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Modelling Transport of Nitrogen Compounds in Geita Wetland along Mtakuja River

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ABSTRACT

The impacts of excessive nitrogen loading to streams in a watershed occur in the receiving waters such as rivers at the outlet of the watershed. To quantify the impacts of land use and management practices on the nitrogen loading at the watershed outlet, simulation models are needed that can both predict the nitrogen loading at the edge of individual fields and predict the fate of nitrogen as it moves through the river network to the watershed outlet. This paper presents the results of a model analysis for describing the processes governing transformations and transport of nitrogen compounds (NO_3-N and NH_4-N) through Mtakuja River in the Geita wetland. The model was made in Soil and Water Assessment Tool (SWAT), a watershed model developed to assess the impact of land management practices on water, sediment and agricultural chemical yields with varying soils, land use and management conditions. Two monitoring stations namely MTSP1 and MTSP2 were established along Mtakuja River. A set of SWAT model inputs representative of the water conditions was collected from the established monitoring stations. The model was calibrated and validated for the prediction of flow and nitrogen compounds (NO_3-N and NH_4-N) transport, against a set of measured mean monthly monitoring data. Sensitive model parameters were adjusted within their feasible ranges during calibration to minimize model prediction errors. At the gauging station MTSP2, the calibration results showed that the model predicted mean monthly flow within 18% of the measured mean monthly flow with the r^2 coefficient and Nash-Sutcliffe (NSE) were 0.84 and 0.82, respectively. At the water quality monitoring station MTSP2, the calibration results showed the model predicted nitrogen compounds (NO_3-N and NH_4-N) loadings within 21% and 23% of their respective measured mean monthly loadings. The mean monthly comparisons of r^2 values for nitrogen compounds ranged from 0.77 to 0.81 while the Nash-Sutcliffe Efficiency (NSE) values were between 0.72 and 0.73. The model results and field measurements demonstrated that about 70% of the annual nitrogen compounds loadings which would otherwise reach Lake Victoria are retained in the wetland. The Mtakuja river model can therefore be used for prediction of nitrogen compounds (NO_3-N and NH_4-N) transformation processes in the Geita wetland.

Keywords: *Ammonia-nitrogen, Geita wetland, Mtakuja River, Nitrate-nitrogen, Soil and Water Assessment Tool (SWAT).*

INTRODUCTION

Wetland is a general term applied to land areas which are seasonally or permanently waterlogged, including lakes, rivers, estuaries, and freshwater marshes; an area of low lying land submerged or inundated periodically by fresh or saline water (Haecker *et al.*, 2010). The value of the world's wetlands are increasingly receiving due attention as they contribute to a healthy environment in many ways. They retain water during dry periods, thus keeping the water table high and relatively stable. During periods of flooding, they mitigate flood and to trap suspended solids and attached nutrients. Thus, streams flowing into lakes by way of wetland areas will transport fewer suspended solids and nutrients to the lakes than if they flow directly into the lakes. In addition, wetlands are important feeding and breeding areas for wildlife and provide a stopping place and refuge for waterfowl (Kayima *et al*., 2018). As with any natural habitat, wetlands are important in supporting species diversity and have a complex of wetland values (Ahalya *et al*., 2002; Kayima and Mayo, 2018).

Wetlands are one of the most threatened habitats of the world. The wetlands in Tanzania, as elsewhere are increasingly facing several anthropogenic pressures. Thus, the rapidly expanding human populations, large scale changes in land use/ land cover, burgeoning development projects and improper use of watersheds have all caused a substantial decline of wetland resources of the country. Mtakuja River in the Geita wetland in Tanzania is one of the tributaries of Lake Victoria, the lake which is shared by three countries namely, Kenya, Tanzania and Uganda. Geita wetland plays a big role of removing pollutants from surface runoff and small streams which would otherwise reach the Lake. Water pollution of Mtakuja River in the Geita wetland is largely because of nitrogen nutrients (NO_3-N and NH_4-N) overloading mainly due to application of fertilizers in agriculture (Machiwa and LVEMP, 2002). The nutrients overloading together with loss of wetland are likely to significantly affect the overall buffering capacity of this wetland.

The water quality models have been important tools for identifying water environmental pollution and the final fate and behaviours of pollutants in water environment (Dai *et al*., 2009). The models provide a means of interpreting and extrapolating monitoring data to mitigate limitations in the quantity of available data and to improve understanding of the environmental factors that affect water quality over large spatial scales and diverse geographic settings. While it is widely recognized that Mtakuja River suffers nitrogen compounds (NO_3-N and NH_4-N) loads, very little is known on the fate and transport of these pollutants. There is no updated information on nitrogen compounds (NO_3^--N and NH_4^+-N) pollution loads in the River and no managerial tools have been developed for managing the pollution loads to this River.

One of the potential models that can be used to model the transport of pollutants in the wetland is Soil and Water Assessment Tool (SWAT), which is a physically based simulation package that describes processes governing transformations and transport of pollutants in the wetland (Neitsch *et al*., 2002). The major components of SWAT model include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. SWAT simulates through time the daily soil water balance, growth of plants, built-up of nutrients in the soil due to agricultural management practices and subsequent erosion and transport of nutrients to streams and rivers. Within its limits, SWAT generates results that can be applied in real life situations such as planning, decision-making, environmental conservation and wetlands management.

The main objective of this research was therefore to use water quality model SWAT for describing the processes governing transformations and transport of nitrogen compounds (NO_3^--N and NH_4^+-N) along Mtakuja River in the Geita wetland. SWAT model has been successfully applied worldwide. Gassman *et al.* (2005) reviewed the literature on SWAT applications worldwide and indicated that SWAT has been increasingly used in U.S to support Total Maximum Daily Load (TMDL) analysis. Recently, SWAT has been applied in the tropical African catchments for various purposes including estimation of the sediment yield from Simiyu-Ngagalu river basin in Tanzania (Ndomba *et al.*, 2005) and assessment of the impact of modern technology on the small holder diary industry in Kenya (Jayakrishnan *et al*., 2005).

MATERIALS AND METHODS

Description of the study area

Mtakuja River in the Geita wetland is located in the southwest of Lake Victoria in the north-western part of Tanzania and it is lies between longitudes of 32^0 00'E - $32^0$12'E and Latitudes $2^0$46'S – $2^0$54'S (Figure 1). The total wetland area which drains to the Mtakuja River is estimated to be 510 km^2. Geita wetland is a seasonally flooded type of wetland with is a mixture of tree swamps in the middle and in the periphery is surrounded by forest reserves. It consists of two arms which join together close to Nungwe bay forming a permanent swamp of about 9 km^2. Mtakuja River flows through the right arm while Mabubi River flows through the left arm adjacent to hills and passing through the Geita forest reserve and discharges into the Nungwe bay. The wetland average slope is 4.8% and its elevation varies from 1138 m above mean sea level in the lowland areas to around 1631 m at the hilltops. The wetland has two distinct rainy seasons, the short one runs from mid November to December and the long rains from mid February to May with the mean annual rainfall in the range between 996 mm and 1128 mm during three years of data collection. The mean annual evaporation ranges between 1256 mm and 1276 mm while the annual minimum and maximum temperatures were 14 ^oC and 32 ^oC, respectively. The most dominant plants in the wetland are *Cyperus papyrus* and mixed wooded grassland-paddy community. There are also patches of mixed sedge-*Miscanthus-Phragmites-Typha* community and mixed *Forest swamp-reed papyrus* community.

Field survey of the study area

At the beginning of this study, a field survey was undertaken in the study area to evaluate agricultural practices, vegetation mapping and establishment of monitoring stations. Ground truthing of remote sensing images was also done, which was used to delineate watershed boundaries and the river network. During the survey, it was noted that in the study area there was wide spread application of fertilizers in agriculture. The agricultural activities in the area were largely paddy farming, but to a lesser extent maize and cotton were cultivated. Two monitoring stations namely MTSP1 (inlet) and MTSP2 (outlet) were established in the study area where flow measurement and water sampling were carried out (Figure 1). The sampling points were located on areas with minimum interference from human activities in order to get samples of good representation of the bulk water.

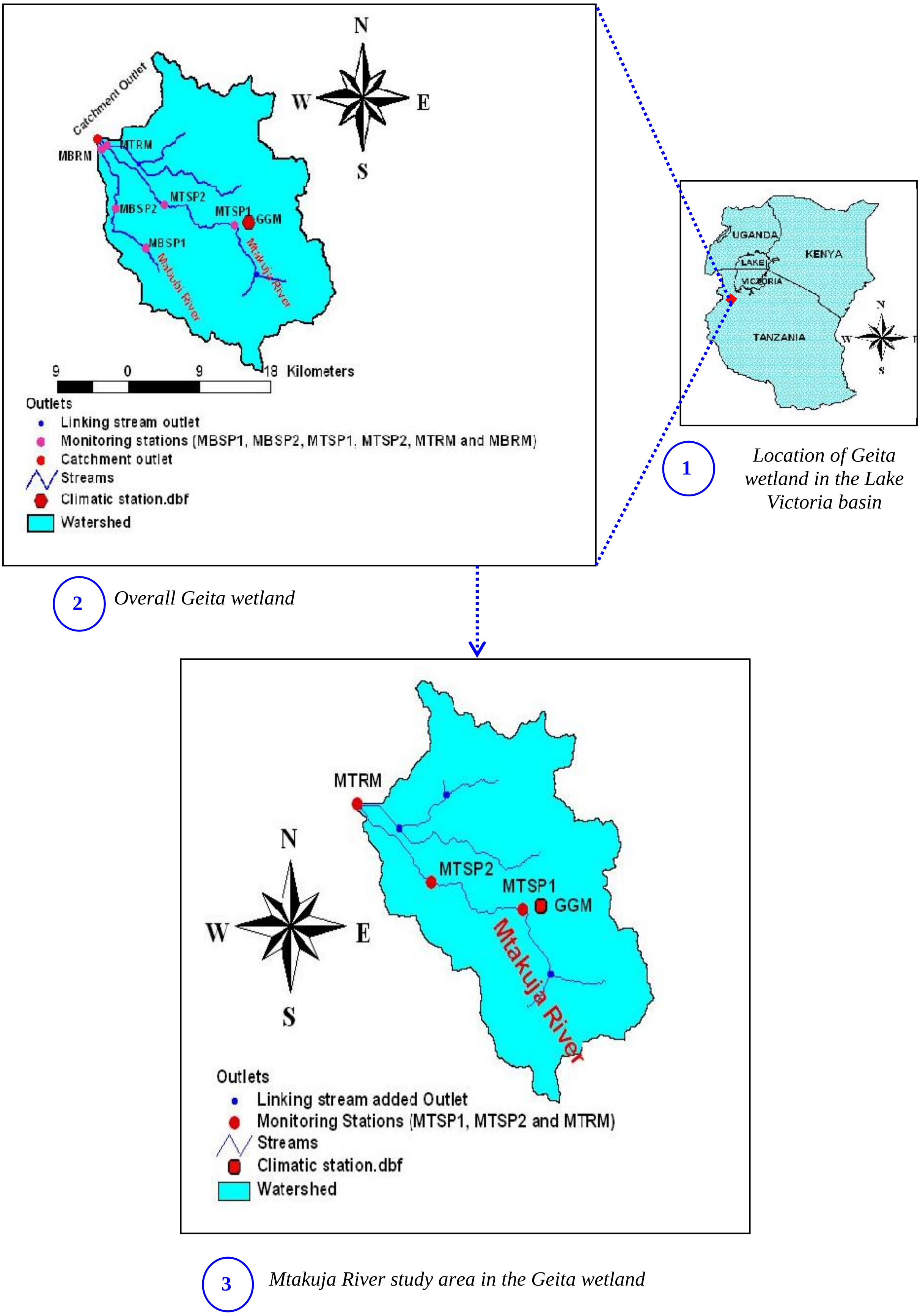


Figure 1: Map of study area

Field flow measurement and water quality sampling

The flow measurement and water sampling exercise in the established monitoring stations started in January 2006. The measurement of water flow in Mtakuja River was carried out using velocity-area method, which comprises of measurement of the mean velocity and the sectional flow area and computing the discharge from the continuity equation. The sectional flow areas were computed from the measured water depth and section width. The water depth was measured using sounding rods of bamboo while the velocity was measured using current meter. The depth and velocity were measured at a number of points along the vertical to define subsections of the River cross section. The sub section flow area was obtained from the product of water depth and the sub-section width. The River cross sectional flow was then determined by summing flow in these sub-sections.

For the case of River sampling, water samples were collected beneath the surface with the mouth directed towards the current. The sampling points were in the water layer of about 4 to 5 cm from the surface at the centre of the main flow. The buckets were rinsed with three separate bucketfuls of River water before collecting samples. Care was taken not to put hands into the water as this could contaminate samples. The sampling bottles were also rinsed 3 times before filling. The bottles were filled almost full, leaving a very small headspace at the top of the bottle.

The water samples from the monitoring stations were collected after every two weeks and were analyzed in the laboratory in accordance with standard methods for examination of water and wastewater samples (APHA *et al.*, 2012). Ammonium nitrogen (NH_4^+-N) was measured using Phenate method whereas the measurement of nitrate nitrogen (NO_3^--N) was carried out using Cadmium Reduction Method. The measured mean monthly concentration levels of the nitrogen compounds were converted to loads by multiplying with the respective measured flow rates.

SWAT model calibration and validation

Watershed models contain many parameters, some of which cannot be measured. The models numerical results can be highly sensitive to small changes in the parameter values. To utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data. The measured data collected between 2006 and 2007 was used for calibration of the model, which was later validated against an independent set of measured data collected in the year 2008.

In the calibration of flow, the important parameters used were: Soil Conservation Service Curve Number (CN2), Manning's coefficient for overland flow (OV_N), Surface runoff lag coefficient (SURLAG) and Lateral flow travel time (LAT_TIME). Other hand the important parameters involved in the calibration of nitrogen compounds were: Initial NO_3 concentration in the soil layer in mg/kg (SOL_NO_3), Initial Organic N concentration in the soil layer in mg/kg (SOL_ORGN), Fraction of fertilizer applied to top 10 mm of soil (FRT_LY1), Biological mixing efficiency (BIOMIX), Nitrate percolation coefficient (NPERCO), Fraction of algal biomass that is nitrogen in mg N/mg alg (AI1). The three numerical model performance measures used in this study are the percentage difference (D_p), coefficient of determination (r^2 coefficient) and the Nash-Sutcliffe simulation efficiency (NSE) (Nash and Sutcliffe, 1970). These indices were chosen as they are the mostly used to assess the predictive power of the hydrodynamic models.

Hydrological modelling using SWAT

SWAT simulates through time the daily soil water balance, growth of plants, built-up of nutrients in the soil due to agricultural management practices and subsequent erosion and transport of nutrients to streams and rivers. SWAT can be used to simulate a single watershed or a system of multiple hydrologically connected watersheds. Each watershed is first divided into sub-basins and then into hydrologic response units (HRUs) based on the landuse and soil distributions. The climatic variables required by SWAT consist of daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity. The upland processes include hydrology, erosion, plant growth, nutrient cycling, pesticide dynamics and agricultural management. The channel processes include photolysis, hydrolysis, nitrification, biodegradation and transformations, dilution and diffusion, deposition and re-suspension, deposition and accumulation, sorption onto sediments and bio-concentration.

Water balance is the driving force behind everything that happens in the watershed (Neitsch *et al.*, 2002) and SWAT uses equation (1) to simulate the same.

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad (1)$$

Where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), w_{seep} is the amount of percolation and bypass flow exiting the soil bottom on day i (mm H_2O), and Q_{gw} is the amount of return flow on day i (mm H_2O).

In-stream nutrient modelling using SWAT

The modelling of in-stream nutrient transformations in SWAT incorporates constituent interactions and relationships used in QUAL2E model (Brown and Barnwell, 1987). In aerobic water, there is a stepwise transformation from organic nitrogen to ammonia, to nitrite, and finally nitrate. Organic nitrogen may also be removed from the stream by settling.

The amount of organic nitrogen in the stream may be increased by the conversion of algal biomass nitrogen to organic nitrogen. Organic nitrogen concentration in the stream may be decreased by the conversion of organic nitrogen to NH_4^+ or the settling of organic nitrogen with sediment. The change in organic nitrogen for a given day is:

$$\Delta orgN_{str} = \left(\sim_1 . °_a . X - \quad_{N,3} . orgN_{str} - \pm_4 . orgN_{str}\right) . TT \quad (2)$$

Where $\Delta orgN_{str}$ is the change in organic concentration (mg N/L), $\sim_1$ is the fraction of algal biomass that is nitrogen (mg N/mg algae biomass), $°_a$ is the local respiration or death rate of algae (day^{-1}), X is the algal biomass concentration at the beginning of the day (mg alg/L), $\quad_{N,3}$ is rate constant for hydrolysis of organic nitrogen to ammonia nitrogen (day^{-1}), $orgN_{str}$ is the organic nitrogen concentration at the beginning of the day (mg N/L), $\pm_4$ is the rate coefficient for organic nitrogen settling (day^{-1}), and TT is the flow travel time in the reach segment (day).

The amount of ammonium (NH_4^+) in the stream may be increased by the mineralization of organic nitrogen and diffusion of ammonium from the streambed sediments. The ammonium concentration in the stream may be decreased by the conversion of NH_4^+ to NO_2^- or the uptake of NH_4^+ by algae. The change in ammonium for a given day is:

$$\Delta NH4_{str} = \left({}_{N,3}.orgN_{str} - {}_{N,1}.NH4_{str} + \frac{\pm_3}{(1000.depth)} - fr_{NH4}.\sim_1 «_a .X \right).TT \qquad .... (3)$$

Where $\Delta NH4_{str}$ is the change in ammonium concentration (mg N/L), ${}_{N,3}$ is the rate constant for hydrolysis of organic nitrogen to ammonia nitrogen (day[-1]), $orgN_{str}$ is the organic nitrogen concentration at the beginning of the day (mg N/L), ${}_{N,1}$ is the rate constant for biological oxidation of ammonia nitrogen (day[-1]), $NH4_{str}$ is the ammonium concentration at the beginning of the day (mg N/L), $\pm_3$ is the benthos (sediment) source rate for ammonium (mg N/m[2]-day), $Depth$ is the depth of water in the channel (m), fr_{NH4} is the fraction of algal nitrogen uptake from ammonium pool, $\sim_1$ is the fraction of algal biomass that is nitrogen (mg N/mg alg biomass) and $«_a$ is the local growth rate of algae (day[-1]).

The amount of nitrite (NO_2^-) in the stream will be increased by the conversion of NH_4^+ to NO_2^- and decreased by the conversion of NO_2^- to NO_3^-. The conversion of NO_2^- to NO_3^- occurs more rapidly than the conversion of NH_4^+ to NO_2^-. Therefore, the amount of nitrite present in the stream is usually very small. The change in nitrite for a given day is given by equation (4).

$$\Delta NO2_{str} = \left({}_{N,1}.NH4_{str} - {}_{N,2}.NO2_{str} \right).TT \qquad .... (4)$$

Where $\Delta NO2_{str}$ is t he change in nitrite concentration (mg N/L), ${}_{N,1}$ is the rate constant for biological oxidation of ammonia nitrogen (day[-1]), $NH4_{str}$ is the ammonium concentration at the beginning of the day (mg N/L), ${}_{N,2}$ is the rate constant for biological oxidation of nitrite to nitrate (day[-1]), $NO2_{str}$ is the nitrite concentration at the beginning of the day (mg N/L), and TT is the flow travel time in the reach segment (day).

The amount of nitrite (NO_3^-) in the stream may be increased by the oxidation of NO_2^-. The nitrate concentration in the stream may be decreased by the uptake of NO_3^- by algae. The change in algae for a given day is described by equation (5).

$$\Delta NO3_{str} = \left({}_{N,2}.NO2_{str} - (1 - fr_{NH4}).\sim_1 .«_a .X \right).TT \qquad .... (5)$$

Where $\Delta NO3_{str}$ is the change in nitrate concentration (mg N/L), ${}_{N,2}$ is the rate constant for biological oxidation of nitrite to nitrate (day[-1]), $NO2_{str}$ is the nitrite concentration at the beginning of the day (mg N/L), fr_{NH4} is the fraction of algal nitrogen uptake from ammonium pool, $\sim_1$ is the fraction of algal biomass that is nitrogen (mg N/mg algal biomass) and $«_a$ is the local growth rate of algae (day[-1]).

Mtakuja River SWAT model

SWAT model development consists of preparing various digital data base inputs including database on landuse/land cover and soil. The input data were prepared to the required format for input to the SWAT model. A statistical weather generator file WXGEN (Sharply and Williams, 1990) was prepared from climatic data obtained from Geita Gold Mine (GGM) station for five years to generate climatic data and fill in gaps in the missing records. The SWAT ArcView interface - AVSWAT (DiLuzio *et al*., 2001) was used to process mapped landuse and soils data and Digital Elevation Map (DEM) to create a set of default model input files. AVSWAT utilized DEM to delineate watershed and sub-basin boundaries, calculate sub-basin average slopes and define the stream network. However, in this study the sub-basin average slopes were replaced by Hydrologic Response Units (HRU) specific slopes. The watershed simulation option was set to start five months prior to the starting period of simulation (2006) to allow the model to get the water cycling properly before any comparisons between measured and simulated data were made.

RESULTS AND DISCUSSION

Processed spatial data

Figure 2 shows the results of AVSWAT processed spatial data. Accordingly, the main types of soil in the area are cambisols (89%) and calcisols (13%). The landuse/ land cover classification shows that Range-Grasses (RNGE) covers 37% while Agricultural Land (AGRL) and Natural Mixed Evergreen (FRSE) cover 34% and 29% respectively. The AVSWAT DEM delineation obtained a total number of 11 sub-basins to represent the Mtakuja river study area.

Gauged climate data

The climate data required for SWAT model application are precipitation, maximum and minimum temperature, evaporation and relative humidity. The annual rainfall was in the range between 996 mm and 1128 mm while evaporation ranged from 1256 mm to 1276 mm during the three years of study. The annual maximum temperature ranged from 20 ^{o}C to 32 ^{o}C and the minimum was between 14 ^{o}C and 16 ^{o}C. The average wind speed ranged from 0.21 m/s to 19.26 m/s whereas the relative humidity was in the range between 44.5% and 96.5%. Figure 3 shows the climatic data used in the study.

Estimated agricultural nitrogen data

The estimated equivalent amount of fertilizer (kg N/acre) application in agricultural activities were Manure - 1.34, CAN (Calcium, Ammonia, and Nitrogen) - 15.1, UREA - 49.7 and NPK (Nitrogen, Phosphorous and Potassium) - 46.4, summing up to 112.54 kgN/acre. This amount was used as a non-point source input in the Mtakuja River SWAT model.

Measured flow and water quality data

Figures 4 shows the mean monthly flow and nitrogen compounds (NO_3-N and NH_4-N) loads at station MTSP2 of Mtakuja River. The high stream flows were recorded in the months of March, April, May and December as these are the months with high rainfall period in the area. The highest recorded flow was 1.52 m^3/s. The mean monthly NO_3^--N loading varied between 246 kgN/month and 7465 kgN/month while the variation on NH_4^+-N loading ranged between 233 kgN/month and 9062 kgN/month. Generally, Figure 4 shows the rise and fall in mean monthly flow and nitrogen compounds (NO_3^--N and NH_4^+-N) loads at station MTSP2 of Mtakuja River. The fluctuations in loading are due to agricultural activities pertaining in the area. High loadings of nitrogen compounds are associated with river flow pattern which is a function of rainfall. High loading appear during high flows between February and May indicating that gross amount of contaminant is collected by runoff from agricultural field where there is a substantial input of fertilizers for crops such as rice, maize and sweet potatoes.

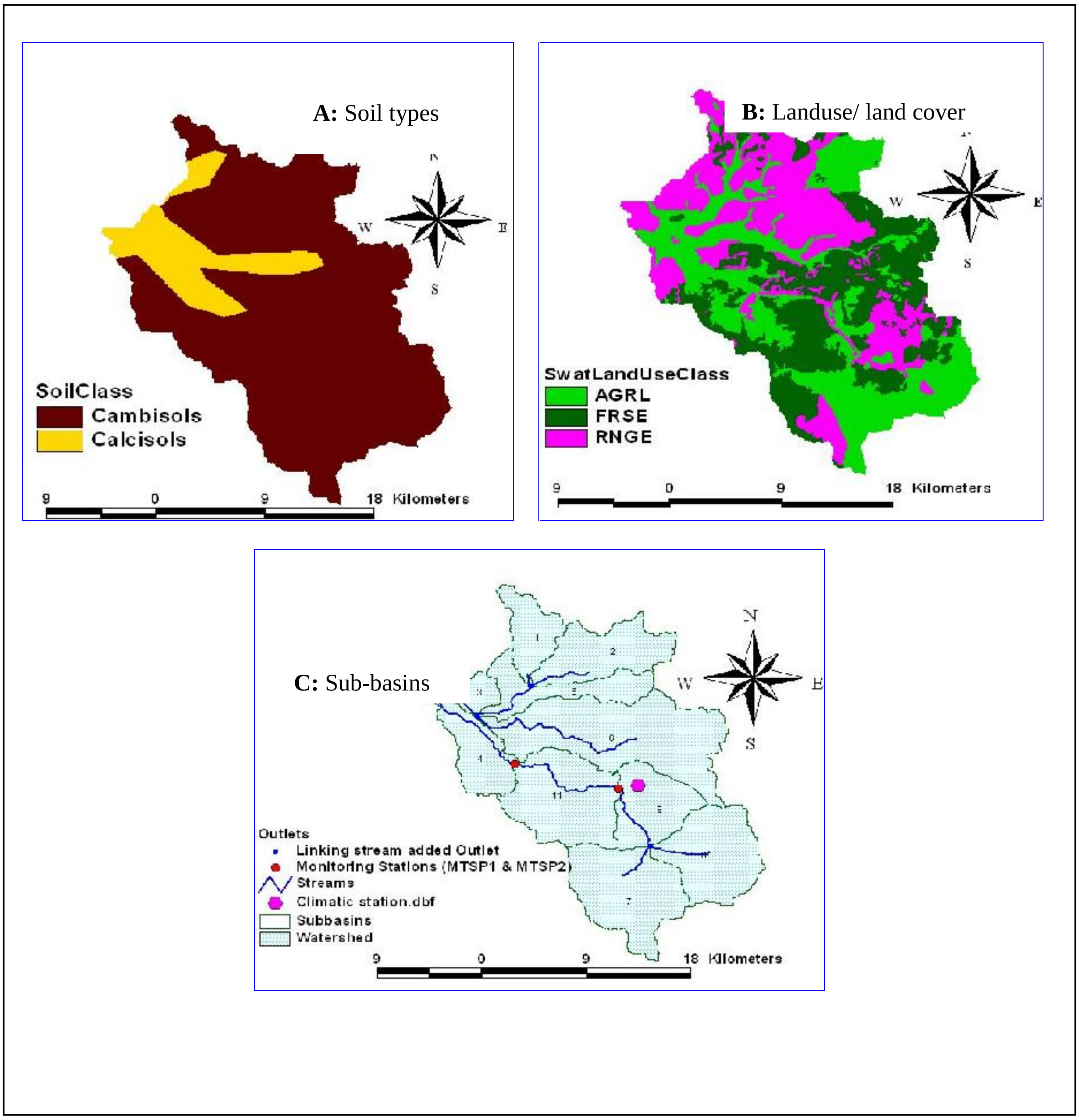


Figure 2: Spatial data results

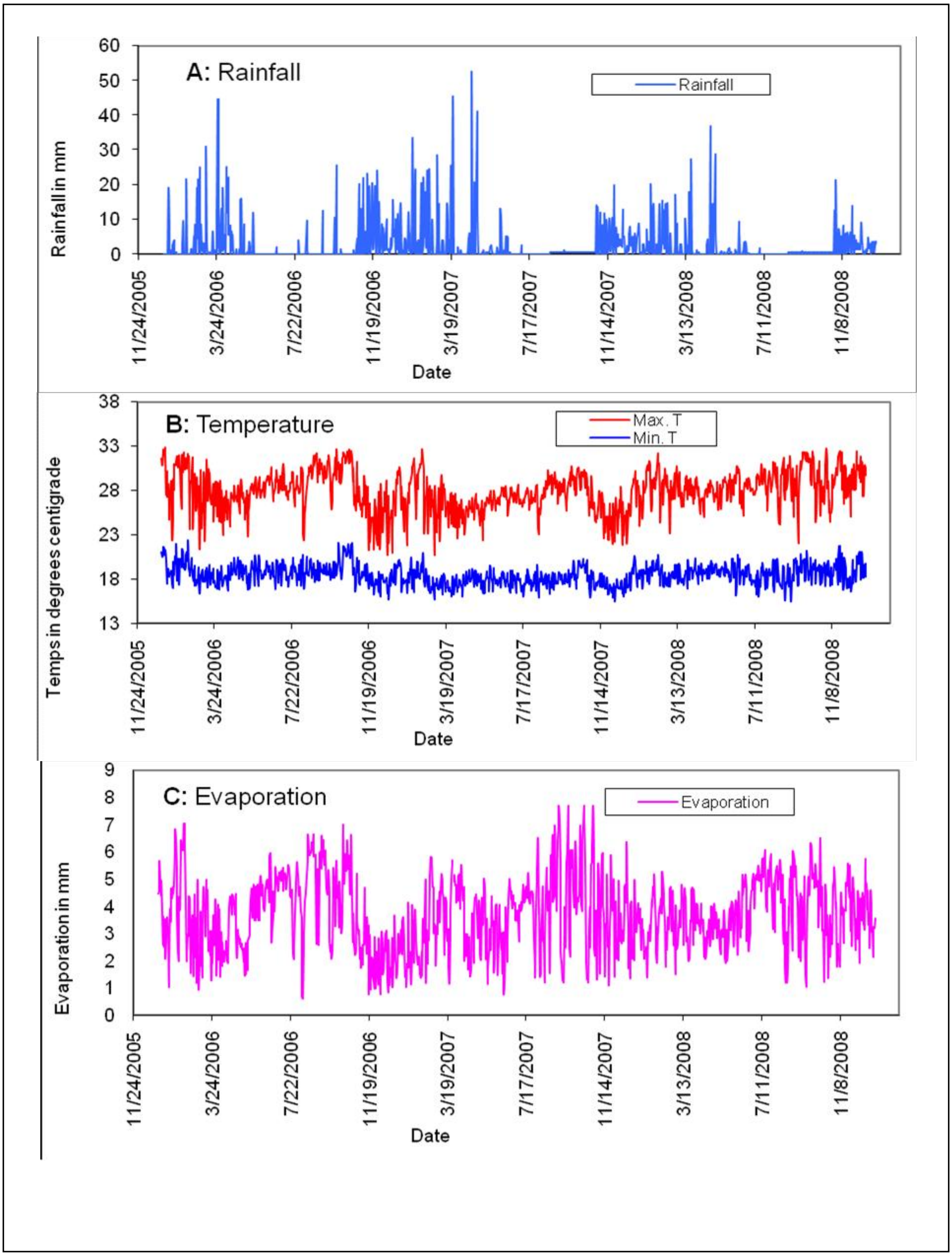
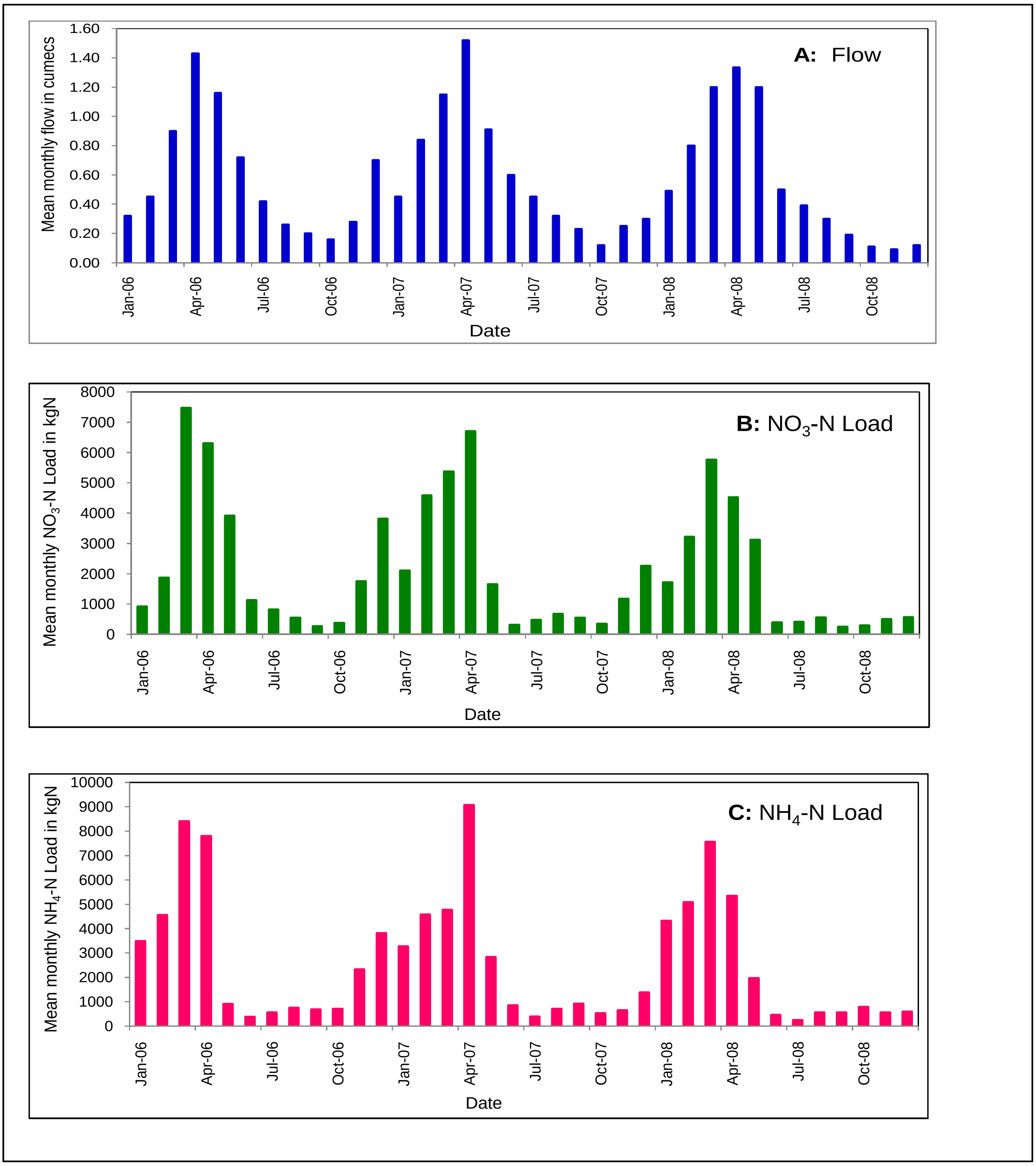


Figure 3: Climate data



Figures 4: Measured mean monthly flow and water quality data at MTSP2 station

Model Calibration

The objective of calibration is to determine the model Performance optimization parameters such that an acceptable match is obtained between the observed behaviours of the variable of interest, say discharge. All performance optimization parameters were modified within their acceptable ranges as found in the SWAT model user's manual (Neitsch *et al.*, 2001b). The calibration was assessed statistically using percentage difference (D_p), coefficient of determination (r^2 coefficient) and the Nash-Sutcliffe simulation efficiency (NSE) indices. The flow performance optimization parameters and their values are presented in Table 1 and the same for NO_3^--N and NH_4^+-N loads are outlined in Table 2.

Table 1: Performance optimization calibrated flow parameters

S/N	Parameter (SWAT variable name)	Change	Final value (Default value)
1	SCS Curve Number (CN2) multiplicative adjustment factor	Reduced base CN2s by 20% relative to their base value	Varies by HRU
2	Manning's *n* for overland flow (OV_N)	Constant value for all land uses due to extremely short model simulated time of concentrations for all HRUs	0.15 (Varied by land use)
3	Surface runoff lag coefficient (SURLAG)	Reduced so that some portion of surface runoff is lagged one day before reaching the channel	1.0 (4.0)
4	Lateral flow travel time (LAT_TIME)	Fixed for all HRUs so that lateral flow lag time was greater than surface runoff lag time	2.0 days (Calculated by model and varied by HRU)

The Mtakuja river SWAT model was calibrated against river flows and water quality monitoring data over a period of two years. The model was calibrated against flow and water quality data measured at MTSP2 station from 2006 to 2007 as shown in Figure 5. Generally, the calibration results show that the model calibration with respect to mean monthly flow predictions is good, with r^2 of 0.84 and NSE of 0.82. Similarly, the comparison in nitrogen compounds demonstrated that the model prediction of NO_3^--N and NH_4^+-N loads is good. The r^2 between calibrated values and observed values for NO_3^--N and NH_4^+-N were 0.77 and 0.81 respectively. On the other side the Nash-Sutcliffe (NSE) for NO_3^--N and NH_4^+-N were 0.73 and 0.72, respectively (Table 3).

Examination of the entire calibration period shows that SWAT model slightly over-predict flow and nitrogen compounds (NO_3^--N and NH_4^+-N) loads. There are some notable periods in which model predictions are not in good agreement with the measured variables. For instance the peak flow in April 2006 tends to be more over-predicted by the model (Figure 5). The over-predictions of flow in April 2006 are consistent with the over-predictions of NO_3^--N and NH_4^+-N loads in that same period (Figure 5). It was also noted that the simulated flow was under-predicted during peak flow in April 2007, which is consistent with the under-predictions of NO_3^--N and NH_4^+-N loads in the same month. The model predictive performance for flow was better than for NO_3^--N and NH_4^+-N loads during calibration period. To a lesser extent, the largest errors in NO_3^--N and NH_4^+-N loads predictions seem to be associated with errors in peak flow (surface runoff) predictions. The seasonal variation in rainfall intensity was observed to influence the rate of flow as well as the loading of the nitrogen compounds. The high rainfall in the study area occurred during months of February, March, April, May and September resulting into high measured and modelled flow.

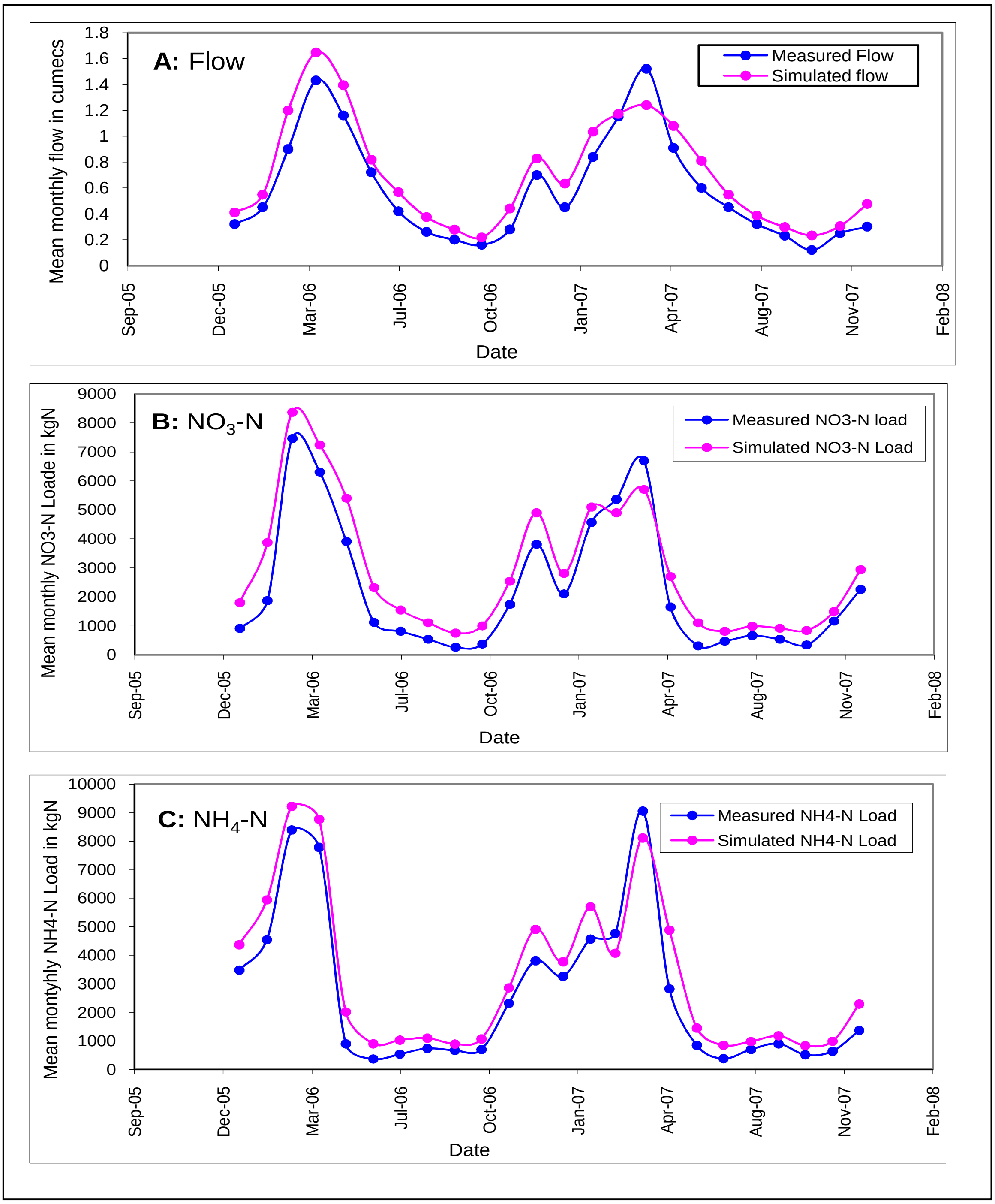


Figure 5: SWAT model calibration results at MTSP2 station

Table 2: Performance optimization calibrated NO_3-N and NH_4-N loads parameters

S/N	Parameter (SWAT variable name)	Adoption	(Range/ Default) Final value
1	Initial NO_3 concentration in the soil layer in mg/kg (SOL_NO_3)	Fixed at 2.0 so that nitrate loadings were reasonably well predicted.	(0.0 – 5.0) 2.0
2	Initial Organic N concentration in the soil layer in mg/kg (SOL_ORGN)	Fixed at 6000 so that organic N loadings were reasonably well predicted.	(0.0 – 10000) 6000
3	Fraction of fertilizer applied to top10mm of soil (FRT_LY1)	Set to 0.0 for the model to apply 20% of the fertilizer to the top 10mm soil layer	0.0 0.0
4	Biological mixing efficiency (BIOMIX)	The default 0.2 value was adopted as the biological mixing efficiency	(0.2) 0.2
5	Nitrate percolation coefficient (NPERCO)	Set to 0.2 for the reasonable prediction of nitrate loadings	(0.01 – 1.0) 0.2
6	Fraction of algal biomass that is nitrogen in mgN/mg alg (AI1)	Set to 0.08 for better prediction of nitrogen compounds loadings	(0.07 – 0.09) 0.08

Table 3: Summary of Mtakuja River SWAT model performance measures for the calibration period

Modeled parameter	% Difference, D	r^2	NSE
Mean monthly flow (Q)	18	0.84	0.82
Mean monthly nitrate (NO_3^--N)	23	0.77	0.73
Mean monthly ammonium (NH_4^+-N)	21	0.81	0.72

Model Validation

Model validation is the process of testing model performance of the calibrated model parameter set against an independent set of measured data. The measured validation and calibration data sets cover different time periods. Figure 6 shows that the model performance with respect to mean monthly flows and nitrogen compounds (NO_3^--N and NH_4^+-N) loading prediction during validation was generally good with r^2 of 0.88, 0.81 and 0.83, respectively. The Nash-Sutcliffe (NSE) for flow, NO_3^--N and NH_4^+-N were 0.84, 0.76 and 073, respectively (Table 4).

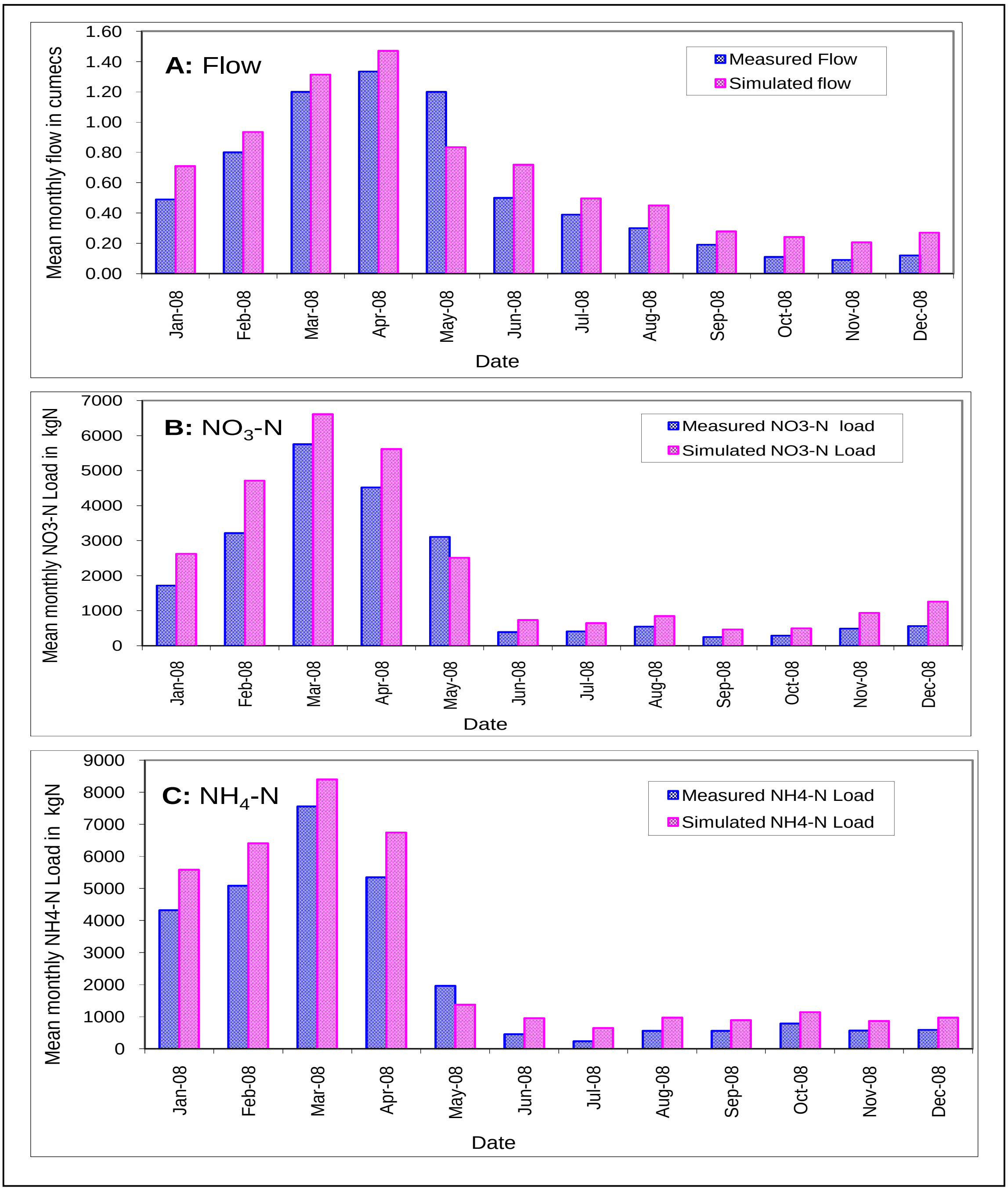


Figure 6: SWAT model validation results at MTSP2 station

Table 4: Mtakuja River SWAT model performance measures for the validation period

Modelled parameter	% Difference, Dp	r^2	NSE
Mean monthly flow (Q)	**17**	**0.88**	**0.84**
Mean monthly nitrate (NO_3^--N)	**19**	**0.81**	**0.76**
Mean monthly ammonium (NH_4^+-N)	**20**	**0.83**	**0.73**

The good validation results support the usefulness of the model to predict future conditions (i.e. NO_3^--N and NH_4^+-N loading) under alternative management scenarios and future climates. The general examination of the entire validation period shows that the SWAT model slightly over-predicts the modelled parameters with exception of February, June, July and October 2008 where the parameters are under-predicted.

Retention capacity of NO_3^--N and NH_4^+-N in Geita wetland

The measured mean monthly NO_3^--N and NH_4^+-N load discharged at the outlet station (MTSP2) suggested that certain amount of pollution load that entered at station MTSP1 has been retained in the wetland. Table 5 shows that NO_3^--N and NH_4^+-N were retained at an average rate of 66.3% and 72.0%, respectively. During three years of the study,NO_3^--N retention in the wetland ranged from 62% to 72% while NH_4^+-N retention ranged from 70% to 75%. The capacity of wetland to retain pollution depends mainly on the existing plants and sediments. Plants have a tendency to uptake pollution into their tissues whereas sediments tend to adsorb and sometimes release pollution in to the wetland. The calculated mean monthly NO_3^--N and NH_4^+-N loading in the upstream and downstream stations of the Mtakuja River study area is shown on Figure 7, which indicates that Geita wetland has a buffering capacity for nitrogen nutrients. Therefore there is a need to conserve and protect this wetland as it acts as a buffer against pollution load entering the Lake Victoria.

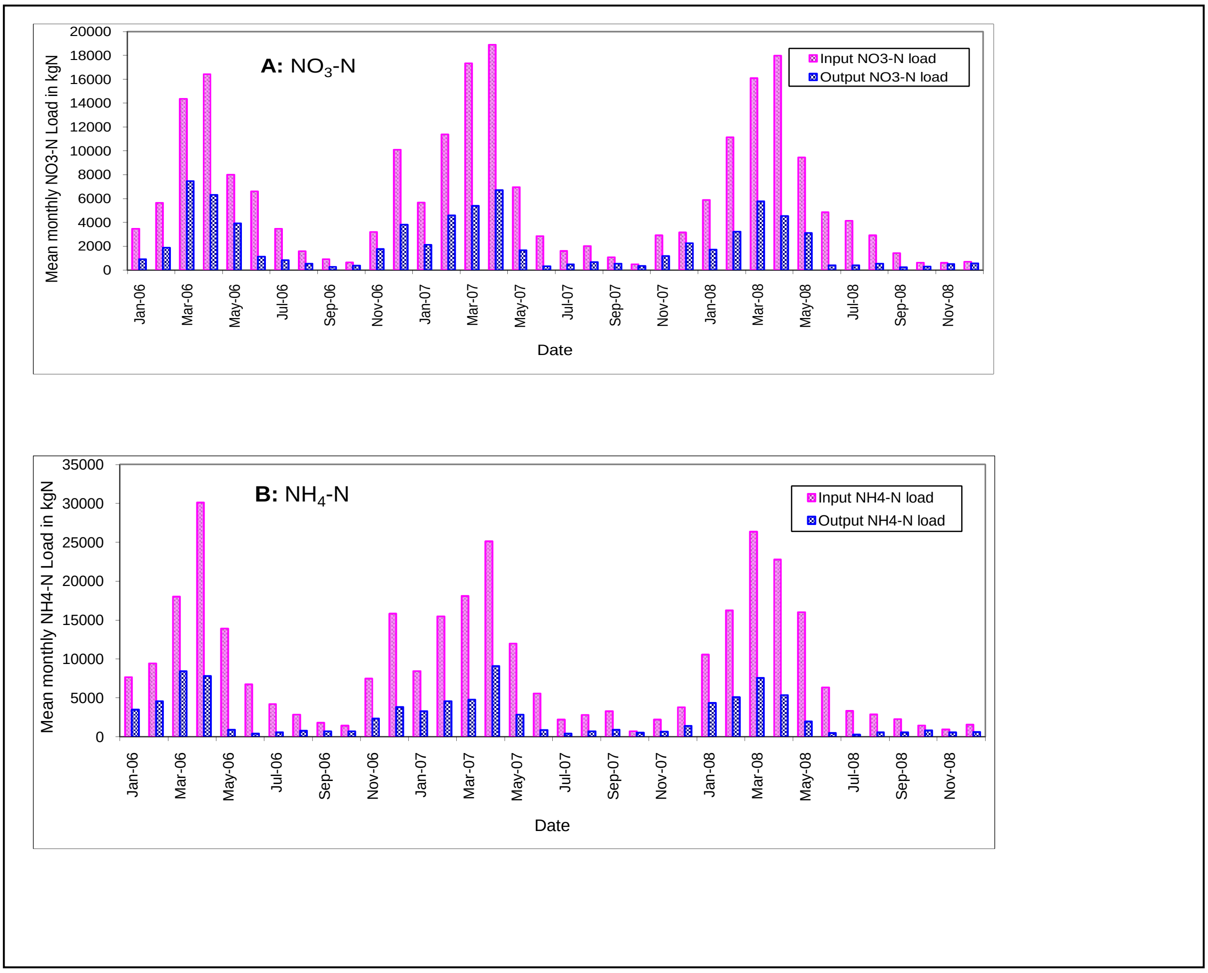


Figure 7: Mean monthly nitrogen compounds NO_3-N and NH_4-N loading

Table 5: Summary of NO_3^--N and NH_4^+-N retention capacity of Mtakuja study area

Parameter	Percentage annual retention			
	2006	**2007**	**2008**	**Mean**
Nitrate nitrogen (NO_3-N)	62	65	72	66.3
Ammonium nitrogen (NH_4-N)	71	70	75	72

CONCLUSIONS

SWAT watershed model was used to predict nitrogen compounds (NO_3^--N and NH_4^+-N) loading from landuse and management practices delivered to the outlet of Geita wetland along Mtakuja River. The SWAT model has shown that it can reasonably predict the temporal nature of the measured flow and water quality data at the monitoring stations along Mtakuja River in the Geita wetland. The measured water quality data and the model results document high levels of nitrogen compounds (NO_3^--N and NH_4^+-N) loadings in Mtakuja River as a result of application of fertilizers in agricultural activities in the area. Examination of the entire calibration and validation periods show that generally the SWAT model slightly over-predicts River flow and the modelled nitrogen compounds (NO_3^--N and NH_4^+-N) loading levels with the exception of some few months where the model under-predicted them. However, the model calibration efficiencies of 0.84, 0.77 and 0.81 for flow, NO_3^--N and NH_4^+-N, respectively, were good. The SWAT model presented here will be valuable for determining the impact of land use and management practices on NO_3^--N and NH_4^+-N loading in the Geita wetland outlet. The assessment of buffering capacity of Geita wetland against nitrogen compounds (NO_3^--N and NH_4^+-N) loading during three years of the study showed that NO_3^--N load retention ranged from 62% to 72% while NH_4^+-N ranged from 70% to 75%. Therefore it is recommended to protect and conserve this wetland as it acts as a buffer against the nutrients pollution load entering the Lake Victoria.

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