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Modelling the Impact of Land Use Changes on Sediment Loading Into Lake Victoria Using SWAT Model: A Case of Simiyu Catchment Tanzania

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Abstract: This study aimed at characterising the land use in the Simiyu catchment of Lake Victoria and using land-uses of 1975 and 2006 and comparing the relative impact of land-use change on sediment loading into the Lake. Remote sensing using the package ILIWIS 3.0. was used to identify and characterize the land-use while Soil and Water Assessment Tool (SWAT) was used to quantify sediment loading from the 1975 and 2006 land-use scenarios. The results of this study indicate that there was an expansion of agricultural land from 19.33% to 73.43% of the catchment at an annual change rate of 2.9%. Furthermore, the land-use of 1975-yielded less sediment loading compared to that of 2006. Model simulation at the catchment outlet for sediment reported a total yield of 98,467 tons/yr while the actual measured sediment loading had the value of 2,075,114 tons/yr. Hence, the model underestimated sediment yield in the catchment. With good model performance, developing management plans to control sediment loading into Lake Victoria can be achieved using the SWAT model.

Keywords: Land use, sediment loading, SWAT modelling, nutrient loading, Simiyu catchment.

1. INTRODUCTION

Lake Victoria in East Africa is the second largest freshwater body in the world with a surface area of 68,500 km^2, and a maximum depth of 84m. The catchment area extends for 184,000km^2 and it has a shoreline length of 3,440km. The lake is shared by Kenya (6%), Uganda (43%) and Tanzania (51%). Although these three countries border the lake, streams and rivers stretching as far as Burundi and Rwanda also feed into it. It is also important to note that Lake Victoria is the source of the River Nile whose waters are greatly committed downstream. In recent years, environmental challenges have beset the Lake Victoria. It is not only a source of food, water, employment, transport, hydroelectric power, and recreation, but it is also a dumping ground for various types of waste [1-3]. The Uganda National Water and Sewerage Corporation charged with treating and supplying water to Kampala City dwellers are complaining of raising treatment costs [4].

According to [5], clearing of forests enhanced surface runoff loaded with suspended sediments into the lake. The problem associated with sediment transport is that it is a carrier for nutrients (especially phosphorus), heavy metals and pesticides that adversely affect water quality. Lake sedimentation is one other factor reducing life in the lake with the sediments being transferred from the catchment by rivers and streams draining from different land-uses. Most of the sediments in our lakes and rivers have been contaminated with pollutants that either flow directly from industrial and municipal waste discharges, while others come from polluted runoff in urban and agricultural areas [6].

Land-use change over the years is one of the factors positively correlating with deterioration in lake water quality. Bolstad and Swank [7] observed that there were consistent changes in water quality variables, concomitant with land-use change. Recent studies [8, 9] on Non-Point Source pollution in Lake Victoria have focused only on nutrients (N and P). Two different transport models to predict sediment transport on the Simiyu River only have been published [10]. The general objective of the study is to assess the impact of land use on sediment loading into Lake Victoria (a case of Simiyu catchment-Mwanza) using SWAT Model. The difference between this paper from the earlier papers is that this paper deals with assessing the impact in a quantitative way the impact of land use changes on the sediment loading in Simiyu Catchment.

2. METHODOLOGY

2.1. Description of Study Area

2.1.1. Location

The Simiyu catchment in located in Mwanza region and is one of the catchments forming the Lake Victoria basin on

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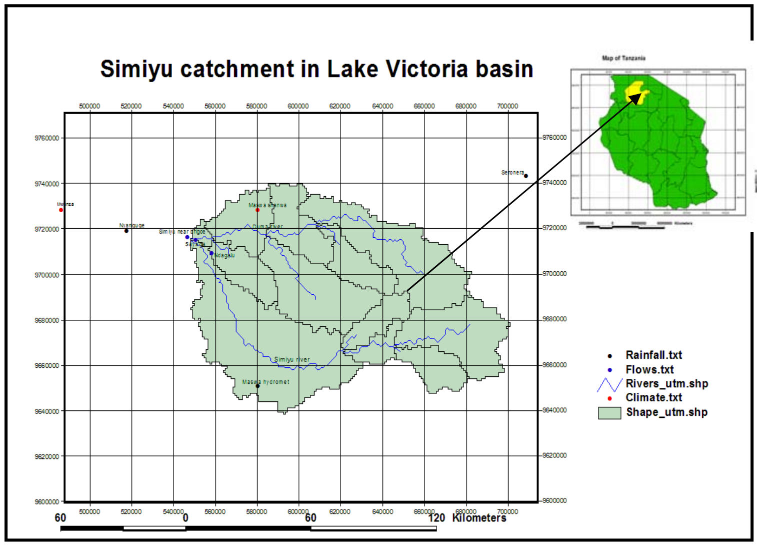

Fig. (1.1). Location of Simiyu catchment in Mwanza region (Tanzania).

the Tanzanian side and it is located between 33^0 15' -35^0 00' E and 2^0 3'-3^0 30'S on the south eastern part of Lake Victoria (Fig. **1.1**). The Simiyu River drains the Serengeti National Park plains and partly Mau ranges in Kenya to Lake Victoria on the downstream before it discharges its waters to the lake [11]. Simiyu catchment has an area of 10312.203km^2. It discharges into the lake at the Speke Gulf and is considered as one of the main sources of sediment load into the lake.

2.1.2. Climate

Rainfall patterns in the catchment are comprised of short rain appearing mainly in November and December and long rain in March to May resulting in a total annual rainfall of 700 to 1000 mm. The catchment hence experiences a bimodal rainfall pattern. The catchment has a warm tropical savannah climate with an average temperature ranging between 22.5^0C and 23^0C and it is in the semi-arid part of Tanzania. According to Rwetabula *et al.*, 2004 [20], Sandy loam soil covers about 60% of the total catchment area.

2.1.3. Hydrology

The Simiyu River is a tributary of Lake Victoria, joining the Duma River before the two discharge their waters into the Lake at the Speke Gulf. Other smaller rivers in the same catchment are Bariadi River and Ngasomo River. Simiyu River is ephemeral, which contain water during and immediately after a storm event and dries up during the rest of the year with exception of some dead channel storage [12]. During the long rainy season, discharge from the river reaches highs of 208 m^3/s [10] and lows of no discharge at all in the dry season.

2.2. Data Collection

2.2.1. Primary and Secondary Data Collection

The data that was used in this research included spatially distributed information used for elevation, soil and land cover/land-use. Others included climatic data of Precipitation, Wind, and solar radiation and finally observed flow data. Most of this data above was obtained in it raw form from Tanzania Metrological Agency (TMA), in USGS format and it was converted into PRNF. The spatial data used were the Digital Elevation Model (DEM), Land-use/Land Cover, and soil. Soil from Soil and Terrain Database for Southern Africa (SOTERSAF) was used to develop the soil map for the catchment. This was updated with FAO soils provided in the FAO soil database. By manually adding soils data into the SWAT soil database, soil parameters characteristic to Simiyu catchment were added.

2.3. Modelling Approach Using SWAT

SWAT model [13] is a spatially distributed, physically based hydrological model, which can operate on a daily time step as well as in annual steps for long-term simulations up to 100. The model allows for predicting the impacts of land-use practices on water quality, sediment yield, and agricultural chemicals yield in ungauged watersheds. According to Neitsch [14], major inputs into the model include weather, soil properties, topography, vegetation, and land management practices in order to model hydrologic and water quality in a watershed. In operation, the watershed schema is divided into sub-watersheds with unique soil/land-use characteristics called Hydrologic Response Units (HRUs) based on threshold percentages used to select the land-use and soils combination.

2.3.1. Water Balance

The water balance of each Hydrologic Response Unit (HRU) in the watershed is represented by four storage volumes; snow, soil profile, shallow aquifer and deep aquifer. Hydrological processes include infiltration, evaporation, plant uptake, lateral flow, and percolation to the deeper layers. The flow, sediment, and Non-point source pollution loading from each HRU in a sub-basin are summed, and the resulting loads are routed trough channels, ponds, and reservoirs to the watershed outlet. The SWAT model applies water balance concept as a basic driver for all processes in the catchment [14].

2.3.2. Surface Runoff

The amount of sediment yield from NPS was estimated as a function of the surface runoff components and their spatial and temporal variations in the catchment. With high rainfall intensity exceeding the infiltration rate, nutrients will be transported through the catchment to the rivers and streams and finally to the receiving water bodies like lakes. This transportation depends on characteristics of the catchment that determine the curve number index. In the curve number method, the daily rainfall was divided into surface runoff and infiltration as a function of antecedent soil moisture condition. In SWAT, the SCS curve number method was used to estimate accumulated runoff for each sub-basin. Estimates of the amount of runoff [14] in the different watersheds as:

$$Q_{surf} = \frac{\left(P - 0.25\right)^2}{\left(P + 0.85\right)} \tag{1}$$

Where; P is rainfall (mm)

S is retention parameter (mm)

Q_{surf} is accumulated runoff (mm)

Neitsch *et al.* [23] (2002) further defines retention parameter (S) as a function of soil, land-use, slope, management scenarios and is given by;

$$S = 25.4\left(\frac{1000}{CN - 10}\right) \tag{2}$$

Where;

CN is the curve number for the decay.

Runoff is a function of many factors like rainfall intensity, soil, vegetation cover, slope, rainfall duration, and the surface moisture content. The SCS curve number is a function of the soil's permeability, land-use and antecedent soil water conditions.

2.3.3. Modelling Sediment Loading in SWAT

Erosion and sediment yield in SWAT are estimated for each HRU with the Modified Universal Soil Loss Equation (MUSLE) [15]. While the USLE uses rainfall as an indicator of erosive energy, MUSLE uses the amount of runoff to simulate erosion and sediment yield. The hydrology model supplies estimates of runoff volume and peak runoff rate, which, with the sub-basin area, are used to calculate the runoff erosive energy variable. The crop management factor is recalculated every day that runoff occurs. It is a function of aboveground biomass, residue on the soil surface, and the minimum C factor for the plant [14].

The modified universal soil loss equation [15] is given by,

$$sed = 11.8 * \left(Q_{surf} * q_{peak} * area_{hru}\right)^{0.56} * K_{USLE} * C_{USLE} * P_{USLE} * LS_{USLE} * CFRG \tag{3}$$

Where; sed is the sediment yield on a given day (metric tons),

Q_{surf} is the surface runoff volume (mm H_2O/ha),

q_{peak} is the peak runoff rate (m^3/s),

$area_{hru}$ is the area of the HRU (ha),

K_{USLE} is the USLE soil erodibilty factor (0.013),

C_{USLE} is the USLE cover and management factor,

P_{USLE} is the USLE support practice factor,

LS_{USLE} is the USLE topographic factor and

CFRG is the coarse fragment factor.

2.4. Soil Properties

The SOTERSAF data was used to extract hydrological groups that were linked with FAO's texture classification. This was then linked with the SWAT database using the soil layers and soil type. This produced Sand Loam soils with two layers (FSL and SCL), covering 68.23%, Clay soils with three layers (C, C, C) covering 6.67%, Clay loamy soils with two layers (CL-CL) covering 11.96% and Sand Clay Loam soil with two layers (L-CL) covering 13.13% of the catchment as shown in the Fig. (**2.1**).

2.5. Land-use Characterisation

Actual land-use data was obtained from Landsat TM satellite images for the year 2006. Two scenes were acquired to complete the study area in the images. For the 1975 land-use, which was base year for the comparison, a copy was obtained already processed from Water Resources Department.

2.6. Model Implementation

Watershed delineation is the first step followed by inputting land-use and soils to create the HRUs in different sub-basins.

2.7. Checking Model Performance

Three criteria recommended by the ASCE Task Committee on Definition of Criteria for Evaluation of Watershed also included in the statistical analysis for hydrology. These criteria are the deviation of water yields, the Nash-Sutcliffe coefficient, and the coefficient of gain from the daily mean. In addition to these three, the coefficient of determination (R^2) is also calculated as part of the hydrologic analysis. The Nash-Sutcliffe coefficient, E_{ns}, measures how well the daily simulated and measured flows correspond. This coefficient is calculated:

$$E_{ns} = 1 - \frac{\sum_{i-1}^{n}\left(O_i - P_i\right)^2}{\sum_{i-1}^{n}\left(O_i - Q_{av}\right)^2} \tag{4}$$

Where

O_i is the measured daily discharge,

P_i is the computed daily discharge, and

O_{av} is the average measured discharge.

A Nash-Sutcliffe value can vary between 0.0 and 1.0 where a value of 1.0 indicates a perfect fit while a value of 0.0 indicates that the model is predicting no better than the average of the observed data.

With the water quality parameters the model evaluation is based on Normal Root Mean Square Error (NRMSE);

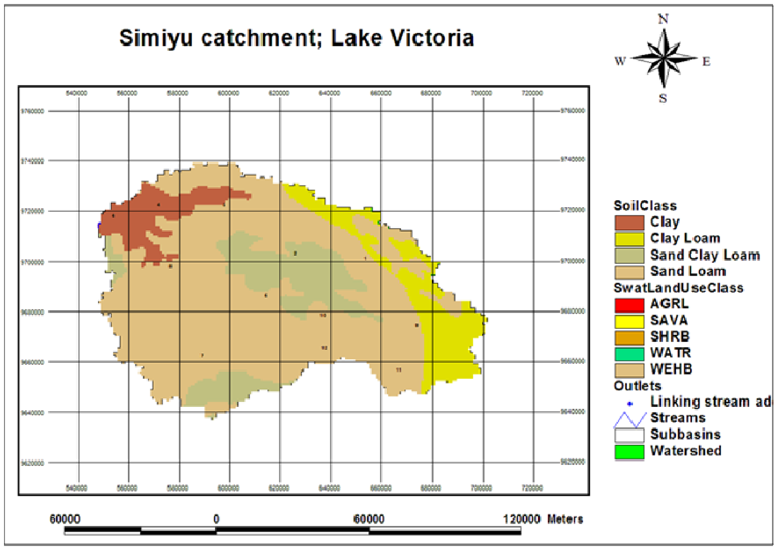

Fig. (2.1). Soils in Simiyu Catchment.

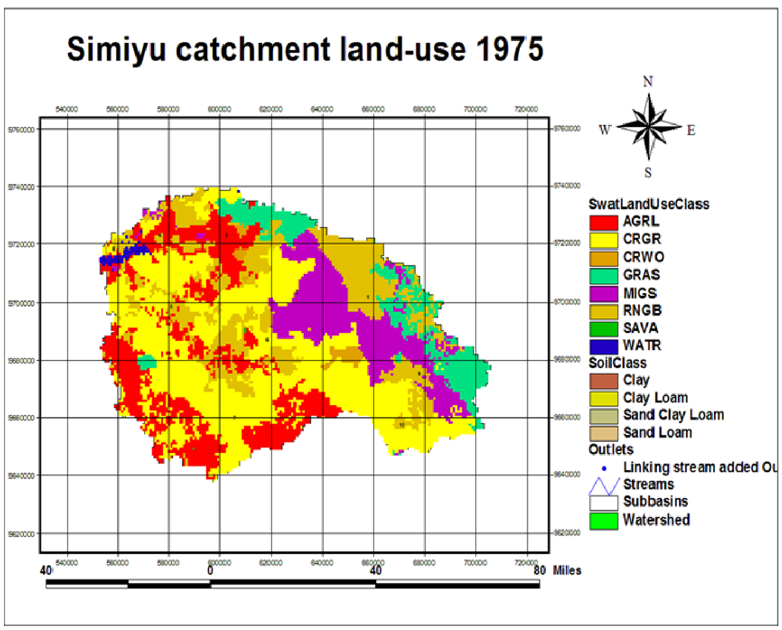

Fig. (3.1). Land Use of 1975.

$$\frac{\sqrt{\sum_i^n \left(\frac{(O_i - F_i)}{n} \right)^2}}{O_{av}} \qquad (5)$$

NRMSE value can vary between 0 and ∞ with the value 0 indicates a perfect fit between the observed and measured data while the value of 1 an acceptable value for concentration simulation.

3. RESULTS AND DISCUSSION

3.1. Land-Use

In this research, two land-use/ cover sets were compared and the relative amount of sediment from both sets compared. For every model run, a different land-use map was input to check its impact on the water quality out. Figs. (**3.1** and **3.2**) below show the land use of 1975 from SWAT modelling processing.

The descriptions of land use for 1975 and 2006 are summarised in Table **3.1** and **3.2**, respectively.

During the classification of the land-use in 2006, main focus was put on the land-cover that has been converted into agricultural land. The catchment as one of the contributors to the deterioration of Lake Victoria quality because of its relatively large area with many agricultural activities using agrochemicals.

Below is an estimation of rate of change for different land covers within the two periods of study i.e. 1975 and 2006.

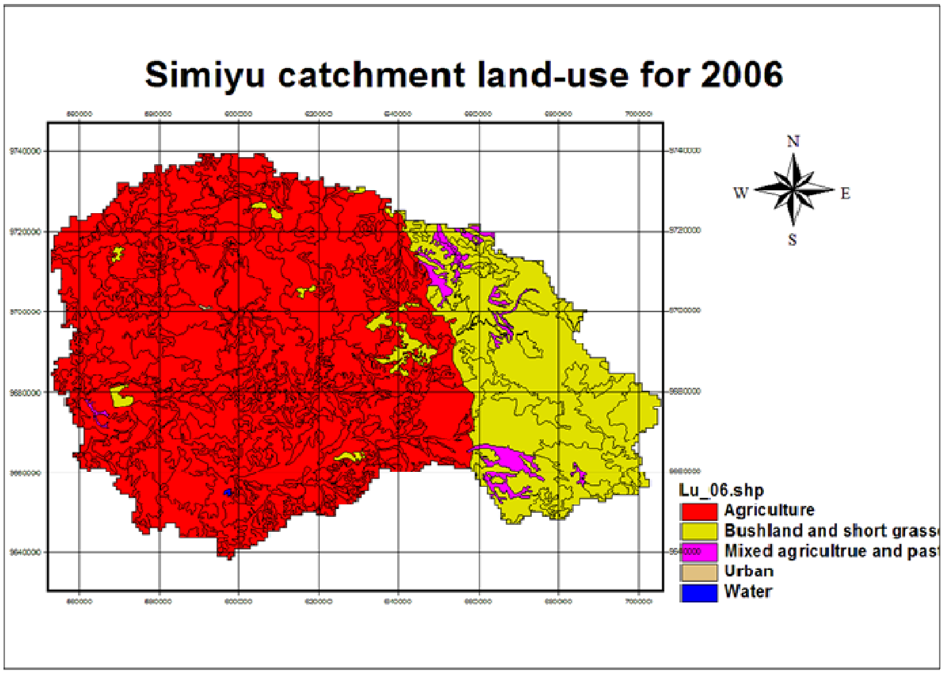

Fig. (3.2). The Land Use of 2006.

Table. 3.1. Land-use Classification of 1975

Processed Land-Use	SWAT Class	Percentage of Catchment Area
Grassland with scattered cropland	Cropland / Grassland Mosaic (CRGR)	38.28
Mixed cropping and cultivation with herbaceous crops	Agricultural land-Generic (AGRL)	19.33
Bush land with emergent trees	Range-brush (RNGB)	18.77
Bushed grassland	Mixed grassland/shrubs (MIGS)	13.25
Open grassland and urban	Grassland (GRAS)	8.73
Wooded with scattered cropland	Cropland / woodland mosaic (CRWO)	1.03
Inland Water	Water (WATR)	0.58
Urban	SAVA	0.03

Table 3.2. Land-use Classification for 2006

Processed Land-Use	SWAT Class	Percentage of Catchment Area
Cultivated	Agricultural Land-Generic (AGRL)	73.43
Mixed Agriculture and pastures	Range-brush(RNGB)	24.42
Bush-land and short grasses	Pasture (PAST)	2.10
Short grasses/Urban	Savanna (SAVA)	0.03
Water	Water (WATR)	0.02

The land use changes between these two scenarios are compared in Fig. **3.3**.

$$\%Change_{yearx} = \frac{Area_{yearx} - Area_{yearx-1}}{Area_{yearx}} * 100\% \qquad (6)$$

$$\%\,Annual\ rate\ of\ change = \frac{Area_{yearx} - Area_{yearx-1}}{Area_{yearx+1}} \qquad (7)$$

There was a land-use shift into agricultural or cultivatable land at an annual rate of change of 2.9% and a change rate of 91.8%.

This already shows how agriculture is growing in the catchment replacing other land-uses. The implication of this on the sediment loading will be analysed from the model results but it is already evident that pollution will increase due to this land-use/cover shift within the catchment.

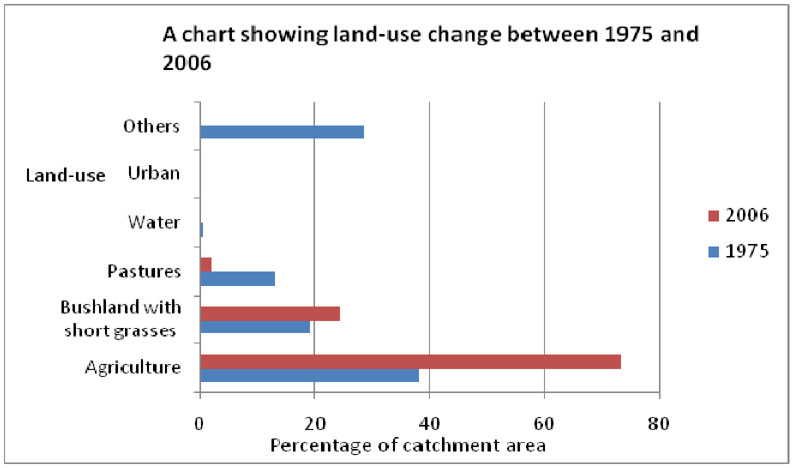

Fig. (3.3). Comparison of land use changes between 1975 and 2006.

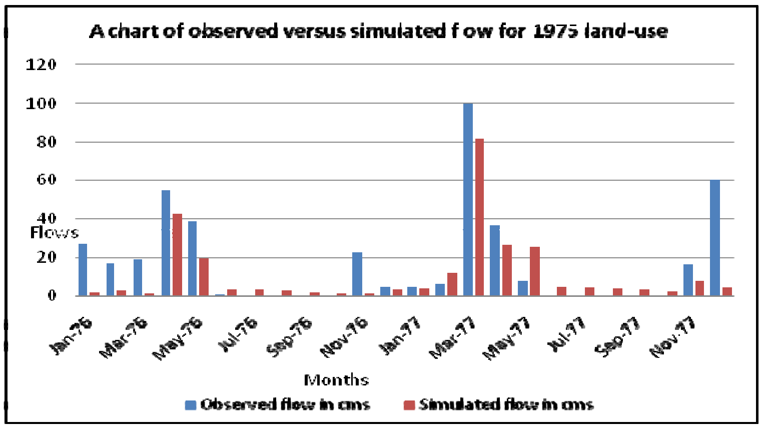

Fig. (3.4). Observed Vs Simulated Flow for 1975 Land use.

3.2. Model Calibration Results

Following change in the vegetation cover, there was a change in the yield of surface runoff, due to a number of factors. Therefore, the model had to be calibrated for different land-use scenarios to match the changes in the hydrology in the catchment. Model calibration is important to achieve good simulated results in water quality studies. To achieve this, the model was calibrated in two phases and the first was hydrology then for sediment. This was done for the two different land-use scenarios.

3.2.1. Model Calibration Results for Hydrological Modeling

For the hydrology, the model was run and a plot of the simulated and observed flows was made using the model's default values. Following this, a sensitivity analysis was carried out and the resulting parameters were ranked according to their importance on model performance and they are summarized in the Table **3.3** below.

Starting with the 1975 land-use, manual calibration was done and efforts were made to adjust the parameters till the Index of Volumetric Fit (IVF) of 0.88 for the long-term water balance was obtained. The ranges used were between 85-70 for CN_II all land-uses, SURLAG of 1, CH_K2 of 3, ALPHA_BF of 0.02, ESCO of 0.001 and SOL_AWC of 0.17. Although RCHRG_DP (.gw) ranked 14 on the sensitivity analysis, adjusting it gave good model performance. It was maintained at 0.5 from 0.05.

Changes in the land-use have an impact on the hydrology of the catchment. This meant, the model had to be calibrated again using the 2006 land-use map. However, due to lack of observed flow data for 2006, the model was calibrated only once for 1975. The land use was changed to that of 2006 using the same model parameters as those of 1975. Using the available flow data at Ndagalu station for period 1977 to 1983, only five years were considered wet years i.e. the annual rainfall average of was above the average of the time step from 1976 to 1983. Hence these five years were used for the long-term water balance. The model was calibrated by manually adjusting parameters throughout the sub-basins, taking one parameter at a time and calculating the efficiency of the model before changing to the next value of the same or another parameter. The parameters were pushed within their ranges and if still the calibration criteria was still not met, then calibration would be stopped for that output.

Model performance indices were an IVF of 88% and Nash-Sutcliffe efficiency, E_{ns} of 34.5% (for the 1975 land-use map) and IVF 72.4% and E_{ns} 30.1% (for 2006 land-use). The relationship between simulated and observed flow for the 1975 land-use was obtained as shown in Fig. (**3.4**) and Table **3.4** gives the sensitivity analysis.

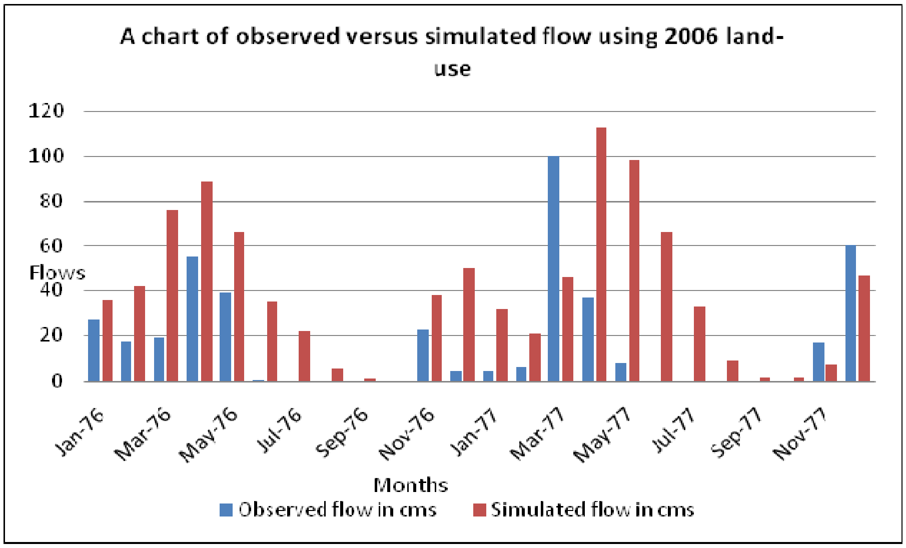

Fig. (3.5). Observed Vs Simulated Flow for 2006 Land use.

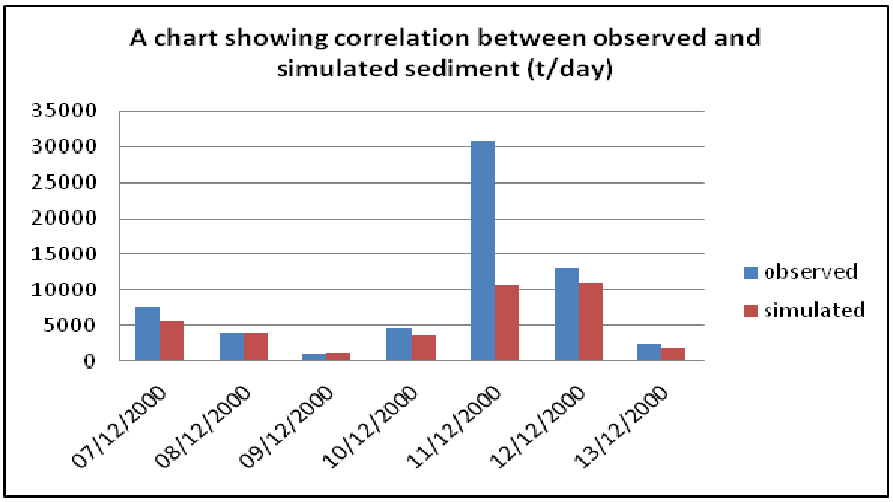

Fig. (3.6). Correlation between observed and simulated sediment loading.

Fig. (**3.5**) above shows the observed and simulated flow for 2006 land use scenarios

3.2.2. Model Calibration Results for Sediment Loading Modeling

The model was then calibrated for sediment. However, the lack of enough sediment data reduced efficiency of model performance. The measured data was not sufficient but the total load per year was compared to the amount Simiyu catchment contributes to the lake i.e. 42.3% of the total 4905.2Kton/yr [16]. Poor model performance was still attributed to lack of sufficient measured data for effective model calibration. Fig. (**3.6**) shows the correlation between observed and simulated sediment loading on the daily time steps.

Model efficiency after calibration for sediments gave a Normal Root Mean Square Error (NRMSE) of 0.61 for the nutrients calibrated at the outlet and 0.95 for sediment calibration. Fig. (**3.7**) shows the comparison between the sediment yield and flow using the 1975 land use scenarios.

Taking an analysis of the catchment at the outlet sub-basin in the 1975 land-use, sediment yield had a positive correlation with surface runoff, with R^2 of 98.8% i.e. as the amount of runoff increased; the yield of sediment also increased.

3.3. Comparing Hydrology and Sediment Load

For the 1975 land-use, agriculture was practiced on 19.33% of the catchment area while in 2006; it covered up to 73.43% of the catchment. In 1975, major activity was in sub basin 7 (also the outlet sub-basin) which was 33.23% of the catchment and agriculture was done in 11.62% in the sub-basin. Similarly, in 2006, sub-basin 7 covered 32.23% of the catchment area and of this agriculture covered up 32.35%.

3.4. Hydrology and Sediment Yield for Land-use 1975 and 2006

3.4.1. Hydrology

From the hydrology, there was increase in the average surface runoff between 1999 and 2000 with 1975 having an

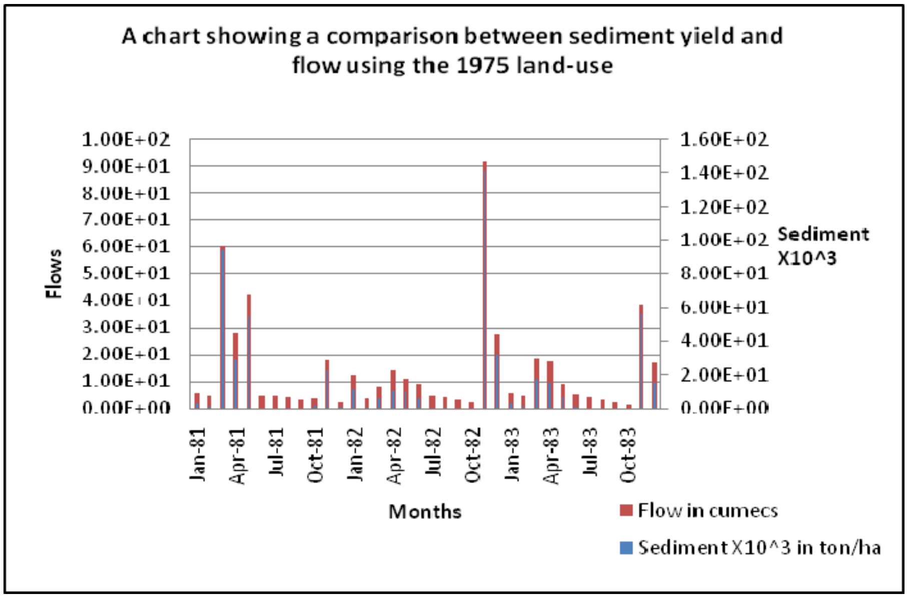

Fig. (3.7). The Relationship between the sediment yield and flow.

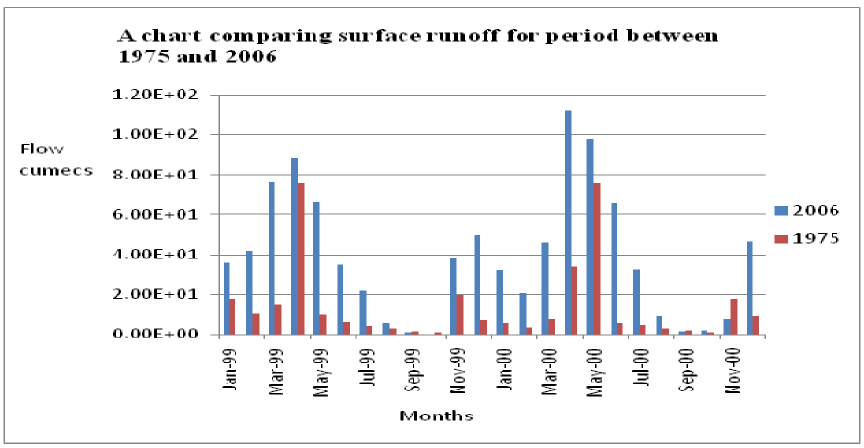

Fig. (3.8). Comparison of surface runoff for period between 1975 and 2006.

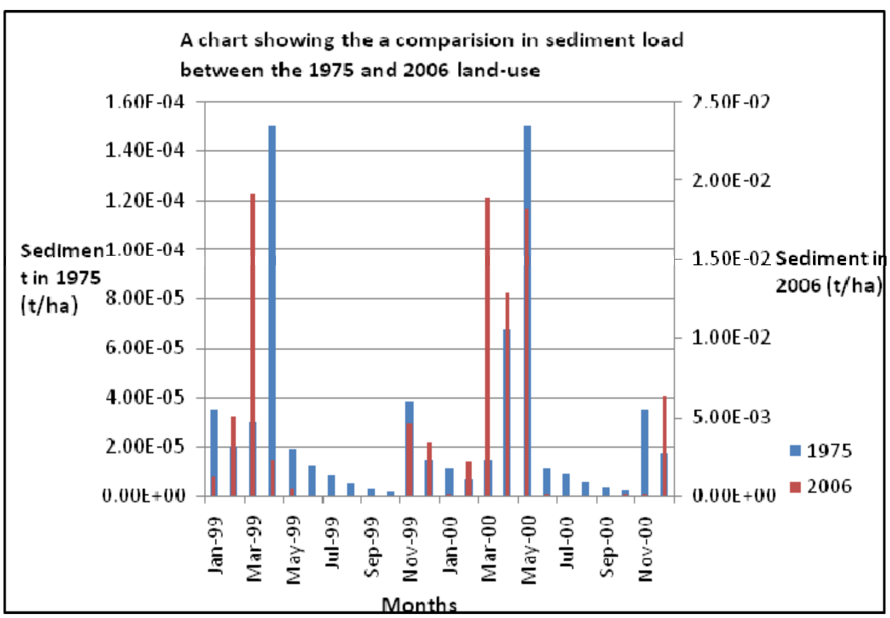

Fig. (3.9). Comparison of sediment load between the 1975 and 2006 land use.

Table 3.3. Sensitive Parameters for Hydrology Model Calibration

Parameter	Description	Range Given in Model
CN2 (.mgt)	Initial SCS Curve Number II value	Varied with land-use between 55 and 98
SURLAG (.bsn)	Surface runoff lag time (days)	4 days
CH_K2 (.rte)	Channel effectiveness hydraulic conductivity (mm/hr)	0.00mm/hr
ALPHA_BF (.gw)	Base-flow alpha factor	0.048 day
ESCO (.hru)	Soil evaporation compensation factor	0.00
SOL_AWC (.sol)	Available water capacity	0.17 and 0.18mm/mm

Table 3.4. Sensitivity Analysis for Sediment Yield Calibration

Parameter	Description	Default	Values used
SPCON (.Bas)	Lin.re-entrainment parameter for channel routing	0.001-0.01	0.006
SPEXP (.Bas)	Exp. re-entrainment parameter fro channel routing	1.0 to 1.5	1.3
LAT SED (.Bas)	Sediment concentration in lateral flow	0 to 5000	35 (10)
PRF (.Bas)	Peak rate adjustment for main channel	0 to 2	0.1
USLE_P (.sub)	USLE support practice factor	0 to 1	0.2 (RANGE) 0.12 (AGRL)

average of 14.14 m^3/s/month and 2006 having 20.16m^3/s/month. This implies that the sediment yield load into the lake within this time period increased. This can be attributed to the change in vegetation cover that has animpact on surface runoff. Fig. (**3.8**) below shows runoff for 1975 and 2006 land use scenarios.

3.5. Sediments Loading Model Results

The average sediment yield between 1999 and 2000 for the 1975 land-use was $2.8x10^{-5}$ ton/ha/month while that for the 2006 land-use went up to $3.95x10^{-3}$ tons/ha/month (Fig. **3.9**) i.e. there was a substantial increase in sediment yield in the two periods which definitely resulted into a higher nutrient load in the lake considering surface runoff also increased within the same period. The results from this study are in agreement with another reported study [17]. However, due to poor model flow calibration on the 2006 land-use, the model underestimated sediment yield in the 2006 land-use. The poor model performance could be attributed to lack of rather inadequate data availability that could be used for modeling mainly calibration process.

4. CONCLUSIONS

This study concludes that there was an expansion of agricultural land from covering 19.33% of the catchment to 73.43% at an annual change rate of 2.9%. Furthermore, the land-use of 1975-yielded less sediment loading compared to that of 2006. Model simulation at the catchment outlet for sediment reports a total yield of 98,467.35 tons/yr while the actual measured sediment loading had the value of 2,075,114 tons/yr. Hence, the model underestimated sediment yield in the catchment. This research found that SWAT modelling tool can be applied to model the impact of land use changes on sediment loading into Lake Victoria only that if the data collection could be improved. With good model performance, developing management plans to control sediment loading into Lake Victoria can be achieved using the SWAT model.

CONFLICT OF INTEREST

None declared.

ACKNOWLEDGEMENT

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NOMENCLATURE AND ACRONYMS

%	=	Percentage
^0C	=	Degree Centigrade
kg	=	Kilogram
kg/ha/yr	=	Kilogram per hectare per year
kgN/ha/yr	=	kilogram of Nitrogen hectare per year
kgN/mm H_2O	=	kilogram of Nitrogen per millimeter of water layer
kgP/ha/yr	=	kilogram of Phoporus hectare per year
km	=	kilometre
km^2	=	Square kilometres
m^3/s	=	Cubic meters per second
Mg/ha	=	million gram per hectare
mg/l	=	Milligram per litre
AGRL	=	Agricultural Land-Generic
ALPHA_BF	=	Base-flow alpha factor
$area_{hru}$	=	the area of the HRU (ha)
ASCE	=	American Society of Civil Engineers
BIOMIX	=	Biological mixing efficiency

BMP	=	Best Management Practise
CFRG	=	the coarse fragment factor
CH_K_2	=	Channel effectiveness hydraulic conductivity
CN	=	the curve number for the decay.
CN_2	=	Initial SCS Curve Number II value
Concn	=	concentration of the nutrient in a layer
CRGR	=	Cropland / Grassland Mosaic
CRWO	=	Cropland / woodland mosaic
C_{USLE}	=	USLE cover and management factor,
DDT	=	dichlorodiphenyltrichloroethane
DEM	=	Digital Elevation Model
E_{ns}	=	Nash-Sutcliffe coefficient
ESCO (.hru)	=	Soil evaporation compensation factor
ESCO	=	Soil evaporation compensation factor
FAO	=	Food and Agriculture Organization of the United Nations
GRAS	=	Grassland
ha	=	Hectares
HRUs	=	Hydrologic Response Units
ILIWIS	=	Integrated Land and Water Information System
IVF	=	Index of Volumetric Fit
K_{USLE}	=	the USLE soil erodibilty factor (0.013)
L	=	Pollutant load, kg/km^2/year
LAT SED (.Bas)	=	Sediment concentration in lateral flow
LS_{USLE}	=	the USLE topographic factor
LVBC	=	Lake Victoria Basin Commission
MIGS	=	Mixed grassland/shrubs
MUSLE	=	Modified Universal Soil Loss Equation
NO_3,	=	Nitrate
NPK	=	Nitrogen, Phosphates, Potassium
NPS	=	Non-Point Sources
NRMSE	=	Normal Root Mean Square Error
$\bar{O}$	=	the average measured discharge
O_i	=	the measured daily discharge,
OrgNact,ly,	=	the concentration of Organic Nitrogen
OrgNfrsh,surf	=	the nitrogen in the fresh organic pool
OrgNhum,ly	=	the concentration of humic organic nitrogen
OrgPfrsh,surf	=	the phosphorus in the fresh organic pool
OrgPhum,ly	=	the concentration of humic organic phosphorus in the layer
P	=	Phosphorus
Pact,ly	=	amount of phosphorus in the active mineral pool
PAST	=	Pasture
P_i	=	the computed daily discharge, and
PO_4-P	=	Phosphate
PRF (.Bas)	=	Peak rate adjustment for main channel
Psurf	=	the amount of soluble phosphorus lost in surface runoff
P_{USLE}	=	the USLE support practice factor
q_{peak}	=	the peak runoff rate (m^3/s),
Qsurf	=	the accumulated runoff (mm H_2O/ha)
R^2	=	coefficient of determination
RNGB	=	Range-brush
S	=	retention parameter
SCS	=	Soil Conservation Service
sed	=	the sediment yield on a given day (metric tons)
SOL_ ORGN	=	Initial Organic N concentration
SOL_AWC	=	Available water capacity
SOTERSAF	=	Soil from Soil and Terrain Database for Southern Africa
SPCON (.Bas)	=	Lin.re-entrainment parameter for channel routing
SPEXP (.Bas)	=	Exp. re-entrainment parameter fro channel routing
SURLAG	=	Surface runoff lag time
SURLAG	=	Surface runoff lag time (days)
SWAT	=	Soil and Water Assessment Tool
TMA	=	Tanzania Meteorological Agency
Ton/yr	=	tone per year
USGS	=	United States Geological Survey
USLE	=	Universal Soil Loss Equation
USLE_P (.sub)	=	USLE support practice factor

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