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A GUIDED SWAT MODEL APPLICATION ON SEDIMENT YIELD MODELING IN PANGANI RIVER BASIN: LESSONS LEARNT

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Abstract: The overall objective of this paper is to report on the lessons learnt from applying Soil and Water Assessment Tool (SWAT) in a well guided sediment yield modelling study. The study area is the upstream of Pangani River Basin (PRB), the Nyumba Ya Mungu (NYM) reservoir catchment, located in the North Eastern part of Tanzania. It should be noted that, previous modeling exercises in the region applied SWAT with pre-assumption that inter-rill or sheet erosion was the dominant erosion type. In contrast, in this study SWAT model application was guided by results of analysis of high temporal resolution of sediment flow data and hydro-meteorological data. The runoff component of the SWAT model was calibrated from six-years (i.e. 1977–1982) of historical daily streamflow data. The sediment component of the model was calibrated using one-year (1977–1988) daily sediment loads estimated from one hydrological year sampling programme (between March and November, 2005) rating curve. A long-term period over 37 years (i.e. 1969–2005) simulation results of the SWAT model was validated to downstream NYM reservoir sediment accumulation information. The SWAT model captured 56 percent of the variance (CE) and underestimated the observed daily sediment loads by 0.9 percent according to Total Mass Control (TMC) performance indices during a normal wet hydrological year, i.e., between November 1, 1977 and October 31, 1978, as the calibration period. SWAT model predicted satisfactorily the long-term sediment catchment yield with a relative error of 2.6 percent. Also, the model has identified erosion sources spatially and has replicated some erosion processes as determined in other studies and field observations in the PRB. This result suggests that for catchments where sheet erosion is dominant SWAT model may substitute the sediment-rating curve. However, the SWAT model could not capture the dynamics of sediment load delivery in some seasons to the catchment outlet.

Keywords: Modelling, Pangani river basin, sediment yield, sediment rating curve, SWAT

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INTRODUCTION

A basin sediment yield refers to the amount of sediment exported by a basin over a period of time, which is also the amount, which will enter a reservoir located at the downstream limit of the basin (Morris & Fan, 1998). The subject of sediment yield modelling has attracted the attention of many scientists but lack of resources and compelling methods to predict sediment yields are some of the bottlenecks towards this direction (Silva *et al*., 2007; Ndomba & Neveen, 2004; Ndomba *et al*., 2005, 2007a,b). Collecting sediment flow data over a decade and periodic reservoir survey information are some resources demanding methods for estimating sediment yield rates at a catchment level (Silva *et al*., 2007). Besides, other workers such as Wasson (2002) have noted the transferability problem of plot or micro scale studies results to larger catchments. Others have also cautioned that long term sediment monitoring of suspended sediment loads does not necessarily give better results (Summer *et al*., 1992). Some workers have suggested that an excellent sediment-rating curve could be constructed from detailed sediment flow data of short period of sampling programme (Summer *et al*., 1992; Ndomba, 2007). However, Ferguson (1986) indicated that most of the sediment-rating curves underestimate the actual loads. Besides, other researchers such as Bogen & Bønsnes (2003) have cautioned that such relationships should be used on catchment where no significant landforms, landuse and sediment supply source changes are expected.

In this study, the authors believe that the lumping nature, stationarity and linearity problems of the rating curve could be avoided by replacing it by distributed and process based sediment yield models. This category of models has particular advantages for the study of basin change impacts and applications to basins with limited records (Bathurst, 2002). Their parameters have a physical meaning and can be measured in the field and therefore model validation can be concluded on the basis of a short field survey and a short time series of meteorological and hydrological data (Bathurst, 2002).

The sediment yield model that is used in this study is the Soil and Water Assessment Tool (SWAT). The SWAT model was originally developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large ungauged basins (Arnold *et al*., 1995). SWAT model has a long time modelling experience since it incorporates features of several (ARS) models (Neitsch *et al*., 2005). Erosion and sediment yield are estimated for each Hydrologic Response Unit (HRU) with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). The runoff component of the SWAT model supplies estimates of runoff volume and peak runoff rate, which, with the subbasin 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 above ground biomass, residue on the soil surface, and the minimum *C* factor for the plant. Other factors of the erosion equation are evaluated as described by Neitsch *et al*. (2005). The current version of SWAT model uses simplified stream power equation of Bagnold's (1977) to route sediment in the channel. The maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity. Sediment transport in the channel network is a function of two processes, degradation and aggradations (i.e. deposition), operating simultaneously in the reach (Neitsch *et al*., 2005).

SWAT model includes an automated calibration procedure that was implemented by Van Griensven of Belgium (Van Griensven & Srinivasan, 2005). The calibration procedure is based on the Shuffled Complex Evolution-University of Arizona algorithm (SCE-UA) as proposed by Duan *et al*., (1992). Autocalibration 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, Santos *et al*., 2003).

In addition to the capability of the model as discussed above, several workers as reported in Ndomba & Birhanu (2008) have satisfactorily applied SWAT model for sediment yield modeling in poorly gauged catchments in Tanzania and the region at large. In order to apply the model operationally, Ndomba *et al*. (2005) recommended SWAT model validation and/or customization in the tropical region. The previous applications pre-assumed sheet or inter-rill erosion as dominant erosion type. This paper reports on the application of SWAT model in a well-studied catchment, i.e. with intensive data on sediment flow in fluvial system and sediment accumulation information at the downstream reservoir, the Nyumba Ya Mungu (NYM). In this study, SWAT model application was guided by results of analysis of high temporal resolution of sediment flow data and hydro-meteorological data. Furthermore, the suitability of short-term sediment flow data for calibrating parameter intensive sediment yield models is investigated.

MATERIAL AND METHODS

In order to estimate sediment yield rates and identify sediment sources/processes from individual subbasin, as **Fig. 1** suggests, multi-sampling sites would have to be installed in each river tributary in the basin. Though the approach seems to be scientifically attractive, practically it is impossible to implement. A compromise lies then to apply physics-based distributed sediment yield or erosion model, the SWAT, guided by a sediment sampling programme and findings analysis.

The Study Area

The Pangani River Basin (PRB) is located between coordinates 36°20' E, 02°55' S and 39°02' E, 05°40' S in the North Eastern part of Tanzania and covers an area of about 42 200 km^2, with approximately 5% in Kenya (**Fig. 1**). The Pangani River has two main tributaries, the Kikuletwa (1DD1) and the Ruvu (1DC1) (**Fig. 1**), which join at NYM, a reservoir of some 140 km^2.

The study area is the NYM Reservoir catchment located in the upstream of PRB (**Fig. 1**). The main subcatchments in the study area are Weruweru, Kikafu, Sanya, Upper Kikuletwa and Mount Meru. The catchment of NYM occupies a total land and water area of about 12 000 km^2 (Ndomba, 2007). It is located between coordinates 36°20'00" E, 3°00'00" S and 38°00'00" E, 4°3'50" S. This area has a Mean Annual Rainfall (MAR) of about 1000 mm. The rainfall pattern is bimodal with two distinct rainy seasons, long rains from March to June and short rains from November to December (Rohr, 2003). Recent findings by Rohr and Killingtveit (2003) indicate that the maximum precipitation on the southern hillside of Mount Kilimanjaro takes place at about 2200 m.a.s.l., which is 400–500 m higher than assumed previously. The altitude in the study area ranges between 700 and 5825 m.a.s.l. with Mount Killimanjaro peak as the highest ground. Based on the Soil Atlas of Tanzania, the main soil type in the upper PRB is clay with good drainage (Hathout, 1983). Actively induced vegetation, forest, bushland and thickets with some alpine desert chiefly characterize the catchment land cover.

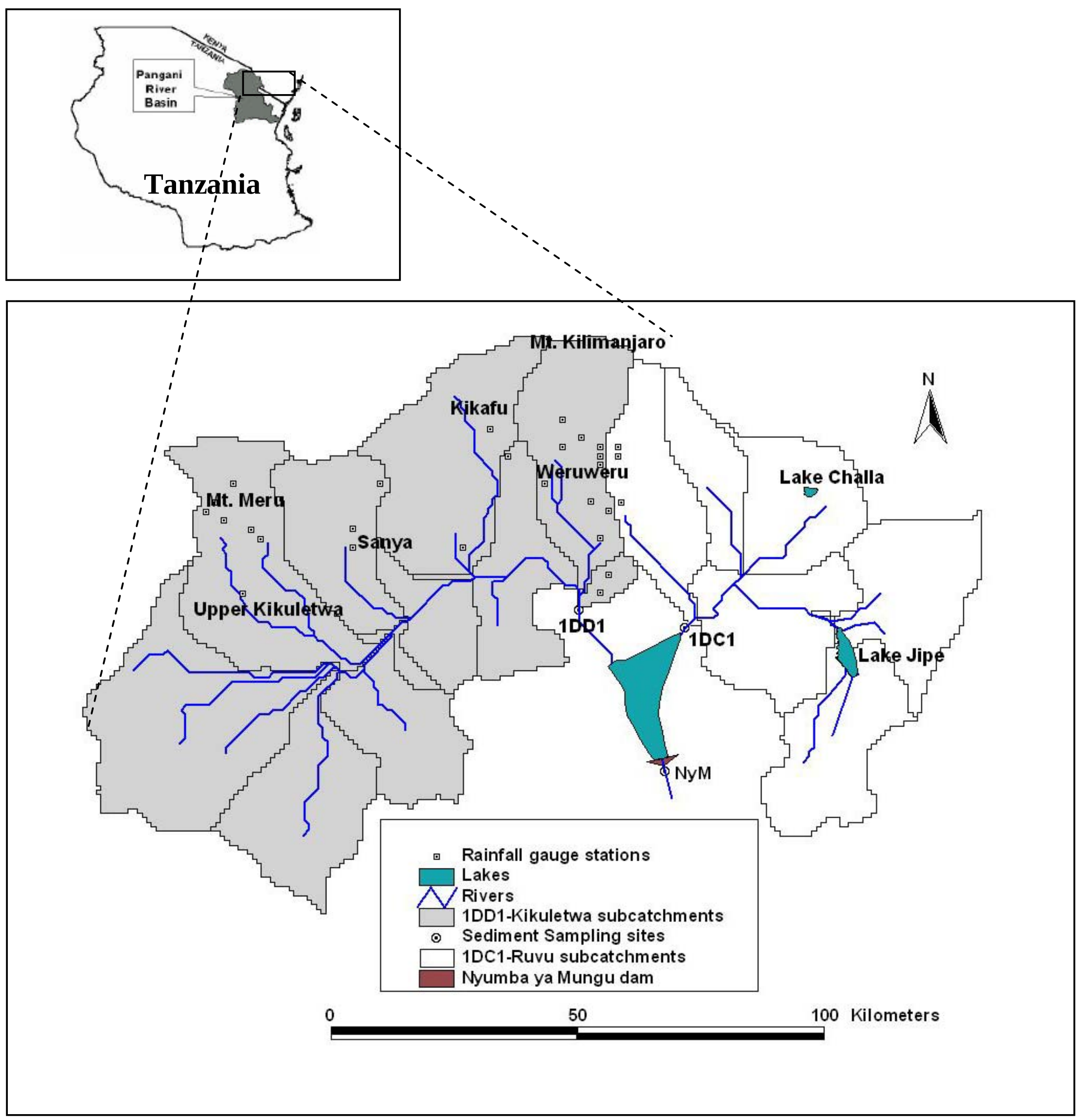

Fig. 1 A location map of Pangani River Basin (PRB), upstream of Nyumba Ya Mungu (NYM) dam.

The majority of the population in the basin depends on irrigated agriculture directly or indirectly. Agriculture is concentrated in the highlands, while the lowlands are better suited for pastoralism. The basin is also important for hydropower generation, which is connected to the national grid. Hydropower plants, which are downstream of NYM Reservoir are NYM (8 MW), Hale (21 MW), and New Pangani falls (66 MW).

Data and Data Analysis

Data collected and used include sediment flow, rainfall, river discharges, climate, topography, landuse, soil type and abstraction data. Topographic data was in a form of Digital Elevation Model (DEM) from a 1 km by 1 km resolution grid. Soil type was in digital map format as presented by De Pauw (1984). Soil Atlas map of Tanzania by Hathout (1983) complemented the lacking soils information. Landuse map in digital format was sourced from Institute of Resources Assessment (IRA) based at University of Dar es Salaam. Other data type was available from Water Resources Engineering Department (WRED) database at University of Dar Es Salaam, Ministry of Water and Pangani Basin Water Office (PBWO).

For the purpose of guiding and validating the SWAT model application, this study adopted different approaches to identify the sediment sources, erosion processes and sediment delivery dynamics. The known methods used in this study include analyses of single hydrological events as sampled from continuous sediment pumping sampler and water levels recording data logger; fingerprinting approach where organic matter contents and particle size distribution of the transported sediment by rivers or deposited in the downstream reservoirs give clues on the origin and processes of sediment in the catchment. This study used the technique of mapping of hydrological variables such as rainfall in spatial and temporal domain in relation to suspended sediment concentrations at the outlet of the catchment. An Automatic pumping sampler, ISCO 6712, was used to collect high frequently subdaily sediment samples (i.e. between 2 and 12 samples a day) at 1DD1 gauging station (**Table 1** and **Fig. 1**). It should be noted that a daily sample collected by Depth Integrating Sampler, D-74, complemented the data especially during the ISCO machine downtime. Accordingly, there was no missing data scenario. The details of data and data analysis can be found in Ndomba (2007) and Ndomba *et al.* (2007a,b). An excellent rating curve developed from data summarized in **Table 1** and used in this study is given in **Eq. (1)** below.

$$Q_s = 0.5713Q^{2.107} \quad (1)$$

where, Q_s is daily sediment load in (t/day) and Q is

Table 1. A summary of sediment flow data as sampled by ISCO 6712 machine at 1DD1 site (i.e. 291 data points)

Statistic	Sampling period	Suspended sediment concentration [mg/l]	Gauge Height [m]	Streamflow discharge (m^3/s)
Maximum	March 18, 2005–November 10, 2005	9110.0	4.44	256.53
Minimum		16.0	0.89	12.19
Mean		282.5	1.32	34.79
Standard Deviation, STD		801.7	0.49	30.02
Coefficient of Variation, Cv (%)		283.8	36.69	86.27
Standard Error of the Mean, SEM		47.0	0.03	1.76

The SWAT Model Application

A SWAT model was applied in a major runoff-sediment contributing subcatchment, 1DD1-Kikuletwa (**Fig.1**). This study could not set up SWAT model in 1DC1-Ruvu subcatchment because it is hydrologically complex and represents an outflow from a natural lake Jipe. The model building is difficult. Sediment flow data collected during sampling programme, March–November 2005 and March, 2005–January 2006 respectively at sites 1DD1 and 1DC1, were used to estimate sediment yields and relative proportion of sediment transport loads between them.

The study catchment, 1DD1, was redefined into five major sub-catchments (i.e. Weruweru, Kikafu, Sanya, Upper Kikuletwa, Mt. Meru) as indicated in **Fig. 1** with areas exceeding 1000 km². From the limitation of the catchment size, the use of 1 km × 1 km DEM was considered to provide comparable results to the use of 90 m × 90 m DEM. In order for the SWAT model to determine the area and hydrologic parameters of each land-soil category, landuse and soil maps were overlaid and the dominance of land use and soil definition were used to create the a dominant Hydrologic Response Unit (HRU) for each sub-catchment. The water abstraction information was distributed within the sub-catchment and entered into SWAT interface independently for river/reach and ground water/boreholes.

The runoff component of the SWAT model as calibrated and reported in Ndomba *et al.* (2008) was used for sediment yield modelling in the basin. Sensitivity analysis tools as implemented in SWAT order to identify important parameters that govern sediment yield and routing phases. It should be noted that both parameters ranking and results of data analysis guided the model calibration exercise. For example, the method of estimation of the most sensitive parameters was critically reviewed. Both manual and Autocalibration approaches were used to train the sensitive model parameters. Additionally, some parameters that affect peak runoff rate and indirectly sediment yield and transport were calibrated. It should be noted here that all the channel sediment routing parameters were calibrated. A proposed equation for soil erodibility for tropical conditions by Mulengera (1999) was used to estimate soil erodibility factor (K_USLE).

It should be noted here that a period between year 2005 and 2006, during sediment sampling programme, was not used for model calibration because the catchment experienced a drought. Alternatively, a sediment rating curve had to be developed, verified and used to generate/extrapolate sediment loads to other periods as reported by Ndomba (2007) for calibration and validation purposes. Therefore, the model was calibrated for one hydrological year between November 1, 1977 and October 31, 1978. The period falls within a normal wet year. In this study, a wet year is defined as that year with total annual rainfall near or above the long-term mean annual rainfall. And the simulation of calibrated model was validated to long-term period (i.e. between January 1, 1969 and December 31, 2005) sediment accumulation in the downstream reservoir. This period corresponds to the age of the reservoir. Besides, the modeling exercise the study included estimating spatial erosion rates.

RESULTS AND DISCUSSIONS

Seven out of nine analyzed SWAT parameters that directly govern the sediment yield and transport in the watershed were found to be sensitive (**Table 2)**. It should be noted that rank 10 signifies that a parameter is not sensitive/important. These parameters can be categorized into two groups that are upland and channel factors. The former group includes parameters such as P_USLE, C_USLE, K_USLE, BIOMIX, and RSDIN; whereas Csp, CCH, KCH and spexp parameters belong to the latter group. **Table 2** indicates that all channel factors are sensitive while two upland parameters (soil erodibility and initial residue cover) are not sensitive and therefore not important. These rankings are not surprising to the author because, the analysis of sediment flow data from ongoing intensive continuous sediment sampling programme indicates that sediment loads though low in magnitudes are sustained even during the dry days. This suggests that in-channel sources and processes are also taking place as well as demonstrated by higher rankings in channel factors in Ndomba, 2002) have indicated agricultural areas in the foot slopes of Mount Kilimanjaro and Meru are the main sources of sediments.

Therefore, the higher importance attached to both soil conservation practice (USLE support practice) and cropping managing (minimum USLE cover) factors was expected. As defined by Neitsch, *et al*., (2005), biological mixing is the redistribution of soil constituents as a result of the activity of earthworms and other soil biota. The activities of such organisms may affect soil structure through mixing soil horizons and organic matter and increasing porosity. This directly determines vulnerability to soil erosion. The importance of this parameter was also revealed in simulation exercise of the runoff component of SWAT for the same case study as reported in Ndomba *et al*. (2008). Using the fingerprint techniques as reported in Ndomba *et al*. (2007b), for instance, it was learned that sediment sources are zones of maximum biological activity - the topsoil (i.e. A-horizon) or plow layer.

Calibration results in daily and monthly time steps are presented in **Fig. 2** through **Fig. 4**. In **Fig. 2** one will note that the rising and falling limbs of a large flood event are reasonably simulated. A few sporadic sediment spikes are also evident. The streamflow and sediment transport in the study area are characterized as highly variable within a day (Ndomba, 2007; Ndomba *et al*., 2007b). It should be noted that the mean streamflows used to compute observed sediment loads are derived from two to three manual gauge height measurements during day time while the SWAT model computes mean stream flow for each day. Sediment loads in the recession limb of the medium flood events such as that of December, 1978 are over-predicted.

Based on field observations, analyses of characteristics of single hydrological events and literatures, the authors believe that the storage for fine-grained sediment in the main tributary river

Table 2. Sensitivity analysis results of sediment component of SWAT for 1DD1 catchment

SN	Parameter	Description of parameter	Rank
1.	Csp	Linear re-entrainment parameter for channel sediment routing	1
2.	CCH	Channel cover factor	2
3.	P_USLE	USLE support practice factor	3
4.	KCH	Channel erodibility factor (cm/h Pa)	4
5.	spexp	Exponential re-entrainment parameter for channel sediment routing	5
6.	C_USLE	Minimum USLE cover factor	6
7.	BIOMIX	Biological mixing efficiency	7
8.	K_USLE	USLE soil erodibility factor (t ha h./(ha MJ mm)	10
9.	RSDIN	Initial residue cover (kg/ha)	10

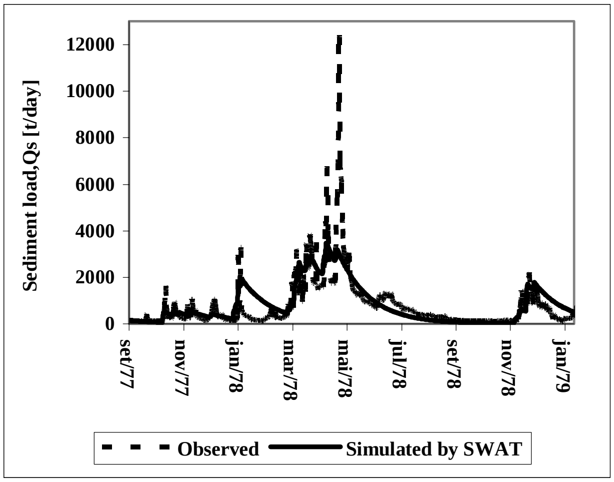

Fig. 2 A comparison between observed and simulated daily sediment loads at 1DD1 sampling site during calibration period. Note: CE = 56% and TMC = 0.9%.

channels is not much (Ndomba *et al.*, 2007b). Therefore, model deficiency here may be a better explanation.

Besides, other workers have successfully used this model at monthly time steps (Schmidt & Volk, 2005; Van Liew *et al.*, 2005). The result from this study at monthly time step is also sound as demonstrated in **Figs 3** & **4**. However, the deficiency of the model to simulate the sediment load in the falling limb for the medium floods as noted above is also reflected in monthly time step in the same periods (**Fig. 3**). However, the performance of the model in simulating monthly total sediment loads is excellent (*CE* = 86%) as **Fig. 4** illustrates. This result suggests that as time step of simulation increases the SWAT model performance improves and therefore, its application for long-term simulation using annual time step is also justified. It should be noted also that the size of the smallest subbasin or Hydrological Response Unit (HRU) used for this study is greater than 1000 km^2 (**Table 3**). As Schmidt & Volk (2005) indicated in their study in Germany that the SWAT model efficiency increases with the size of the catchments with a break point at a basin area size of approximately 300 to 500 km². This is compounded by the insufficient capability of SWAT to simulate the process dynamics in small catchments. However, Schmidt and Volk recommended the use of the highest scale-adequate input data resolution available for predicting high-resolution dynamics and process quantification. It should be noted that studies by Mulungu & Munishi (2007) and critical review of model applications in Nilotic catchments by Ndomba & Birhanu (2008) have shown that high resolution of spatial data does not necessarily improve the model performance.

Table 3. Comparison of catchment sediment rates based SWAT model simulations and reservoir survey

Method	Sediment yield rate (t/year)
SWAT model prediction and sampling programme	430 000
Reservoir survey and sampling programme	419 000
Absolute error	11 000
Relative error in percent = 2.6%	

Long-term simulation result in **Fig. 5** above generally indicates that estimated and observed (i.e. based on suspended sediment rating) annual total sediment loads are comparable. However, according to Total Mass balance controller (TMC) as objective function the simulated loads overestimate the observed by 28.7 percent. Similarly, the authors would like to note that such a discrepancy was expected because the SWAT model simulates bed-material load (i.e. bed and suspended load) while the rating curve computes only

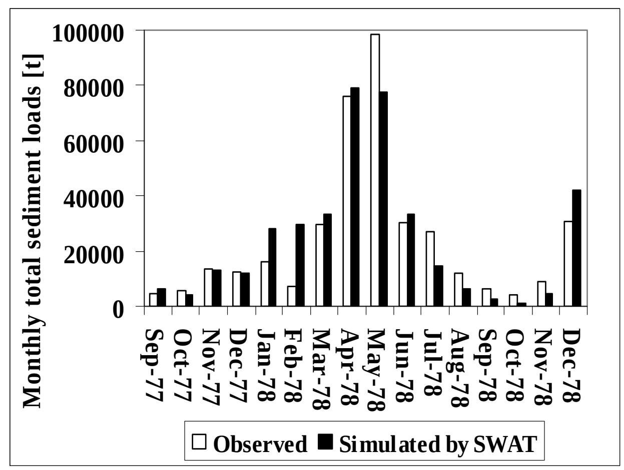

Fig. 3 A comparison between observed and simulated monthly total sediment loads at 1DD1 sampling station during calibration period (TMC = 0.9%).

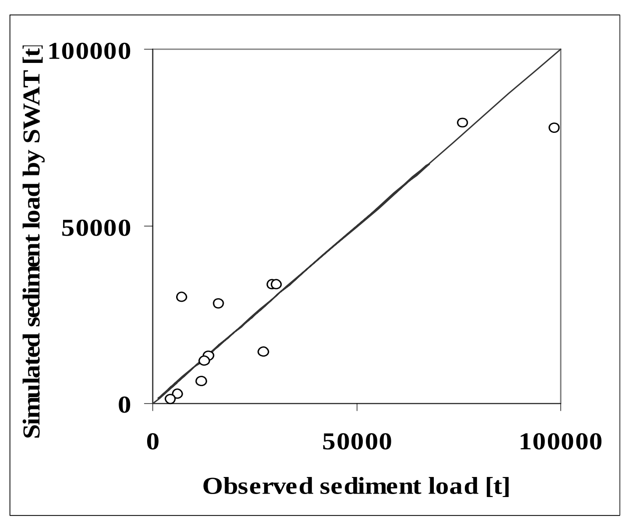

Fig. 4 Scatter diagram of total monthly sediment loads for calibration period between November 1, 1977 and October 31, 1978 (CE = 86%).

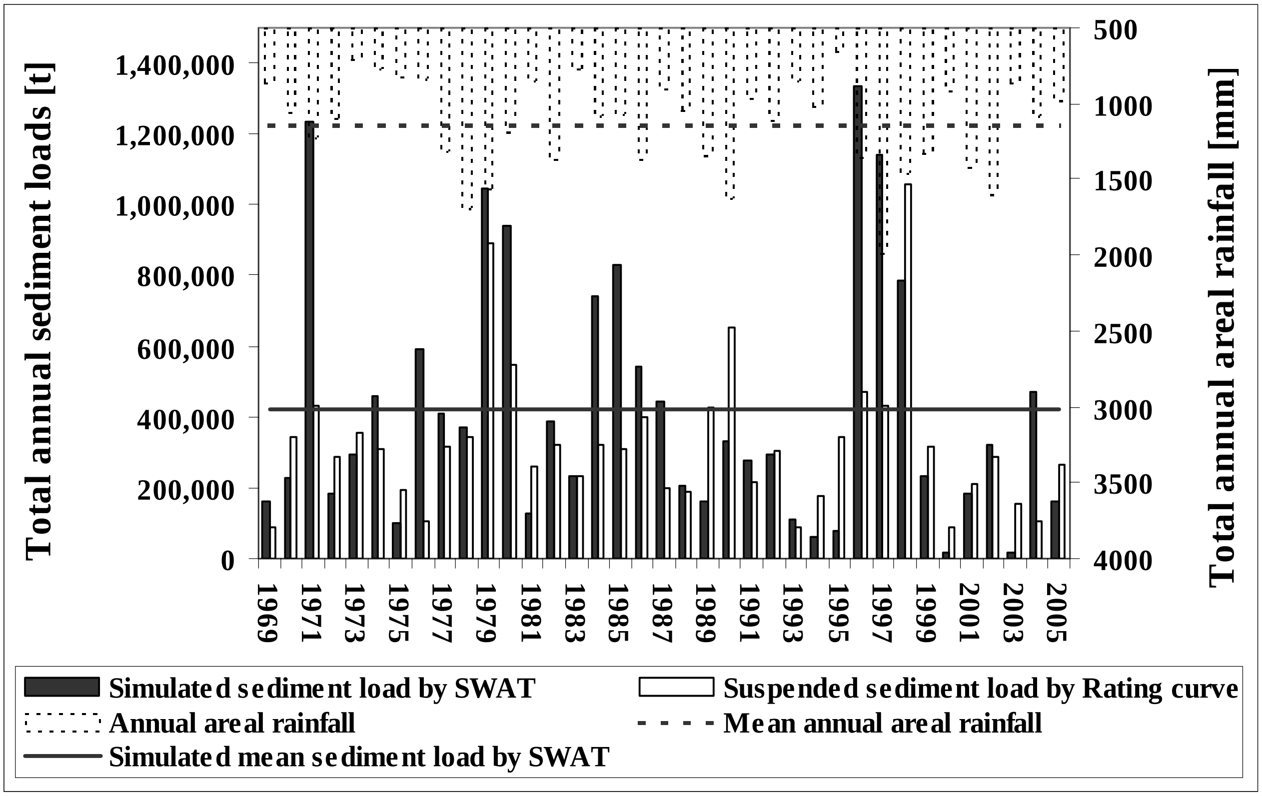

Fig. 5 Comparison between simulated (i.e. by SWAT) and observed (i.e based on suspended sediment rating) total annual loads between 1969 and 2005 (TMC=28.7%).

suspended sediment load. It should be noted here that the rating curve was used by Ndomba (2007) to estimate the long-term sedimentation rate in the Nyumba Ya Mungu reservoir and gave reasonably good results with relative error of 20.3 percent. With the exception of a few cases, **Fig. 5** above indicates that wet years seem to transport more of the sediment loads. One would note also that problems of linearity as assumed in the rating curve concept are well demonstrated between 1979 and 1999 period, where sediment loads increase with rainfall and vice versa. On the other hand, SWAT model results suggest that not all rainfalls yield the same rates of sediment. The latter observations are supported by results of field data analysis (Ndomba *et al*., 2007b). The inter-annual variability of sediment loads as depicted in **Fig. 5** suggest that sediment sources from upland catchments are not exhausted. This is explained by the fact that fine-grained soils on the mountain slopes as the case for Pangani River Basin are always available for transportation (Ndomba *et al*., 2007b). Ndomba *et al.* (2007b) attributed seasonal sediment concentration exhaustion in the study area, among others, to the high clay content in the source upland soils.

The long term (i.e. 37 years) simulation by SWAT model was used to estimate total sediment yield and long term sediment yield rate for 1DD1-Kikuletwa catchment. The long term predicted total sediment yield

SWAT model is 15.50 Mt and 0.419 Mt/year (i.e. 419 000 t/year), respectively. A 2.6% of 1DD1-Kikuletwa catchment sediment yield/rate as simulated by SWAT model derived sediment fluxes for 1DC1-Ruvu catchment. Therefore, long term sediment yield and sediment yield rate for 1DC1-Ruvu are 0.40 Mt and 10 890 or 11 000 t/year, respectively. Total sediment yield for NYM reservoir catchment (i.e. 15.90 Mt) was derived by summing up long term sediment yield from 1DD1-Kikuletwa and 1DC1-Ruvu catchments. Therefore, the predicted long term NYM reservoir catchment sediment yield rate (i.e. 15.90 Mt/37 years) is 0.430 Mt/year or 430 000 t/year.

It has been established in the sampling programme that 7939 t/year (about 8000 t/year) of sediment load is released from the reservoir annually (Ndomba, 2007). Actual sedimentation rate based on reservoir survey is 411 000 t/year. Therefore, the long term actual catchment sediment yield rate is 419 000 t/year (**Table 3**). The comparison is based on relative error in percent performance criterion (**Table 3**). A relative error in percent (i.e. 2.6%) is computed as the ratio of absolute error (11 000 t/year) to actual sediment yield rate based on reservoir survey and sampling programme (419 000 t/year) (**Table 3**).

Based on the relative error of estimate of 2.6 percent as presented in the last row of **Table 3**, one would note that the SWAT model has predicted the actual sediment according to TMC criterion, this approach overestimates the actual sediment yield rate by 2.6 percent. The accuracy achieved by using SWAT model was expected because one of the underlying hypotheses in this study stipulates that correct estimation of surface runoff will lead to better prediction of sediment yield. As demonstrated and reported in Ndomba *et al*. (2008) such hypothesis was met. Other workers such as Garde & Ranga Raju (2000) are of similar opinion.

In this study, erosion processes and sediment sources areas were also explored. In **Table 4** below five major representative subbasins as depicted in **Fig. 1** with their long-term simulated annual averages of sediment yields (SYLD_MUSLE), and surface runoff (SURQ) are presented. Two main observations can be made on those catchments that experience high sediment yields. Firstly, the dominant landuse is agriculture and secondly, the subbasins are located in the slopes of Mount Kilimanjaro (Weruweru and Kikafu) and Mount Meru. On the other hand, low sediment supply subbasins (Upper Kikuletwa and Sanya) are located in rangeland and/or low-lying terrain. It should be noted from **Table 4** that not all subbasins yield high sediment load. Probably, this can be explained by the fact that surface runoff generation from these subcatchments is low as shown in the last column of **Table 4**. Ndomba *et al*. (2007b) suggest that sediment sources are those areas where both agriculture and pastoralism are practiced.

One would also note from **Table 4** that high sediment yields are occurring in headwater regions of Pangani River Basin (i.e. Weruweru, Kikafu and Mt. Meru). Independently, from data analysis, Ndomba *et al*. (2007b) have found out that sediment sources are located in runoff generating regions of the basin, the Mountains Meru and Kilimanjaro foot slopes. Besides, based on literature the latter result is well supported.

For instance, Wasson (2002) noted that the headwater regions yield almost all of the sediment transported downstream, and channels and slopes in downstream areas contribute very little. Although the result of this study is encouraging, the stationarity assumption as the case for rating curve has not been well addressed. Only, a static landuse map developed in late 1990's has been used for the entire period of 37 years. Nevertheless, a good result obtained from this study would probably, suggest that landuse from main sediment sources areas have not significantly changed. Field observations in the foot slopes of the Mountains by the authors indicate that agricultural practice in this area has hardly changed.

Table 4. Long-term simulated average spatial sediment yields (SYLD_MUSLE) and surface runoff (SURQ) by SWAT model

Subbasin (HRU)	Area (km^2)	Sediment yield (SYLD_MUSLE) (t/ha)	Land/use	Surface runoff (SURQ) (mm)
Weruweru	1361	1.21	Agriculture	83.6
Kikafu	1082	0.95	Agriculture	74.5
Mt. Meru	1079	0.83	Agriculture	44.4
Sanya	1039	0.26	Agriculture	20.6
Upper	2674	0.08	Rangeland	12.2

Besides, the authors are aware of a number of disadvantages of physically based and distributed models. They include heavy computer requirements, the need to evaluate many parameters (i.e. uncertainty) and a complexity, which implies a lengthy training period for new users (Bathurst, 2002). As reported by Ndomba *et al*. (2008), parameters identifiability and evaluation exercise for the runoff component of the SWAT model were limited to six years of daily streamflows data because of a huge computational resource requirement. Eight wet years of calibration data as recommended by Yapo *et al*. (1996) resulted in longer computer simulation time. Thus, some of a few insensitive parameters have been assumed spatially uniform in order to achieve a practical computation time. In this study the issue of parameter uncertainty has not been dealt with as attempted by others (Beven & Binley, 1992). Alternatively, the suspended sediment loads as computed from rating curve and the long term reservoir sediment accumulation information are used as lower and upper bounds of the model outputs. It should be noted that SWAT model has overestimated the actual sediment yield rate by 2.6%. Probably, some sediment loads are deposited in the main tributaries and river channels upstream of the NYM reservoir. Therefore, a comprehensive sediment transport channel network model is recommended to account for the discrepancy.

CONCLUSION

A semi-distributed, physically-based distributed watershed model (SWAT) has reasonably simulated sediment yield, and has replicated the erosion processes and sources in the Pangani River Basin using a normal wet one hydrological year daily sediment loads. The SWAT model captured 56% of the variance of the observed daily sediment loads during calibration. The application of the model in longer period (i.e. 37 years) has predicted well the reservoir sediment accumulation with a relative error of estimate of 2.6 percent. Such estimation accuracy can be attributed to both sound sediment sampling programme design, well calibrated components of SWAT model and the instituted guidance of SWAT model application using results of field data analysis. The results also suggest that for catchments where sheet erosion is dominant, SWAT model is a better substitute of the sediment-rating curve and long-term sediment yield rate prediction can be done with reasonable accuracy. It should be noted that when most of hydrometeorological data required for SWAT model application is available.

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