Sediment Yield Modelling Using SWAT model at Larger and Complex Catchment: Issues and Approaches.

A Case of Pangani River Catchment, Tanzania

by

P.M. Ndomba[1*], F.W. Mtalo[1], and A. Killingtveit[2]

[1]University of Dar es Salaam, Tanzania and [2]Norwegian University of Science and Technology, Norway.

Email: pmndomba@ucc.ac.tz or pmndomba2002@yahoo.co.uk*

OUTLINE

- Introduction
- Description of the study area
- Methodology
  - Modelling Issues
  - Modelling Approach and Assumptions: The conceptual framework
  - Primary data collection technology, analysis,and approach
- Results and Discussions
- Conclusions and Recommendations

INTRODUCTION

- SWAT model is a semi-distributed, physics based watershed model
- The model is now being applied/customized in Tanzania
- The succeful stories on SWAT applications motivated the study
- Unfortunately, the model is developed from maltitudes of parameters, hence complex. It is also data intensive
- Modelling uncertainty is high if not applied with caution.
- Unfortunately, SWAT model applications techniques have NOT been adequately documented.
- Little has been done by other workers to COMPARE SWATsimulations performance with data from intensive sediment sampling programme
- Therefore, this study used SWAT model in larger and complex catchment in order to estimate sediment yield and document application techniques and give insights to possible model customization opportunities

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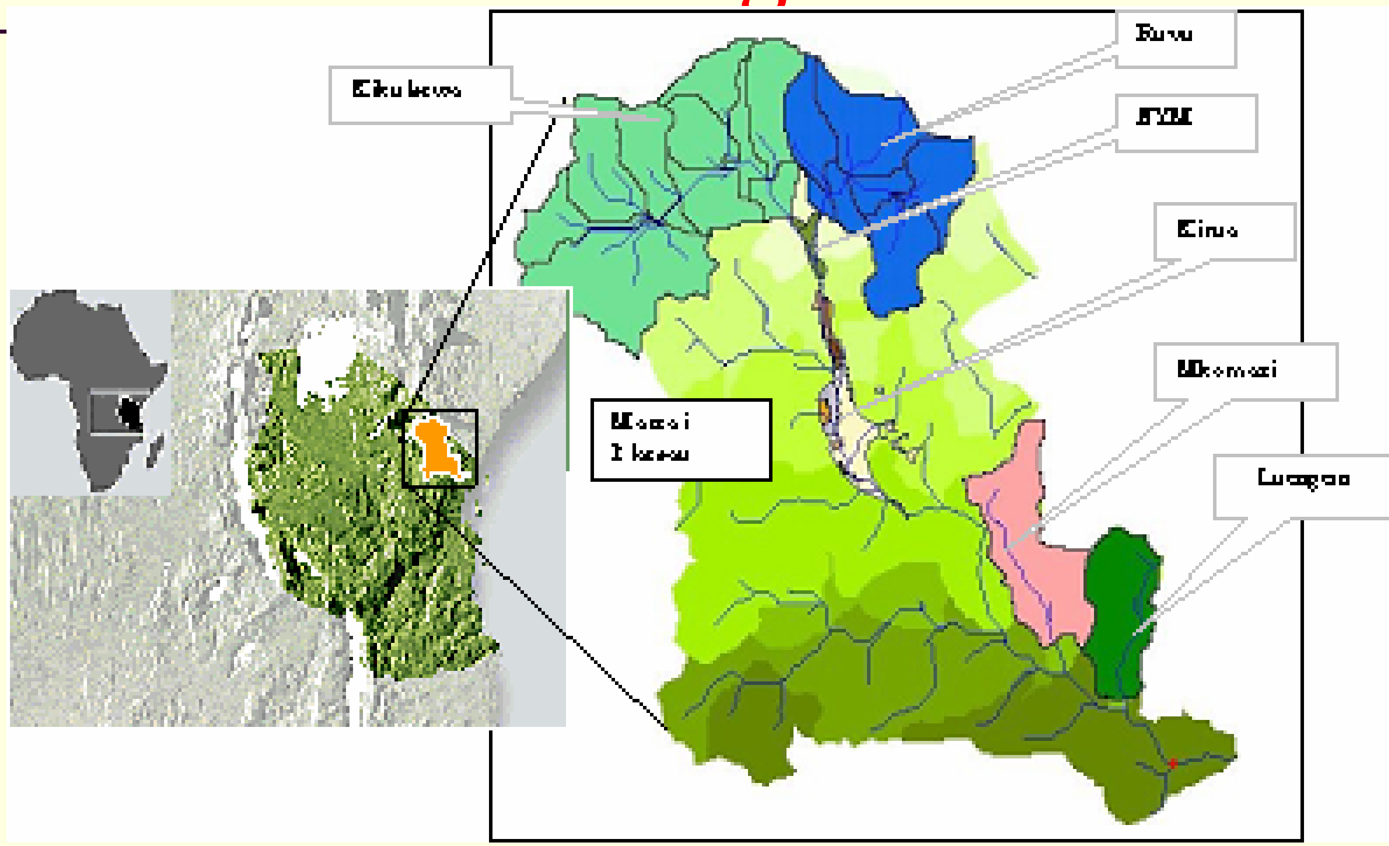
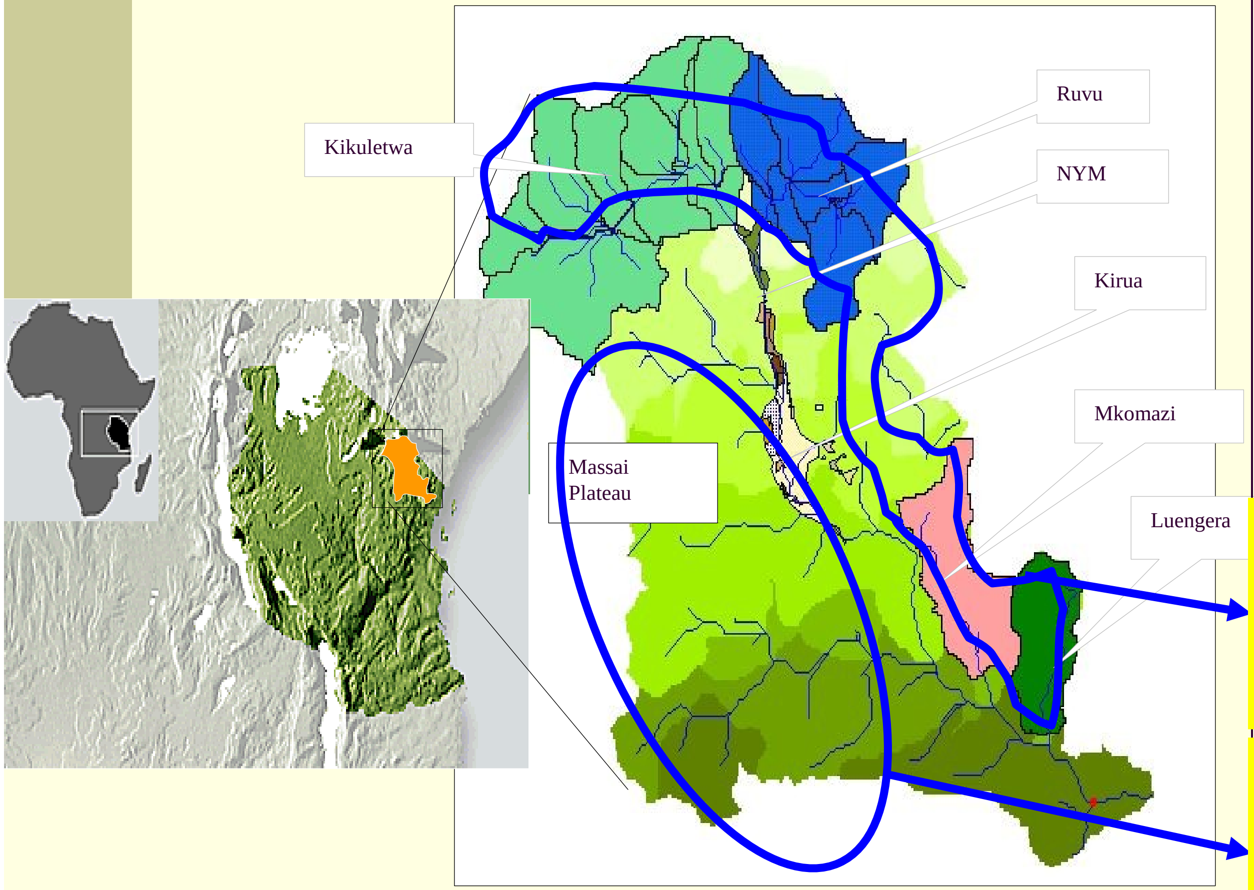
DESCRIPTION OF THE STUDY AREA:The Pangani River Basin



Location: North eastern Tanzania, **Size** 43,650 sq. km
Population: 3.4 Million 1998
Economy: Coffee, flower, power generation, Sugar, Tea, Tourism, Sisal
Elevation: From sea level, Indian ocean to over 5000 masl on Kilimanjaro

Source WREP(2003)

DESCRIPTION OF THE STUDY AREA: Major Hydrological Regimes



Major Hydrological Regimes

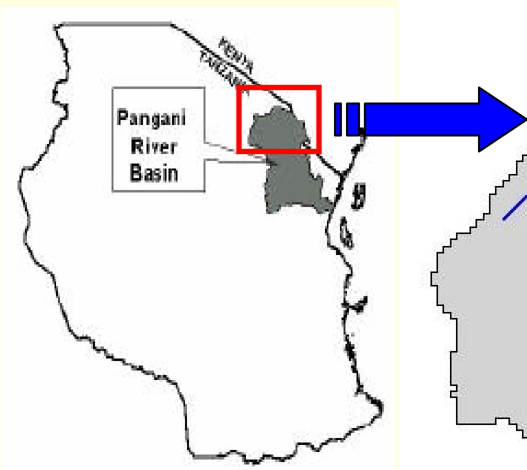
- 4 major Catchments
- NYM reservoir
- Kirua Swamp
- Channel regime

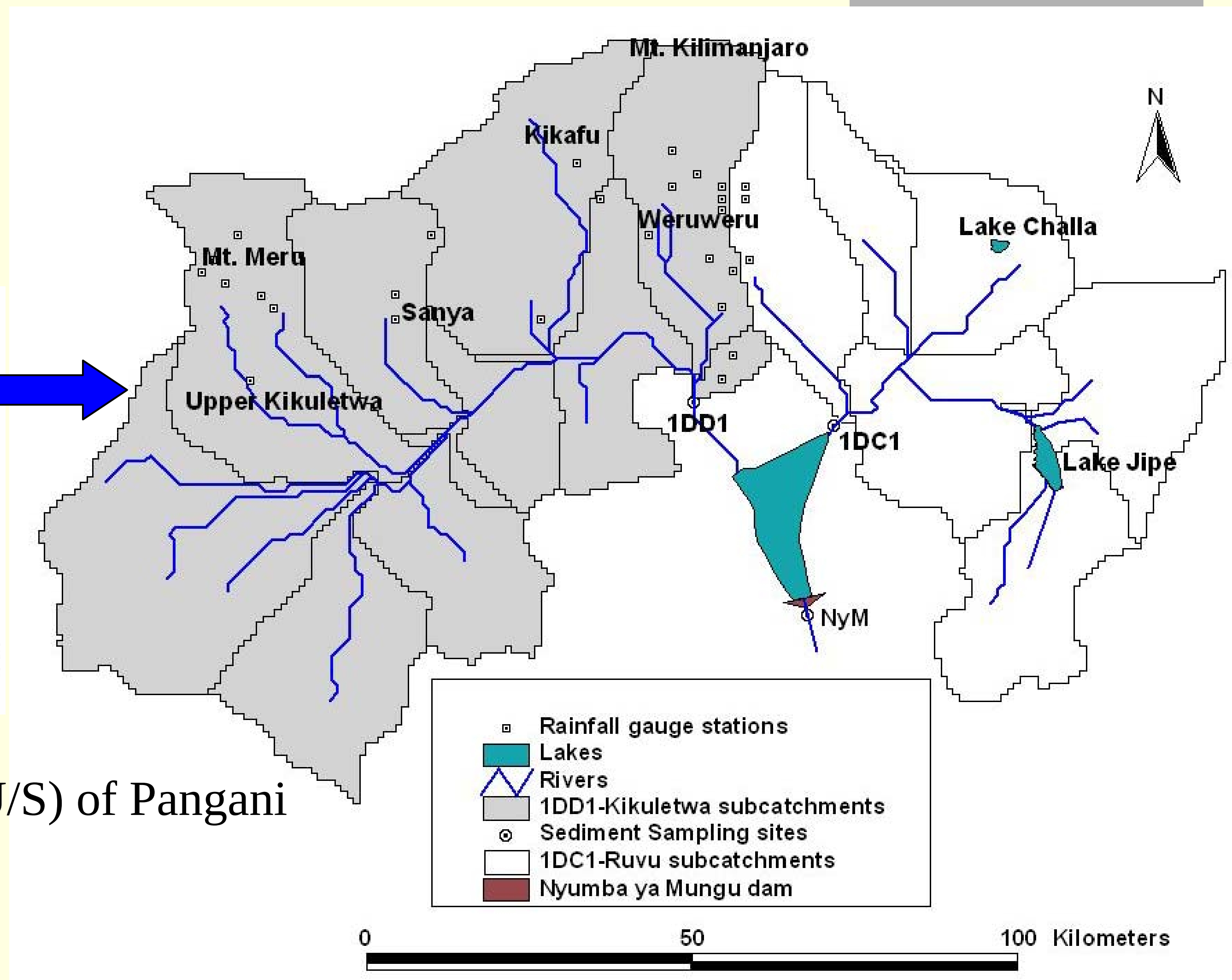
Hydrological conditions

Eastern half Humid to Semi-arid & mountainous (RF>1000)

Western half is flat, dry & little flow Contribution (RF < 500mm)

DESCRIPTION OF THE STUDY AREA: U/S of Pangani River Basin



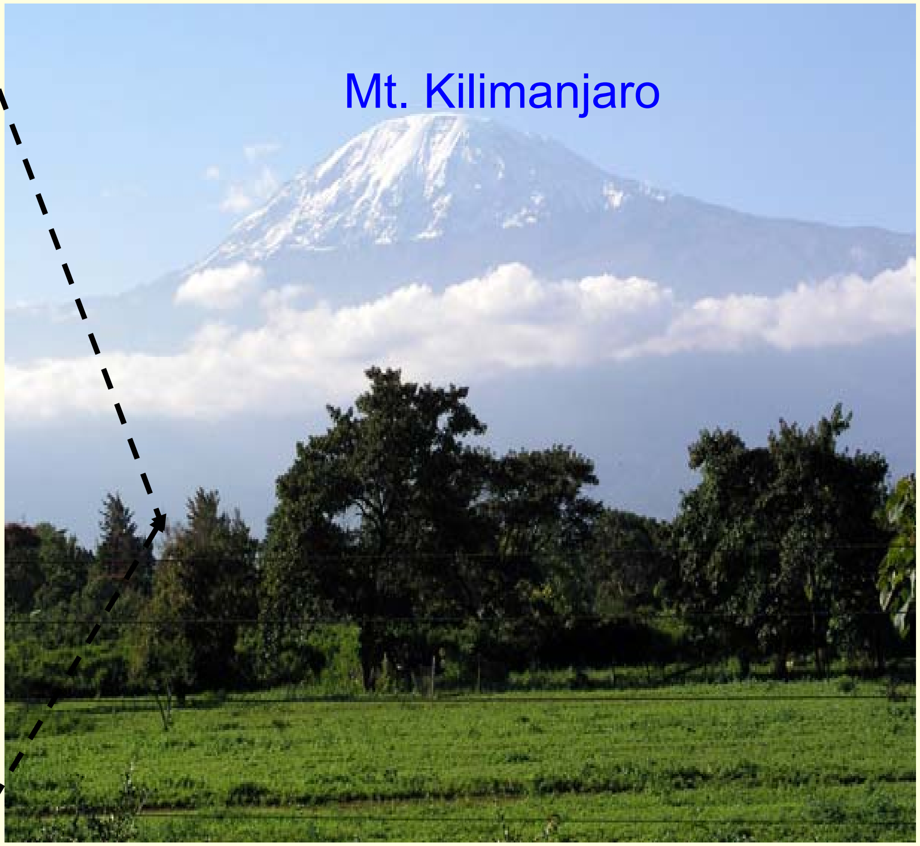


Location: Upstream (U/S) of Pangani Basin,

Size 9,000 sq. km

Source Ndomba(2007)

DESCRIPTION OF THE STUDY AREA: U/S of Pangani River Basin



Sediment-laden Rivers in the foot-slopes of Mt. Kilimanjaro.
Source: Ndomba(2005)

Typical Landcover/Landuse; topography: mountains and plains.
Source: Ndomba(2005)

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METHODOLOGY

Modelling Issues

- Scarce data characterizes Pangani River basin:
  - Nearly half of the catchment is poorly gauged
  - Declining number of regular hydro-meteorological monitoring stations
  - Unrepresentative historical sediment flow data: few spot measurements
- Complex catchment:
  - Large swamps, Lakes, and plains
  - Highest mountain in Africa (Kilimanjaro), and Mixed landuse
- Dominant erosion, sediment delivery and sedimentation processes in the catchment are not known
- No compelling models/tools: available models/tools have not been well tested in the Basin and rating curves are known to underestimate sediment loads
- Lack of resources
  - Fieldwork: calibration and verification data
  - Computational facilities
  - Expertise

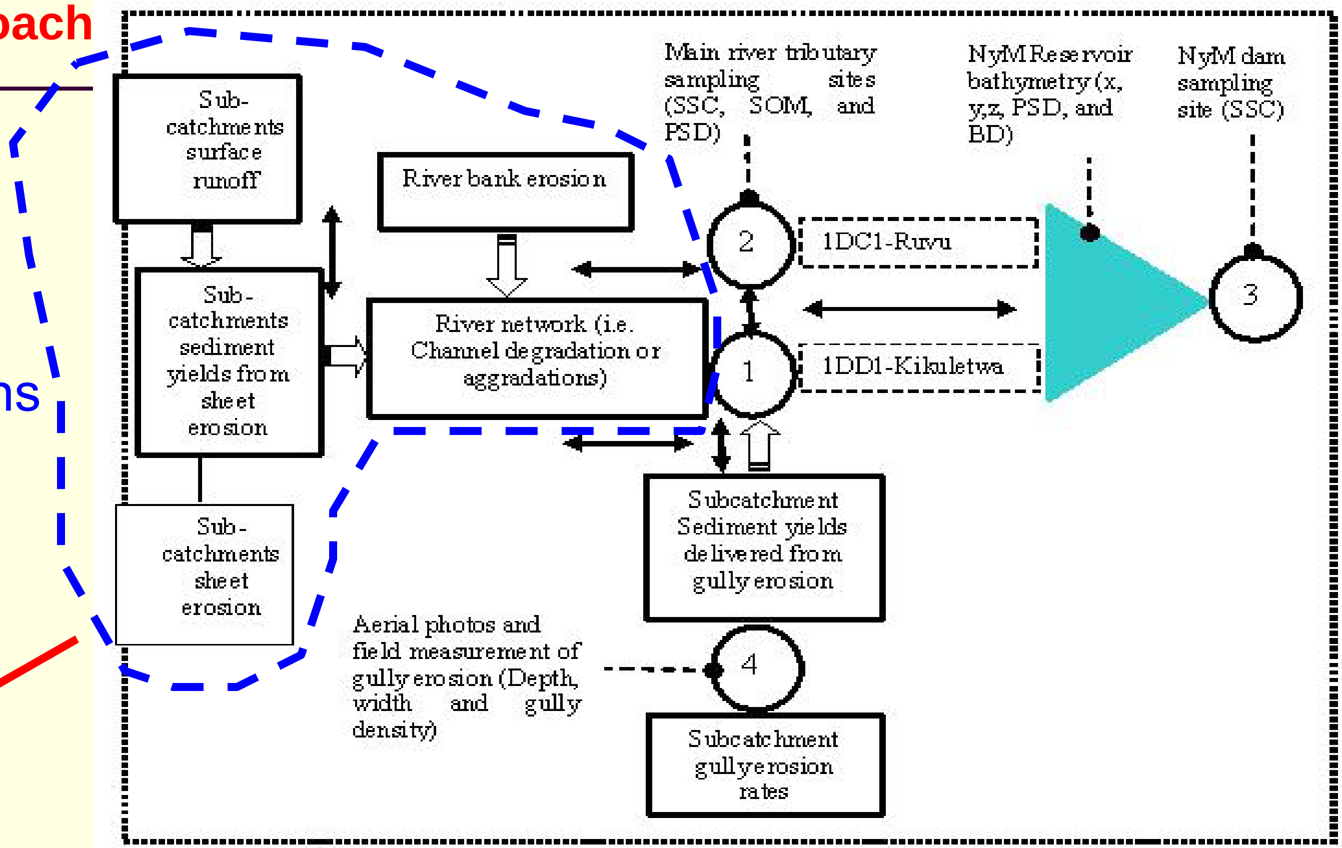
METHODOLOGY

Modelling Approach

The conceptual framework:

Problem schematization and Assumptions

SWAT componets



LEGEND

Symbol	Descriptions	Symbol	Descriptions
	A major modelling component		Nyumba ya Mungu reservoir (NyM)
	A minor modelling component		A feedback loop pointer
	Sampling or measurement site and main feedback loop node		A strong link between modelling components
	A weak link between modelling components		A river reach between sampling sites and inlet of NyM reservoir

METHODOLOGY (Contd.)

Modelling approach and assumptions

- Calibrating SWAT runoff component using historical hydrometeorogical data
- Intensive fluvial system sediment sampling programme (alround hydrological year) and Reservoir survey
- Sediment loads data extrapolation by Rating curve
- Identifying erosion processes and location based sediment sources using field data alone
- SWAT sediment yield component calibrating at test catchment (i.e. 1DD1) using extrapolated loads by sediment rating curve. The period falls under normal wet hydrological year
- Model application and verification using NyM reservoir survey information and identified sediment sources/erosion processes

METHODOLOGY (contd.)

Fluvial sediment sampling using Automatic pumping sampler at main runoff/sediment contributing river tributary:

1DD1 test catchment at Node 1

Source:Ndomba(2007)

Equipment and methods used to collect high frequency (sub-daily) suspended sediment samples at 1DD1-Kikuletwa station (i.e. Node 1).

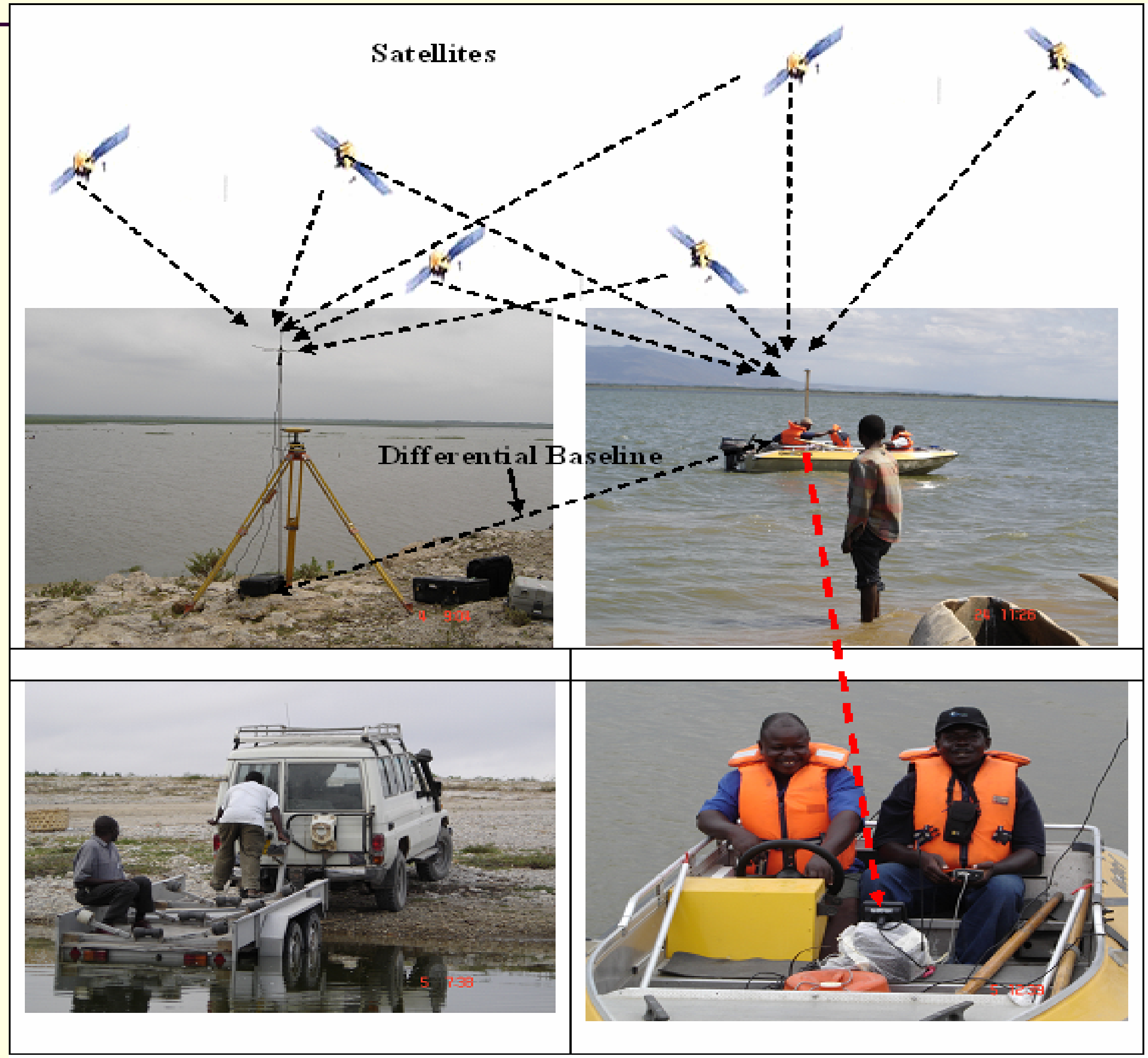
METHODOLOGY (contd.)

Reservoir survey by DGPS and Digital echo sounder:

Verification data collection technology

High technology: improves precision and accuracy of measurements/computed accumulated sediment volume in NyM reservoir

Source:Ndomba (2007)



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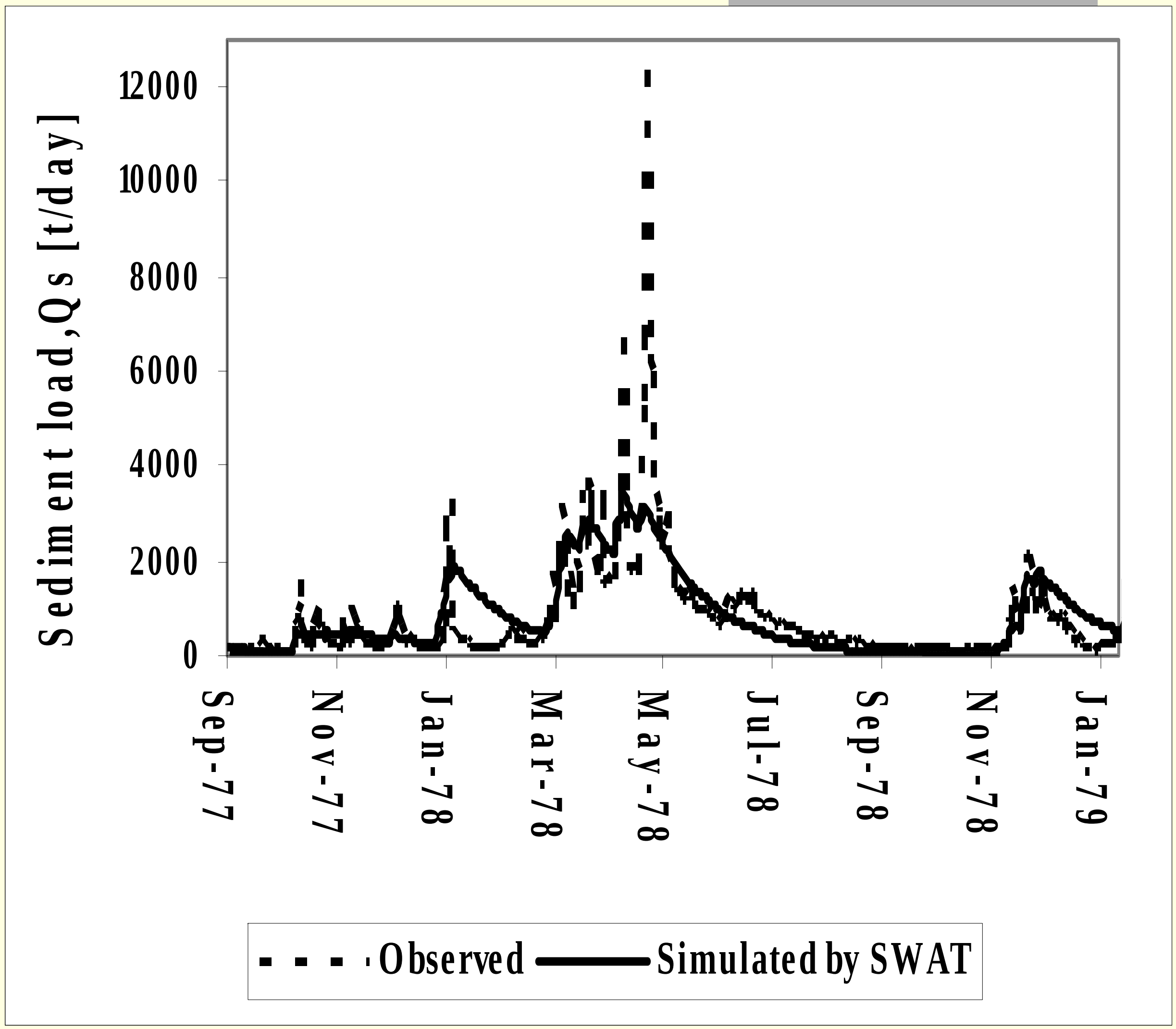
RESULTS AND DISCUSSIONS

Calibration at 1DD1 (Daily) done during normal wet year

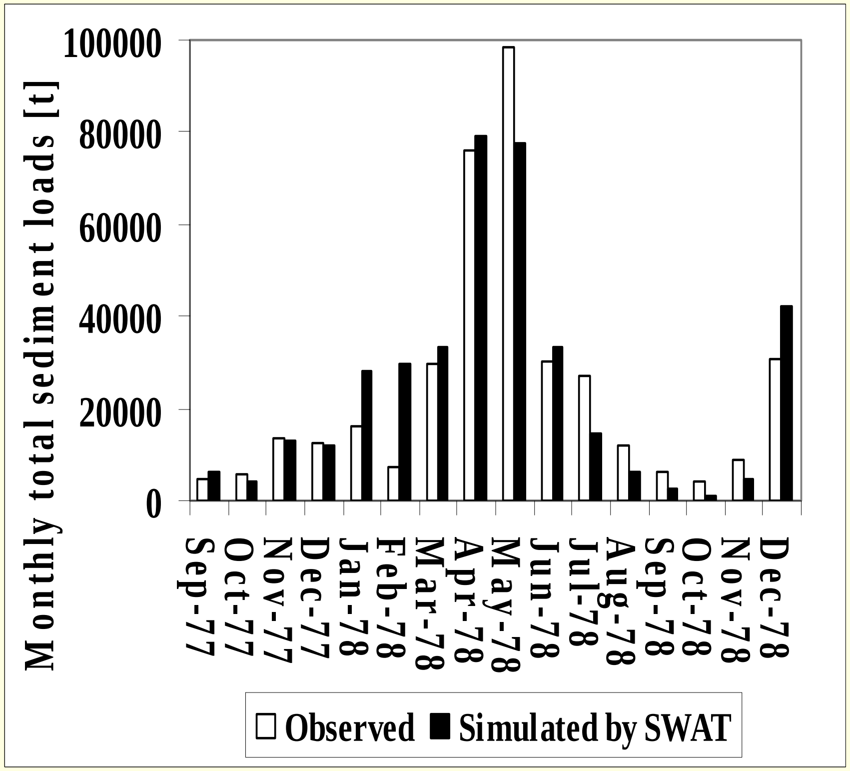
- A test catchment, 1DD1(R^2=56% and TMC=0.9%).
- Some Sediment load peaks are poorly simulated due to poor representation of daily mean flows as derived from low frequency flow measurements in a day
- Recessions during medium flow conditions such as those of December are poorly represented due to model deficiency

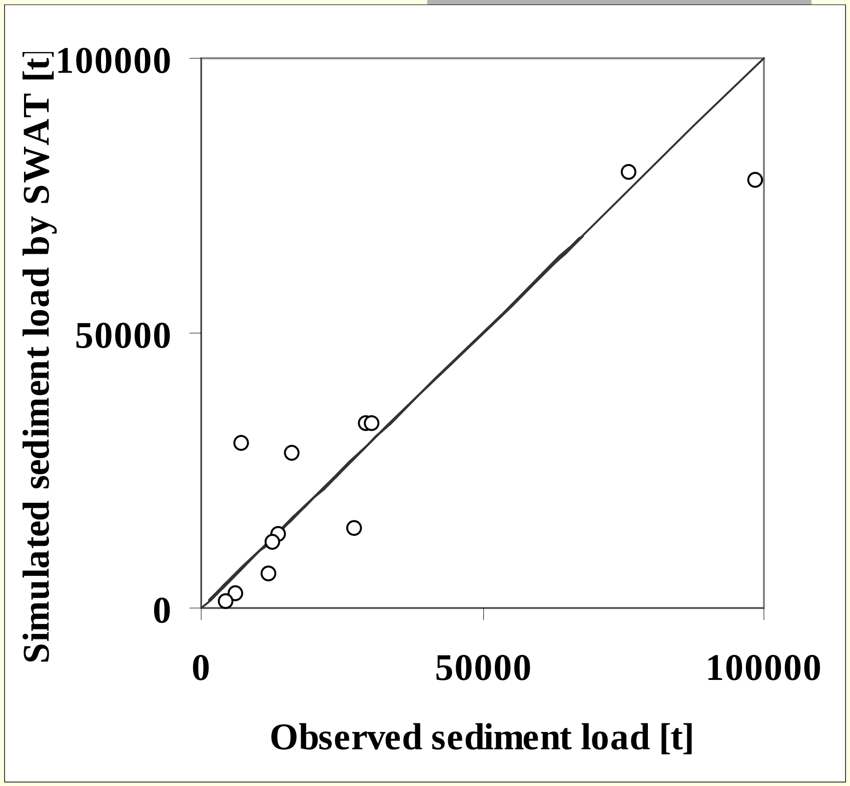


RESULTS AND DISCUSSIONS

Calibration at 1DD1 (Monthly)

- R^2=86%; TMC=0.9%
- The performnce improves with increase in time step

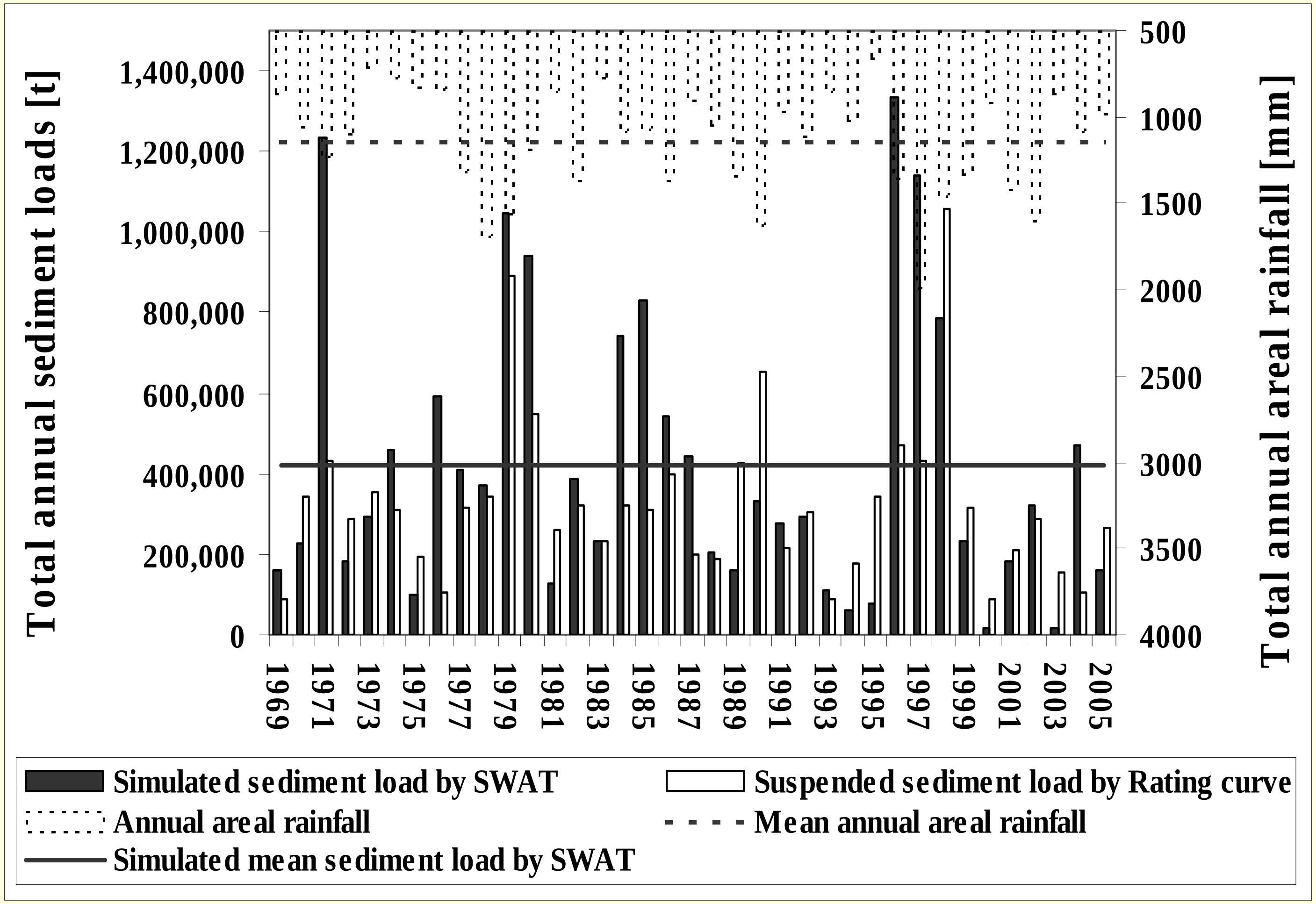




- Suggests that annual time step will further improve the performance in long term simulation at larger ctchment

RESULTS AND DISCUSSIONS

SWAT simulations Vs Rating curve-sediment loads at 1DD1 (Annually), **between January,1969 –December, 2005**



Performance (TMC=28.7%).

- Rating curve demonstrates linearity
- SWAT model demonstrates nonlinearity i.e. Not all rainfalls deliver sediment to outlet

RESULTS AND DISCUSSIONS

Estimating proportion of sediment yields between 1DD1 and 1DC1 sampling stations based on all-round hydrological year sampling programme of year 2005

Sampling station	Annual sediment yield for year 2005 [tonnes]	Proportion (1DC1/ 1DD1) [%]	Remarks
1DD1	266,611		Gauged (available historical streamflows data)
1DC1	6,970	**2.6**	Poorly gauged

Assumed!

- Major runoff/sediment river tributaries contributors to NyM reservoir
- River tributaries with the same stream order would dynamically/temporally respond in a similar manner

RESULTS AND DISCUSSIONS

Estimating long term total sediments inflows and outflow loads at NyM reservoir

Station/Parameter	Method	Sediment [Mt]
1DD1-Kikuletwa sediment yield	Corrected suspended sediment rating curve applied to historical streamflows of 37 years	12.10
1DC1-Ruvu sediment yield	As **2.6%** of 1DD1-Kikuletwa sediment yield (note: derivation method of the proportion of sediment yield contribution is based on sampling programme)	0.31
Total sediment yield (**inflow**)	Summation of 1DD1-Kikuletwa and 1DC1-Ruvu sediment yields	**12.41**
Sediment load released at NyM dam outlet (**outflow**)	Derived from average sediment concentration based on sampling programme and long term average flow discharge release at the dam	**0.29**

RESULTS AND DISCUSSIONS (Contd.)

VERIFICATION: Comparison of reservoir sedimentation rates based on SWAT model simulations and sampling programme and reservoir survey.

Method	Sedimentation rate [t/yr.]
SWAT model prediction and sampling programme	422,000
Reservoir survey	411,000
Absolute error	11,000
Relative error in percent = 2.6 %	

REMARKS!

SWAT model prediction and sampling programme combined method overestimates the actual sedimentation rate by 2.6 percent

This suggests also that runoff component of SWAT was satisfactorily calibrated

RESULTS AND DISCUSSIONS (Contd.)

VERIFICATION: Erosion and sediment delivery processes

Method	
SWAT model	**Sampling programme (indirect methods, fingerprinting techniques and field observations)**
❖ Sheet erosion dominates in 1DD1 ❖ Within channel sediment sources	❖ Top layer A-horizon or Sheet erosion dominates in 1DD1. High organic matter content and fine-grained characterize the sediment contents delivered at outlet ❖ Lesser extend within channel sediment sources in 1DD1. Sediment concentrations delivery at outlet though low are sustained even during low flow or dry season ❖ Insignificant gully erosion process in 1DD1. Based on aerial photos, few and localized growing gullies in some mountain foot slopes ❖ Bank erosion in 1DC1. Sometimes sediment peaks lead the flood peaks

RESULTS AND DISCUSSIONS (Contd.)

VERIFICATION: Sediment sources

Subbasin (HRU)	Area [Km^2]	Sediment yield (SYLD_MUSLE) [t/ha]	Landuse	Surface runoff (SURQ) [mm]
Weruweru	1,361	1.21	Agriculture	83.6
Kikafu	1,082	0.95	Agriculture	74.5
Mt. Meru slopes	1,079	0.83	Agriculture	44.4
Sanya	1,039	0.26	Agriculture	20.6
Upper Kikuletwa	2,674	0.08	Rangeland	12.2

Remarks!

Sediment sources as predicted by SWAT model are comparable to those identified by analysing field data alone.

The sources are characterised as headwater regions of the catchment

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CONCLUSIONS

- The SWAT model captured 56 percent of the variance of the observed daily sediment loads during calibration period.
- The model underestimated the observed sediment load by 0.9 percent.
- The model has identified erosion sources spatially and has replicated some erosion processes as determined from indirect methods, fingerprinting techniques and field observations.
- The predicted and measured long-term sediment yields are comparable with a relative error of 2.6 percent.
- This result suggests that for catchments where sheet erosion is dominant SWAT model is a better substitute of the sediment-rating curve and long-term prediction of sedimentation rate can be done with reasonable accuracy.
- It should be noted that the calibration was done during the normal wet year when most of hydrometeorological data required for SWAT model is available.

RECOMMENDATIONS

- **A comprehensive sediment transport channel network model is recommended to account for the discrepancy between predicted and measured reservoir sedimentation rate**
- **SWAT model parameter uncertainty has to be dealt rigorously in subsequent studies**
- **Calibrate SWAT sediment yield component using measured daily sediment flow data and not loads derived from rating curve**

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THANKS

For your attention!