# Blue Nile flow, Sediment & Impact of Watershed Interventions: Case of Gumera Watershed

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**Abstract**

High population pressure, inappropriate agricultural policies, improper land-use planning, over-dependency on agriculture as source of livelihood and extreme dependence on natural resources are inducing deforestation, overgrazing, expansion of agriculture to marginal lands and steep slopes, declining agricultural productivity and resource-use conflicts in many parts of Blue Nile. Increased land degradation from poor agricultural practices and erosion results in increased siltation and the reduced water quality in the river basin. The rainfall, runoff and sediment are highly variable both in time and space. Poor water and land management upstream severely affect runoff characteristics and the quality of water reaching downstream. The result is a downward spiral of poverty and food insecurity for millions of people both within the upper catchment and downstream across international borders. Quantification of the erosion, sedimentation processes and evaluation of impacts of interventions are difficult tasks. This paper schematizes the Blue Nile Basin (BNB) at various spatial levels as micro watershed, watershed, sub-basin to basin. It considers a particular watershed to model runoff, sediment and impact of watershed intervention. The result shows that runoff can be reasonably simulated with calibration of $R^2$=0.87 and validation of result of 0.82, and comparable sediment modelling results. The study also demonstrates, by undertaking spatial analysis using topographic, soil and land use parameters it is possible to identify the high sediment risk sub-watersheds. Impact of typical watershed intervention using various widths of vegetative filter and application on high erosion risk watersheds show reduction of sediment yield from 52% to 74%

**Media Grab:** Over 60% of flow and sediment of Nile is caused by Blue Nile, aggravating poverty and loss of livelihood in upstream-downstream areas and require urgent interventions.

## Introduction

Soil erosion is a major watershed problem in many developing countries causing significant loss of soil fertility, loss of productivity and environmental degradation. Generally, soil erosion and ensuing sediment transport is a function of many processes. Erosion from the land surface takes place in the form of sheet erosion, rill and inter rill erosion, or gully erosion part of which is delivered to rivers. This, together with in stream bed and bank erosion of rivers constitutes the sediment load in the river. Blue Nile (Abay) contributes up to 62% of the Nile flow measured at Aswan and similar proportion of sediment in the Nile. The upper Blue Nile is heavily affected by watershed management problems, caused by overpopulation, poor cultivation and land use practices, deforestation and overgrazing, resulting in significant loss of soil fertility, rapid degradation of natural systems, significant sediment depositions in the lakes and reservoirs and sedimentation of irrigation infrastructures such as canals. This paper focuses on characterizing the Blue Nile Basin in terms of runoff generated from various watersheds and tributary rivers; provide schematic layouts how erosion problem is addressed; evaluate the rainfall-runoff-sediment relationships under specific conditions. By considering typical watershed, results are provided for rainfall-runoff relationships, sediment runoff relationships and the sensitivity and accuracy of the modeling. Using the developed model, we attempted to show the importance and quantify the impact of watershed intervention on the sediment budget.

## Methodology: Data acquisition, erosion, sediment and interventions impact modeling

Modeling erosion, sedimentation and evaluation of impact of watershed management interventions on the sediment budget is a difficult task. The most widely used empirical model is the universal soil loss equation (USLE). The USLE model estimates average annual soil loss by sheet and rill on those portions of landscape profiles where erosion but not deposition is occurring. The model neither predicts single storm loss nor does it predict gully erosion (Dilnesaw 2006). USLE or Modified/Revised method (M/RUSLE) estimate erosion at small catchments based on relationship established on soil conservation site data. Applying such relationships in the basin such as Blue Nile is difficult, as such models are not primarily designed for such large scale systems and obtaining pertinent data for calibration, validation and impact evaluation are also difficult to obtain. Attempt is made to use the method at selected small research catchment. Other techniques based on discharge-sediment rating curve can also be used to establish sediment relationship and estimate sediment data from runoff. Direct measured sediment data such as the data at the dams can also be useful to understand the cumulative yield and amount of sediment at key outlet locations. While these kind of data are under development related to wider research program, this paper is primarily focusing on focuses only the use of SWAT model at selected catchment known as Gumera watershed in the Blue Nile to carry out runoff, sediment, and impact of intervention modeling.

In terms of understanding the broad context of the study from which this paper is extracted, Figure 1 below shows the schematic representations and how sediment modeling is addressed at various scales in the entire Blue Nile basin. The schematically shown levels of Figure 1 include: a) Micro watershed, b) watershed c), sub-basins and major lakes, basin outlet and large reservoir d) downstream of outlets and large reservoir. Such schematization helps to understand the levels of possible modeling for sediment and describes the methodology of accounting the sediment and modeling framework of the ongoing work. The sequences of these levels are cumulative in a nested fashion from micro watershed to basin outlet and large reservoir levels, where a given watershed includes a number of micro watersheds and in turn a number of watersheds build sub-basins and etc. Note that Figure 1 shows only partial nesting.

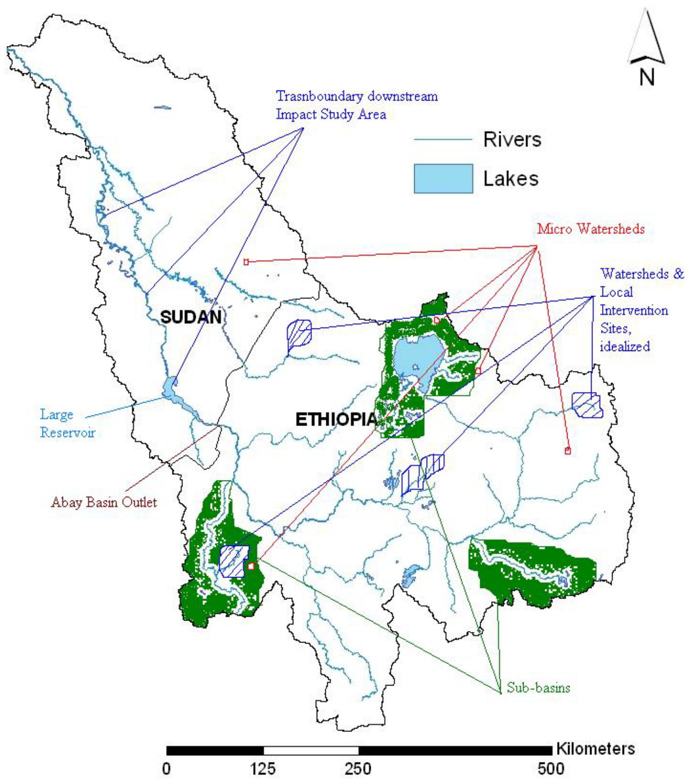


Fig. 1: Map showing the BNB and schematization of levels for erosion and sediment modeling

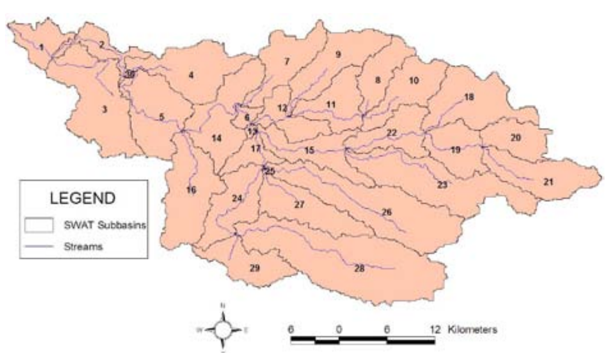


Fig. 2: Gumera watershed, one of BN small watershed and sub-watersheds under SWAT.

Figure 2 shows Gumera watershed, and a number of micro watersheds within the boundary of Gumera. We developed rainfall runoff and runoff sediment relationships at watershed outlet. We used water balance model for water accounting and soil conservation service method to estimate surface runoff volume under SWAT model environment. We used the modified universal soil loss equation (MUSLE) (Williams, 1995). For detailed discussions, refer Tenaw, A (2008). Sensitivity analysis was carried out to identify which model parameter is most important or sensitive in flow modeling. From this analysis ten parameters, such as initial curve number, available water capacity, average slope steepness, hydraulic conductivity were identified as the most sensitive parameters that significantly affect surface runoff and base flow generation. The Basin level sediment prediction were earlier addressed by Steenhuis et al (2008) and will not be repeated here. Currently, we are also testing a revised version of rainfall runoff model to improve the distributed runoff predictions without changing the discharge prediction at the outlet (White et al., 2008) and results will be available in future.

For sediment modeling we used MUSLE procedure. The calibration and validation have been carried out using data measured at the outlet of the watershed. Among many watershed interventions to reduce erosion and sediment yield in to rivers, use of filter strips is one of effective methods. These method has been tested in micro watersheds in Ethiopia and results from five soil and water conservation research stations of Maybar, Andit Tid, Anjeni, Gununo, and Dizi indicated that soil loss was respectively reduced by 55 %, 73%, 72 %, 57, 84% and 81% with grass strip (Tenaw, M, 2008). In the model, we used filter strips of 5m and 10m to see the impact on the potential of sediment delivery reduction. The filter strip trapping efficiency for sediment, nutrients and pesticides is calculated by (NEITSCH et al, 2005) as Tef = 0.367 $(WF)^{0.2967}$**.** Where Tef is the fraction of the constituent loading trapped by the filter strip, WF is the width of the filter strip (m).

In order to evaluate the efficiency of the models three measures were employed: the Nash – Sutcliffe simulation efficiency (ENS), correlation coefficient ($R^2$), and mean deviation of errors (D). In addition we evaluated the impact of watershed intervention by taking a number of micro/sub-watersheds and scenarios to understand the impact of alternative interventions. Data requirements used in the model and for flow and sediment calibration/validation include digital elevation data, land use and soil data obtained from various previous studies. Daily river flow and sediment discharges at the gauging station obtained from the Ministry of Water Resources, Ethiopia are used for discharge and sediment yield calibration and validation in the modeling work.

## Results and discussion

Physical setup of the catchment: under the SWAT modeling environment we have developed Digital Elevation Model (DEM), land use, soil, area rainfall, crop land management factor, etc and obtained good resolution of catchments data and information.

### ***Flow modeling***

Calibration resulted in Nash– Suttcliffe simulation efficiency (ENS) of 0.76, correlation coefficient ($R^2$) of 0.87, and mean deviation (D) of 3.29 % showing a good agreement between measured and simulated monthly flows, and shown in Figure 3, as demonstration. Similarly the validation results shows good agreement between measured and simulated with ENS of 0.72, $R^2$ of 0.82 and D of -5.4%.

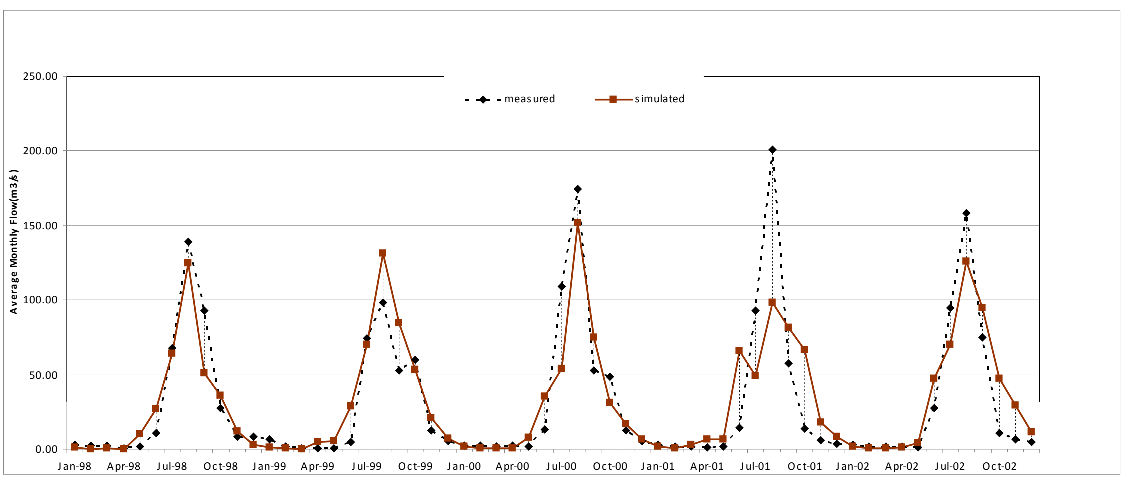


Figure 3: Calibration results of average monthly measured and simulated flow

The erosion predictions (Figure 4) shows a good agreement between calibrated monthly sediment and measured sediment yield with ENS of 0.74, $R^2$ of 0.85, and D of -14.2%. Validation result shows values for ENS of 0.62, $R^2$ of 0.79, and D of -16.9%.

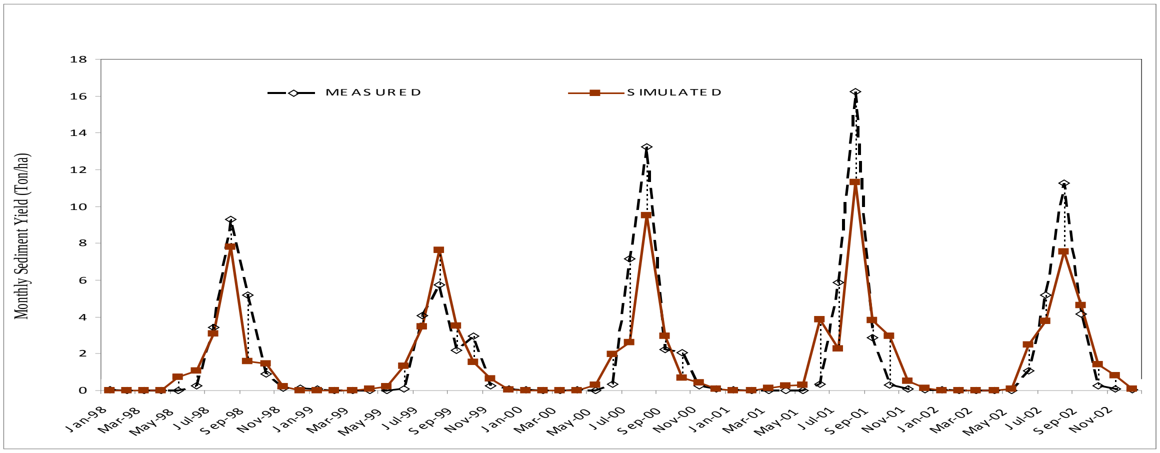


Figure 4: Calibration results of monthly measured and simulated sediment yield

***Spatial pattern of Sediment source areas***

The spatial distribution of sediment generation for the Gumara River watershed based on watershed characteristics is developed. Figure 5, below provides demonstration of annual sediment yield and it can be observed that 18 sub-watersheds (micro watershed) out of 30 sub watersheds produce average annual sediment yields ranging from 11-22 ton/ha/yr, while most of the low land and wetland areas are in the range of 0-10 ton/ha/yr.

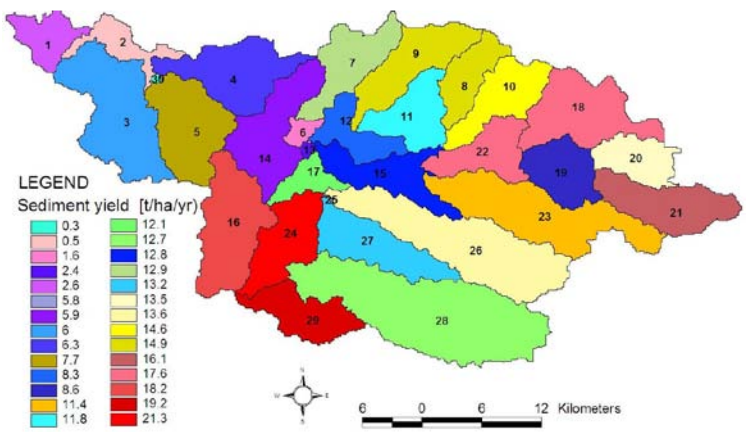


Figure 5 Spatial Distribution SWAT simulated average annual sediment yield by Micro Sub watershed(t/ha/yr). Number (1-30) are sub watershed numbers in Gumera watershed

***Watershed Intervention Impact Analysis***

By considering, high eroding areas of (sediment yield > 11 t/ha/yr), we have identified 7 high erosion micro watersheds. With implementation of vegetation strips, an average annual sediment yields were reduced by 52 % to 62 % for 5m buffer strip width and 74.2 to 74.4% for 10m strip width. This shows that it is possible to reduce the amount of sediment yield effectively by employing watershed management interventions such as vegetative strips. Such measures at micro watershed levels can have significant cumulative effect to the sub-basin and basin and to reduce sedimentation problems at lakes, man made reservoirs and natural river systems. Note also that impact of vigitative strip

**Conclusion**

Erosion, sediment transport and sedimentation are critical problems in Abbay-Blue Nile basin. The current level of degradation leading to erosion, sediment transport and sedimentation are causing considerable loss of soil, deposition in rivers and reservoir and can cause irreversible level of degradation, loss of livelihood and already causing significant canal and reservoir sediment cleaning costs. The BNB, which is providing significant flow also yield heavy sediment load. While a broad study undergoing to attempt to model the entire BN flow, sediment and impacts of interventions, the results presented in this paper demonstrate the usefulness of modeling such as SWAT to model a complex and data scarce basin. Through modeling of Gumera watershed we showed that runoff and sediment can be simulated with reasonable accuracy This also indicates that similar long term data can be generated for ungauged basins. Impact of interventions, as demonstrated by modeling the vegetative filter can also be quantified and the results show possible significant reduction of sediment removal from the upper Blue Nile. Actions taken at the farm, field or irrigation scheme level have broader basin-wide impacts. Application of the demonstrated and similar interventions through out the basin can help to reverse degradation and improve the livelihood of the people upstream and reduce the cost[1] of operation and maintenance of hydraulic infrastructure and other sedimentation damages downstream.

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[1] Unofficial data describes that 70% of the cost of operation and maintenance in the Blue Nile part of Sudan is spend on sediment related and canal maintenance