 1:2500000. Almost 5000 soil types at a spatial resolution of 10 km are differentiated and some soil properties for two layers (0–30 cm and 30–100 cm depth) are provided. Further soil properties (e.g., particle-size distribution, bulk density, organic carbon content, available water capacity, and saturated hydraulic conductivity) are as reported in Magoma(2008). FAO furnishes ARC/INFO export files that can be imported to ArcView program through import utility called import71. FAO data comprises of soil mapping units from which the attributes required for SWAT input were derived. The Image was then converted to shapefile and projected.

Land use (or land cover) map was downloaded from the USGS Global Land Cover Characteristics (GLCC) database (http://edcsns17.cr.usgs.gov/glcc/afdoc2_0.html). This map has 1-km nominal spatial resolution and is based on 1-km Advanced Very High Resolution Radiometer (AVHRR) data spanning April 1992 through March 1993.

2.3. Data Processing and Analysis

The DEM preparation was done in Arc View GIS version 3.2 Environment in order to remove sinks and no data cells from the original DEM. The parameterization of the land use classes is based on the available SWAT landuse classes and literature search. Land use/land cover is an important input parameter to SWAT, and ideally should be contemporaneous with discharge data record. However, no land use data was available that matched the timeframe evaluated, and therefore were judged to adequately represent past land use despite the changes that have occurred in the catchment due to social economic activities. All of the spatial data used are global and freely obtained and were in Lambert Azimuthal Equal Areas projection.

Raw daily rainfall data collected covers a period ranging from 1916 to 2005 (Table 2). However, rainfall data for the period 1971 to 1989 were used in the analysis. This is a concurrent period with recorded flow discharge time series. The period was divided into two periods: Wettest and dry periods. Other researchers have used long term mean annual rainfall as the threshold (Ndomba et al., 2008b; Wu et al., 2007) to classify the periods. This study has adopted the latter approach. In this context, the period with annual rainfall amount equal or greater than long term mean annual rainfall of 1,241.9 mm in the catchment was defined as wet otherwise dry years. Basing on this analysis two periods that is 1967-1972 and 1977-1991 have been identified as wettest periods. 1962-1965 and 1992-2003 have been identified as dry periods. It is known in literature that reduction in parameter uncertainty is maxima when the wettest data periods on record are used as reported in Ndomba et al., (2008). Therefore, wettest period was used for parameter optimization or model calibration. Rainfall were assessed for outliers and missing values. Missing climatic data were filled by generated data from WXGEN built in SWAT.

Wetlands coverage was sourced from Hategekimana and Twarabamenye (2005). The maximum wetland surface area is 6092 ha as per wetland distribution coverage (Table 4). The overland water flow depth of 50 cm has been computed after adopting the marsh water storage of 43 million m^3 as reported by Hatekigamana (2005). Other researchers such as Liu and Yang (2007) have used normal wetland surface area of 30% of the maximum surface area.

Table 4: Marshland distribution (Source: Hategekimana and Twarabamenye, 2005)

No	Sub basin	Sub basin Area (ha)	Area of Marsh (ha)	%age coverage
1	Kamiranzovu	3244	652	20
2	Rugezi North	2688	1116	42
3	Rugezi Central part	6092	3316	54
4	Rugezi South Western	2587	1316	51
5	Rugezi South Eastern	5049	1870	37
	TOTAL	**19660**	**8270**	

Kangsheng and Carol (2007) assumed 60% of the maximum wetland surface area as surface area at normal water level. They also assumed the volume at normal water level to be 40% of the volume of water held in wetlands when filled to maximum water level. This study has also adopted a normal wetland surface area of 80% of the maximum surface area and the maximum wetland water depth of 50 cm. The wetland water volume has been assumed to occupy 40% of the total volume. The normal and maximum water volume is as presented in Table 5 below.

Table 5: Wetland SWAT interface derived parameters

No	Sub-Basin Name	Fraction of are of sub basin flowing into wetland	Normal Level		Maximum Level	
			Surface Area (ha)	Volume ($x10^4$ m^3)	Surface Area (ha)	Volume ($x10^4$ m^3)
1	Kamiranzovu	0.8	487.6	190.8	609.4	312.7
2	Rugezi Central par	0.46	2948.7	1167.4	3685.8	1904.6
3	Rugezi North	0.58	248.4	104.7	310.5	166.8
4	Rugezi South Western	0.49	1304.7	500.7	1630.8	826.8
5	Rugezi South Eastern	0.63	1757.1	693.1	216.3	1132.3

2.4. SWAT Model Application

2.4.1. Model set up

This study has adopted the procedure for SWAT model set up as suggested by Di Luzio et al. (2002). The most important steps adopted include Watershed delineation; soil and land use data, and weather data definitions. Particularly, in this study wetland features were implemented as defined in Tables 4 & 5.

2.4.2. Swat model simulation

The criterion on selecting simulation options was based on the type of data collected and gathered experience from previous studies (Ndomba, et al., 2005; Van Liew et al., 2005). Surface runoff was estimated by the SCS Curve Number (SCS-CN) method from daily precipitation records using default parameters values provided in SWAT, which were defined based on land use and soil data in the study area. The potential evapotranspiration was computed using Hargreaves method based on observed daily air temperature data collected from 1971 to 2003. Hargreaves method was used as it requires only temperature data, in contrast to the more extensive data requirements methods such as Priestley–Taylor and Penman–Monteith. The computed runoff from each subbasin was routed through the river network to the main basin outlet by using the Muskingum method. A first order Markov Chain Skewed normal was used to determine rainfall distribution. In order to compare the effect of wetlands in the model, model simulation was tested in two scenarios: The first scenario was run without inclusion of wetlands in the model. For the case of simulation without considering the effects of wetlands, wetlands were treated as natural forest or grass cover in SWAT land use classification. The second scenario was to run the model after implementing the wetlands.

2.4.3. Sensitivity analysis

In this research a sensitivity analysis was done for runoff generation and delivery processes. Various simulation periods were used. This was necessary in order to investigate the uncertainty of length of measured data records and data requirements. The Latin Hypercube-One factor At a Time (LH-OAT) design as built in SWAT was used as sensitivity analysis tool. The latter analysis was used to identify sensitive parameters.

2.4.4. Calibration and validation

Like many other models, SWAT is based on conceptual representation of physical processes that govern the flow of water through the catchment. As documented in Sorooshian and Gupta (1995), SWAT model has two types of parameters: The process and physical parameters. While the physical parameters represent the physical measurable properties of the catchment, the process parameters are not directly measurable at the scale of application and need to be determined through calibration. The physical parameters are estimated using SWAT ArcView GIS interface. The interface is known to overestimate some channel physical parameters such as widths (Ndomba and Birhanu, 2008). Therefore, some physical parameters were changed prior to calibration basing on extracted or scaled out data from ground photos. Channel roughness parameters were derived from Chow (1959). There are not available site specific data for soil classes existing for the watershed. Therefore, information from FAO (1995) was used to prepare soil class layers.

SWAT model has a built in interfaces of auto-calibration tool, Parameter Solutions Methods (PARASOL) as implemented by van Griensven et al., (2005). The PARASOL uses the Shuffled Complex Evolution Algorithm (SCE-UA), which is a global search algorithm for minimization. The algorithm combines the direct search method of the simplex procedure with the concept of a controlled random search, a systematic evolution of points in the direction of global improvement, competitive evolution and the concept of complex shuffling. Auto-calibration option in SWAT provides a powerful, labour saving tool that can be used to substantially reduce the frustration and uncertainty that often characterizes manual calibration (Van Liew et al, 2005). In auto calibration, the SWAT interface provides three methods for varying the parameters. The first option allows you to replace the value directly. The second method allows adding values to the initial values. And the third method allows multiplying the initial value with the drawn parameter value. Therefore this research adopted auto calibration to optimize the sensitive parameters and test the calibrated model using independent input data sets. The sum of squares of residuals (SSQ) and Nash and Sutcliffe Coefficient of efficiency (CE) objective functions were used to measure the performance of the model.

Different workers have come up with different remarks on selection of calibration periods. Research by Yapo et al., (1996) indicated that approximately 8 years of data, specifically including some of the wettest years were adequate to ensure a quality of calibration of the model. Again, Yapo et al. commended that the reduction in parameter uncertainty is maxima when the wettest data periods on records are used. Therefore, this study adopted the wettest period concept as suggested by Yapo et al., (1996) in calibration. The calibration period was set from 1977 to 1980.

3. RESULTS AND DISCUSSIONS

3.1. Comparison of Model Simulations Performance Between With and Without Wetlands Features

Simulation with wetlands reflects reduction of peak discharges by 44% and 47% on 18th November 1977 and 11th April 1980, respectively, as compared to simulations without wetlands under default parameters set. This suggests that a good representation of runoff controlling features in the Rugezi catchment would improve the SWAT model performance. This result compares to what reported in Ndomba and Birhanu (2008).

3.2. Sensitive Parameters

Twenty seven (27) physical and process model parameters were used in the sensitivity analysis in order to capture the major processes represented by SWAT Table 5). Parameter sensitivity was assed according to Van Griensven *et al.*, (2006) where the Global ranking method is proposed. In this study, global rank 1 is categorized as "very important", rank 2 to 6 "important", rank 7 to 15 as "slightly important" and rank 28 as "not important". In other words the result of sensitivity analysis shows that parameters with global ranking between 1 and 15 are sensitive (Table 6). The rest eight (8) model parameters with global rank 28 are considered insensitive (Table 6).

Table 5: Parameters used for sensitivity analysis

No	Name	Definition	Process
1	ALPHA_BF	Baseflow alpha factor (days)	Groundwater
2	BIOMIX	Biological mixing efficiency	Soil
3	BLAI	Leaf area index for crop	Crop
4	CANMX	Maximum canopy index	Runoff
5	CH_K2	Effective hydraulic conductivity in main channel alluvium (mm/hr)	Channel
6	CH_N	Manning coefficient for channel	Channel
7	CN2	SCS runoff curve number for moisture condition II	Runoff
8	EPCO	Plant evaporation compensation factor	Evaporation
9	ESCO	Soil evaporation compensation factor	Evaporation
10	GW_DELAY	Groundwater delay (days)	Groundwater
11	GW_REVAP	Groundwater 'revap' coefficient.	Groundwater
12	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	Soil
13	RCHR_DP	Groundwater recharge to deep aquifer (fraction)	Groundwater
14	REVAPMN	Threshold depth of water in the shallow aquifer for 'revap' to occur (mm).	Groundwater
15	SFTMP	Snowfall temperature (^{0}C)	Snow
16	SLOPE	Average slope steepness (m/m)	Geomorphology
17	SLSUBBSN	Average slope length (m)	Geomorphology
18	SMFMN	Minimum melt rate for snow during the year (occurs on winter solstice) (mm/^{0}C /day)	Snow
19	SMFMX	Maximum melt rate for snow during the year (occurs on winter solstice) (mm/^{0}C /day)	Snow
20	SMTMP	Snow melt base temperature (^{0}C)	Snow
21	SOL_ALB	Moisture Soil albedo	Evaporation
22	SOL_AWC	Available water capacity of the soil layer (mm/mm soil)	Soil
23	SOL_K	Soil conductivity (mm/h)	Soil
24	SOL_Z	Soil depth	Soil
25	SURLAG	Surface runoff lag coefficient	Runoff
26	TIMP	Snow pack temperature lag factor	Snow
27	TLAPS	Temperature laps rate (^{0}C /km)	Geomorphology

Table 6: Parameter sensitivity classification

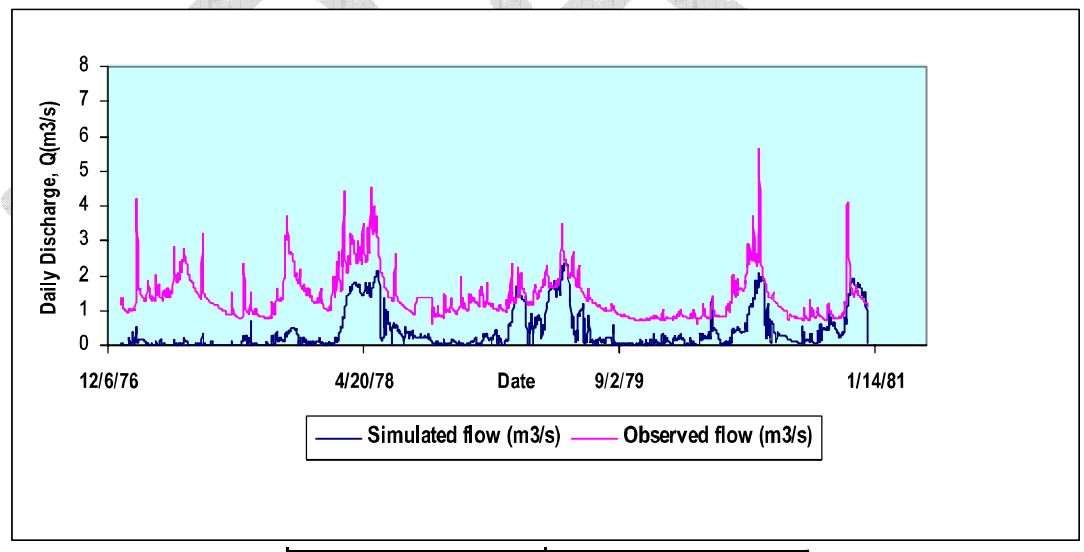
No	Parameter	Rank	Sensitivity Category
1	CH_K2	1	Very important
2	SURLAG	2	Important
3	CN2	3	
4	CH_N	4	
5	ESCO	5	
6	SLOPE	6	
7	SOL_AWC	7	Slightly important
8	SOL_K	8	
9	SOL_Z	9	
10	SLSUBBSN	10	
11	ALPHA_BF	11	
12	CANMX	12	

No	Parameter	Rank	Sensitivity Category
13	SOL_ALB	13	
14	BIOMIX	14	
15	EPCO	15	
16	BLAI	28	Not important
17	GW_DELAY	28	
18	GW_REVAP	28	
19	GWQMN	28	
20	RCHR_DP	28	
21	REVAPMN	28	
22	SFTMP	28	
23	SMFMN	28	
24	SMFMX	28	
25	SMTMP	28	
26	TIMP	28	
27	TLAPS	28	

In all simulations, the authors have observed that the first four (4) process parameters are the same with only difference in swapping. This is an indicative sign of their high sensitivity in influencing the hydrologic processes of the catchment in the study area. These parameters areCH_K2, CN2, SURLAG and ch_n (Table 6)

3.3. Calibration Results

Sensitive parameters were firstly optimized using autocalibration tool. The default parameters ranges were adopted. The lower and upper bounds of optimized parameters were chosen from SWAT user's Manual (Neitsch et al., 2005). However, when these optimized parameters were used, the results were poor as depicted in Fig. 3.



R^2 =-1.92	IVF =0.29

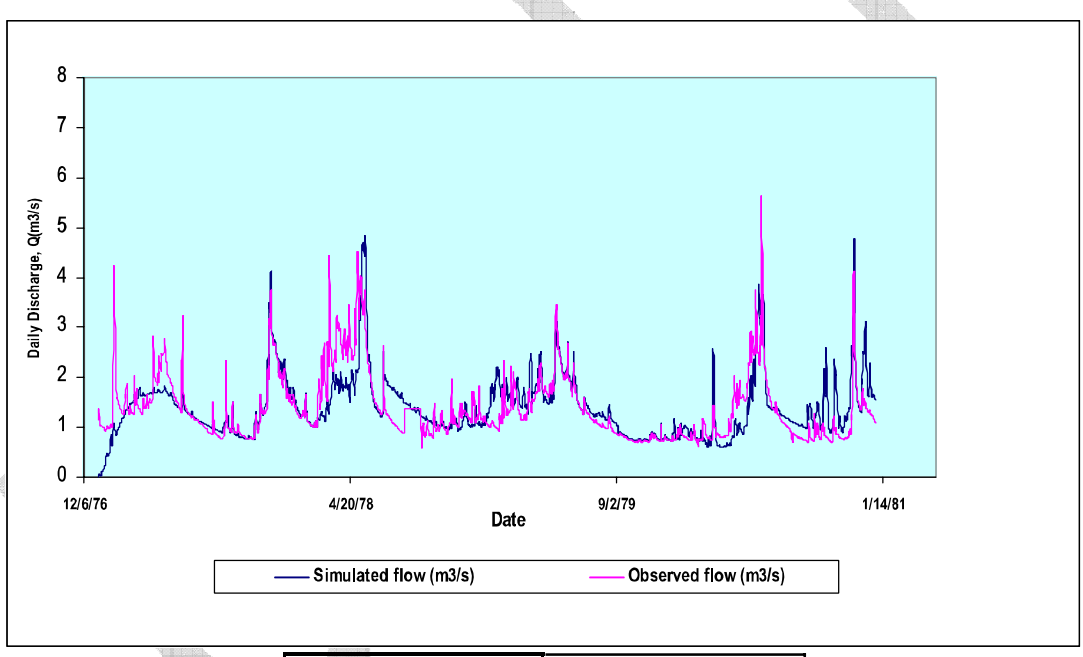
Figure 3: Comparison between observed and simulated daily streamflows for the period 1977-1980 based on first set of optimized parameters at Rusumo gauging station

In order to capture good model performance the parameters values were fine-tuned manually. Table 7 below lists the final set of optimized parameters and values. However, for parameters which SWAT model does not explicitly give range their boundary values were arbitrarily set.

Table 7: SWAT parameters, default values, optimized values and lower and upper bounds

Parameter	SWAT default Value	Optimized Value	Bounds
ALPHA_BF	0.048	0.01	0-1.0
BIOMIX	0.2	0.99	
CANMX	0.00	12	0-20
CH_K	0.00	2.5	-0.010-150
CH_N	0.014	0.3-0.5	-0.010-0.3
CN2	83.00	62	35-98
EPCO	1.00	0.001	0-1.0
ESCO	0.95	0.01	0.01-1.0
SOL_AWC	0.16-0.19	0.08-0.11	0-1.0
SOL_K	22.7-24.73	11.4-18.54	0-2000
SURLAG	4.0	0.7	0-6.0

The CE for calibration period were considered satisfactory since the model was capable of capturing 49.15% of variance. The IVF was computed to be 95.6%. However, the model was not able to capture some of the peaks (Fig. 4). This might be attributed to poor representation of rainfall data used. The observed daily average flow for the calibration period is 1.38 m^3/s and the simulated result from the model is 1.31 m^3/s.



R^2 =49.15%	IVF =95.6%

Figure 4: Comparison between observed and simulated daily stream flow for calibration period1977-1980 at Rusumo gauging station (CE=49.15%)

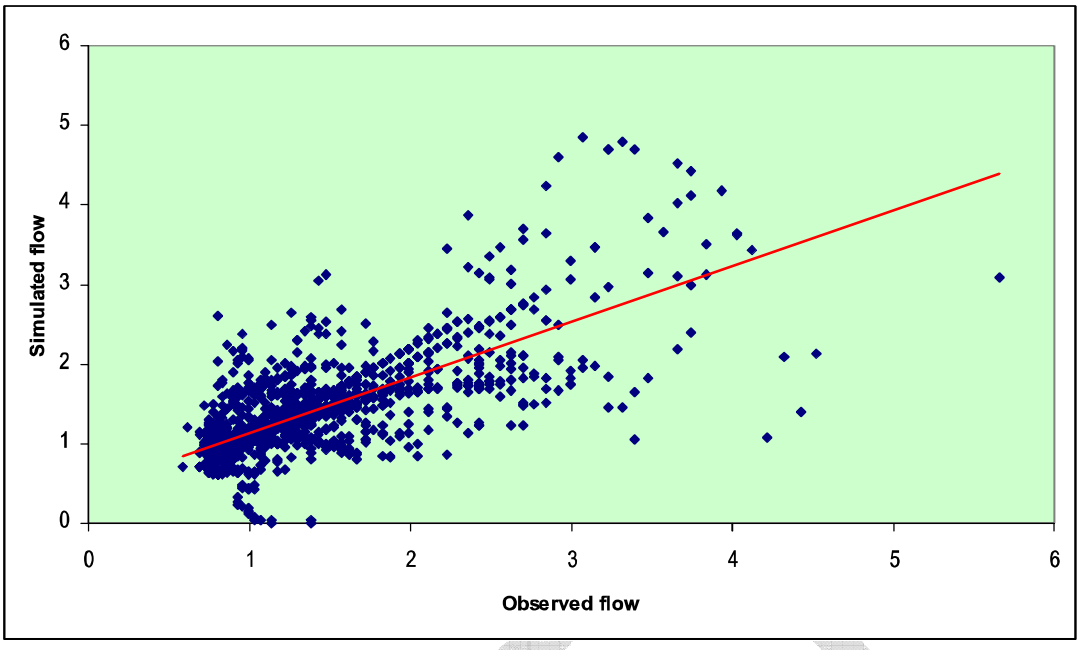
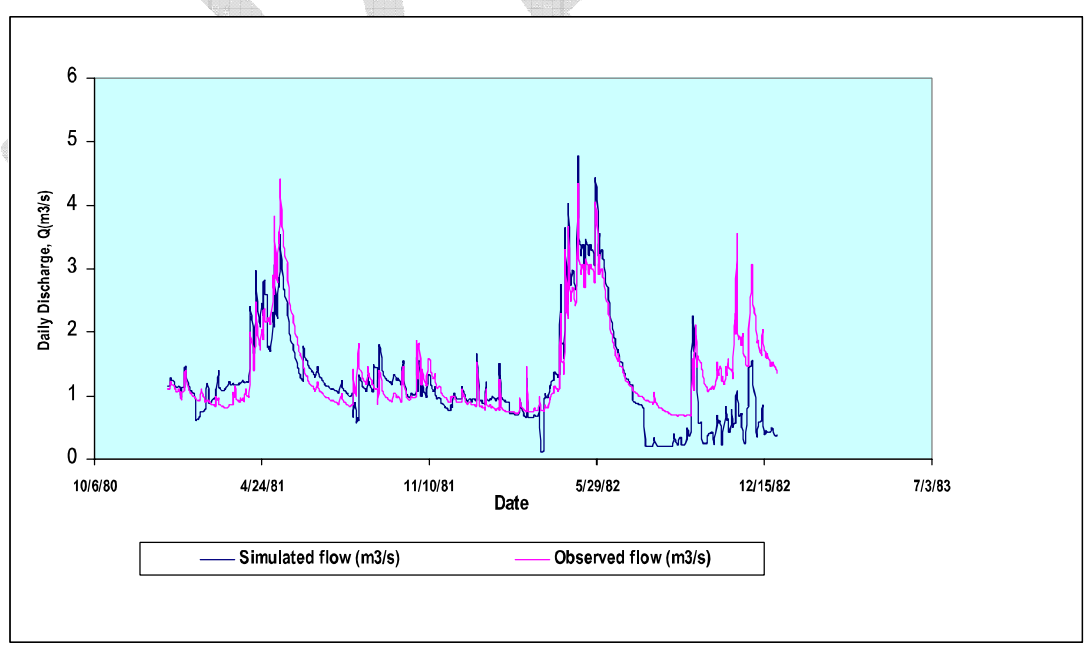


Figure 5:Scatter diagram between observed and simulated daily streamflows for calibration period 1977-1980 at Rusumo gauging station

The scatter diagram (Fig. 5) shows that the model satisfactory predicts the observed streamflows. There is significant scattering during high peak flows.

3.4. Validation Results

The predictive capability of the model was measured by applying the model to various boundaries conditions other than those used for calibration. The model validation with respect to stream flow for the period 1981 to 1982 was satisfactory (Fig. 6) (CE=51.4% and IVF= 98.6%.)



R^2 =51.4%	IVF =98.6%

Figure 6: Comparison between observed and simulated daily streamflows for the validation period 1981-1982 at Rusumo gauging station (CE=51.4%)

4. CONCLUSSION AND RECOMMENDATIONS

The objective of the study was to apply a Hydrologic Model, SWAT, in Rugezi wetland catchment in Rwanda using readily available data. Wetlands coverage data were based on documentation by other researchers who have had researched in wetlands. Other confined physical parameters were derived by this study from DEM and ground photos.

The study has found that fifteen (15) out of twenty seven (27) model parameters included in sensitivity analysis ranges from very important to slightly important. However; four of them CN2, CH_K2, SURLAG and CH_N are the most sensitive and might control the rainfall-runoff transformation process of the catchment. Given the interactive processes taking place simultaneously and consecutively at different times and places within the watershed, it is quite remarkable that the simulated flow results comparable the measured ones. Thus the results suggest that the SWAT model may be a potential model to be used for hydrological modeling in the Rugezi wetland catchment.

The Nash and Sutcliffe coefficient values (CE) and Index of Volumetric Fit (IVF) were 49.15% and 95.6% for calibration and 51.4% and 98.6% for validation periods, respectively, indicating a satisfactory simulation. It was evident from this study that the wetland was a major hydrological controlling feature in the basin and should be safeguarded.

These results suggest that SWAT model is potentially useful in studying the hydrology of natural wetland catchments with limited data. Besides, the authors would like to recommend extensive testing of the model in other wetland catchments in the region.

5. ACKNOWLEDGEMENT

This study was co-sponsored by Applied Training Project (ATP), Nile Basin Capacity Building Network-River Engineering Initiative, and UNESCO-IHE Partnership Research Fund (UPaRF) through Adaptation to Climate Change Impacts on the Nile River Basin (ACCION) project.

6. REFERENCES

1. Bora, D.K., and M. Bera, M, 2003, *"Watershed-scale hydrologic and nonpoint-source pollution models"*, Review of mathematical bases, *Trans. ASAE* 46(6): 71553-1566.
2. Bora, D.K., and M. Bera, M, 2004, *"Watershed-scale hydrologic and nonpoint-source pollution models"*, Review of mathematical bases, *Trans. ASAE* 47(3): 789-803.
3. Hategekimana, S. and Twarabamenye, E., 2005, *A paper presented at V International Symposium on En_Hydrology.*
4. ICWE, 1992, *The Dublin Statement and report of the conference, International Conference on Water and the Environment: Development issues for the 21st century,* 26-31st January 1992, Dublin, Ireland.
5. Kangsheng Wu and Carol A. Johnston, 2007, *"Hydrologic response to climatic variability in a Great Lakes Watershed: A case study with the SWAT model", Journal of Hydrology (2007), 337, 187– 199.*
6. Liu, Y. and Yang, W. 2007, *"An interface of drainage division for modeling wetlands and riparian buffers in agricultural watersheds"*, Journal of Spatial Hydrology, 7: 66-80.
7. Magoma, D. 2008, *Hydrological Modelling using SWAT in wetland Catchments. A case of Rugezi Catchment in Rwanda,* MSc Dissertation. University of Dar es Salaam, Tanzania.
8. Mulungu, D.M.M., and Munishi, S.E., 2007, *"Simiyu River catchment parameterization using SWAT Model"*, Physics and Chemistry of the Earth, Parts A/B/C, Volume 32, Issues 15-18, pp 1032-1039
9. NBCBN, 2005, *Sediment Yield Modelling Using SWAT in Tropical Catchments. A case of Rugezi catchment in Rwanda*, A research proposal approved for funding by Nile Basin Capacity Building Network (NBCBN).
10. Ndomba, P.M. and Neveen Saad Y., 2004, *"Predicting Sediment Yield in Simiyu Catchment."* Scientific Bulletin Faculty of Engineering Ain Shams University, Vol. 39, No.4, December 31, 2004, pp.413-425

11. Ndomba, P.M, Mtalo, F. and Killingtveit,A., 2005, *"The suitability of SWAT model in Sediment yield modeling for ungauged catchments. A case of Simiyu subcatchment, Tanzani"*, Proceedings of 3rd International SWAT conference, pp61-69. EAWAG-Zurich, Switzerland, 11th -15th July 2005.
12. Ndomba, P.M., 2007, *Modelling of Erosion Processes and Reservoir Sedimentation Upstream of Nyumba ya Mungu Reservoir in the Pangani River Basin*, A PhD Thesis (Water Resources Engineering) of University of Dar es Salaam.
13. Ndomba, P.M. & Birhanu, B.Z., 2008, *Problems and Prospects of SWAT Model Applications in Nilotic Catchments: A Review*, Nile Basin Water Engineering Scientific Magazine, Vol.**1**, (2008), pp 41-52.
14. Ndomba, P.M., Mtalo, F. & Killingtveit, A., 2008. *SWAT Model application in a data scarce tropical complex catchment in Tanzania.* Journal of Physics and Chemistry of the Earth, V.**33**, (2008), 626-632. ISSN 1474-7065.
15. Neitsch, S.L., Arnold, J.G., Kiniry, J.R., & Williams, J.R., 2005. *Soil and Water Assessment Tool Theoretical Documentation Version 2005*. Grassland, Soil and Water Research Laboratory; Agricultural Research Service 808 East Blackland Road; Temple, Texas 76502; Blackland Research Research Center; Texas Agricultural Experiment Station 720 East Blackland Road; Temple, Texas 76502, USA.
16. REMA, Rwanda Environment Management Authority, 2005, *Economic Analysis of Natural Resource Management in Rwanda*, With UNDP and UNEP, Republic of Rwanda
17. Schuol J., K. C. Abbaspour, 2006, *"Calibration and uncertainty issues of a hydrological model (SWAT) applied to West Africa"*, Advances in Geosciences, 9: 137–143.
18. van Griensven, A., Meixner, T., Grunwald, S., Bishop, T., Diluzio, M., Srinivasan, R., 2006, *"A global sensitivity analysis tool for the parameters of multi-variable catchment models"*, Journal of Hydrology, 324: 10-23
19. van Liew, M.W., Arnold, J.G., and Bosch, D.D., 2005, *"Problems and Potential of Autocalibrating a Hydrologic Model"*, Soil & Water Division of ASAE, Vol.48 (3):pp1025-1040
20. Willetts, E., 2008, *Watershed Payments For Ecosystem Services And Climate Change Adaptation Case Study: Rugezi Wetlands, Rwanda*, Masters project submitted in partial fulfillment of the requirements for the Master of Environmental Management degree in the Nicholas School of the Environment and Earth Sciences of Duke University Hughes D.A, Hannart, P. and Watkins, D. 2002.
21. Yapo, P.O., Gupta, H.V., & Sorooshian, S., 1996, *Automatic calibration of conceptual rainfall-runoff models: sensitivity to calibration data*, Journal of Hydrology, vol.181, pp23-48.

AUTHORS BIOGRAPHY

Dr. Ndomba, P.M.; Dr. Nobert, J.; and Prof. Mtalo, F are lecturers at University of Dar es Salaam (UDSM). They are also NBCBN/FRIEND Nile researchers. Mr. Magoma, D. is Civil/Water engineer in Tanzania

DRAFT