Development of Rainfall-Runoff-Sediment Discharge Relationship in the Blue Nile Basin

Fikadu Fetene[1], Seleshi Bekele Awulachew[2] and Nigusie Teklie[3]

[1] *Arba Minch University, Hydraulic and Hydropower Engineering, Arba Minch, Ethiopia*
[2] *International Water Management Institute, Addis Ababa, Ethiopia*
[3] *Arba Minch University, Arba Minch, Ethiopia*

Abstract

The Blue Nile (Abbay) Basin lies in the western part of Ethiopia between 7^0 45'-12^0 45' N and 34^0 05'-39^0 45' E. The Blue Nile region is the main contributor to flood flows of the Nile, with a mean annual discharge of 48.5 km^3. Soil erosion is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerated the rate of erosion. The SWAT was successfully calibrated and validated for measured streamflow at Bahir Dar near Kessie and at the border of Sudan for flow gauging stations, and for measured sediment yield at Gilgel Abbay, Addis Zemen and near Kessie gauging stations in the Blue Nile Basin. The model performance evaluation statistics (Nash–Sutcliffe model efficiency (E_{NS}) and coefficient of determination (r^2)) are in the acceptable range (r^2 in the range 0.71 to 0.91 and E_{NS} in the range 0.65 to 0.90). It was found that the Guder, N. Gojam and Jemma subbasins are the severely eroded areas with 34% of sediment yield of the Blue Nile coming from these subbasins. Similarly, the Dinder, Beshilo and Rahad subbasins only cover 7% of sediment yield of the basin. The annual average sediment yield is 4.26 t/ha/yr and the total is 91.3 million tonnes for the whole Blue Nile Basin in Ethiopia.

Introduction

Establishing a relationship among hydrological components is the central focus of hydrological modeling from its simple form of unit hydrograph to rather complex models based on fully dynamic flow equations. Models are generally used as utility in various areas of water resource development, in assessing the available resources, in studying the impact of human interference in an area such as land use change, climate change, deforestation and change of watershed management (intervention of watershed conservation practices).

Sediments are all the basin rock and soil particles water carries away by sliding, rolling or jumping on the bed and suspended in the flow. Very fine particles move in suspension. The finer the particles and/ or the stronger the flow turbulence, the greater is the transport in suspension. Once the sediment particles are detached, they may either be transported by gravity, wind or/ and water.
Sediment transport by flowing water is strongly linked to surface soil erosion due to rain on a given catchments. Water seeping in to the ground can contribute to landslides (subsurface erosion) which may become major sources of sediments for rivers.

The whole process can be seen as a continuous cycle of: Soil erosion= detachment + transport + deposition.

Problem Statement and Justification

Flood discharge, and sediment carried assessment and monitoring for the basin using conventional methods which rely on the availability of weather data, field measurement are tedious, costly and time consuming. On the other hand, these weather data and field data are often incomplete and limited in the basin.

Soil erosion is a major problem in Ethiopia. Deforestation, overgrazing, and poor land management accelerated the rate of erosion. With the fast growing population and the density of livestock in the basin, there is pressure on the land resources, resulting in forest clearing and overgrazing. Increasingly mountainous and steeper slopes are cultivated, in many cases without protective measures against land erosion and degradation. High intensity rain storms cause significant erosion and associated sedimentation, increasing the cost of operation &maintenance and shortening lifespan of water resources infrastructure.

Specifically, the problems and constraints in the study area lack of sediment data, difficulty of gathering this data, variation of land management due to highly increasing deforestation for search of agricultural land and climate change makes the things difficult and this study with little effort and cost, continuously can predict sediment yield in the basin and sediment transported with streams flow.

Objective of the study

The objective of this study was to determine rainfall, runoff and sediment yield relationship in Blue Nile basins. The specific objectives of the studies are:

determination of spatiotemporal distribution of sediments in the Blue Nile basin,

to evaluate applicability of SWAT model in predicting sediment yield and concentration in the Blue Nile basin,

To analyze the lag time of Hydrograph, LAG and lag time of sediment graph, LAGs.

Identify sensitive regions for erosion and deposition.

Description of the Study Area

The Blue Nile (Abbay) basin lies in the western part of Ethiopia between 70 45'-120 45' N and 340 05'-390 45' E. The study area covers about 199,812 square kilometers with a total perimeter of 2440 Km.

Most of the important tributaries of the Blue Nile are located in the Ethiopian highlands (North western part of the country) with elevation ranging from about 300 to 4200m above mean sea level. According to recent study by Conway (2000), in Ethiopia only it comprises 17.1 percent of the total surface area of the country excluding Dindar and Rahad sub basins (176 000km2, out of 1.1Mkm2) with mean annual discharge of 48.5 Km3.

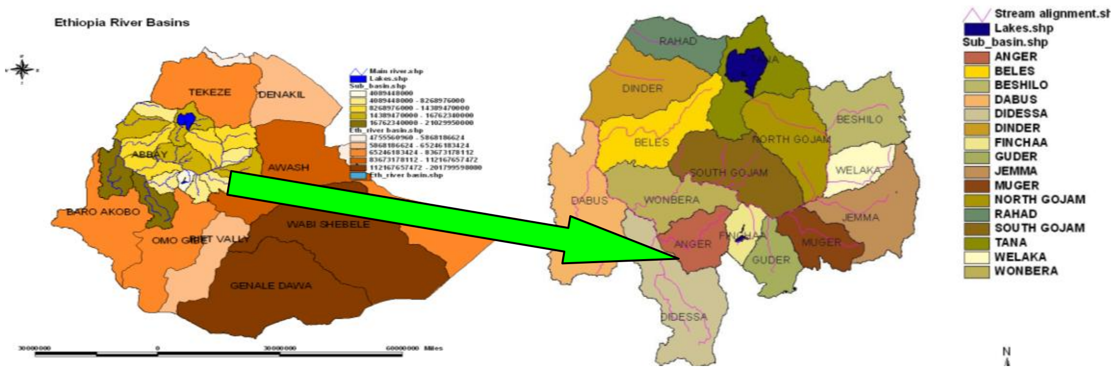


Figure 1: Ethiopian Major River Basins and sub basins of Blue Nile basin

Concepts and Practices of Rainfall-Runoff-Sediment Relationship

Hydrological modeling is a great method of understanding hydrologic systems for the planning and development of integrated water resources management. The purpose of using a model is to establish baseline characteristics whenever data is not available and to simulate long-term impacts that are difficult to calculate, especially in ecological modeling (Lenhart et al. 2002).

Soil erosion models can be separated into models simulating a single hill slope or a single field and models simulating a watershed. Determination of accurate runoff rate or volume from the watershed is a difficult task, however, some common runoff estimation methods are Rainfall-Runoff Correlation, Empirical Methods, Rational Method, Infiltration Indices method, Hydrograph Method and using different models now a days, like HEC-HMS, MOWBAL, SWAT model and others.

Several models are available for predicting erosion too, including the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Modified Universal Soil Losses Equation (MUSLE), Kinematics Runoff and Erosion Model (KINEROS), and Water Erosion Prediction Project (WEPP).

For this runoff sediment relationship determination we have used SWAT model. SWAT is the acronym for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA, Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. The SWAT model is chosen for physically based, uses readily available inputs, is computationally efficient, enables users to study long-term impacts, capability for application to large-scale catchments (>100 km2), and capability for interface with a Geographic Information System (GIS).

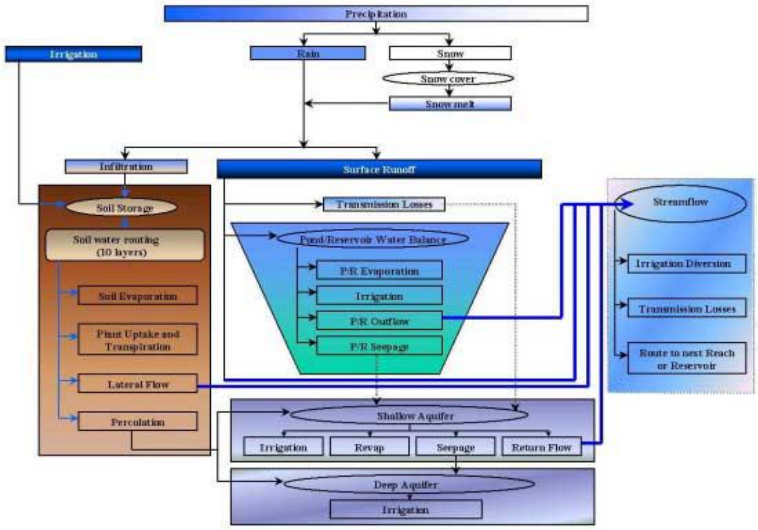


Figure 2: Overview of SWAT hydrologic component (Arnold et.al, 1998)

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

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

Where: SWt -is the final soil water content, SW0 -is the initial soil water content on day i , t -is the time (days), Rday -is the amount of precipitation on day I, Qsurf -is the amount of surface runoff on day i , Ea -is the amount of evapotranspiration on day i , Wseep -is the amount of water entering the vadose zone from the soil profile on day i, and Qgw -is the amount of return flow on day i.

The subdivision of the watershed in to HRU enables the model to reflect differences in evapotranspiration for various crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases accuracy and gives a much better physical description of the water balance.

The climatic variables required by SWAT consist of daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity.

Surface Runoff Volume is computed using a modification of the SCS curve number method (USDA Soil Conservation Service, 1972) or the Green & Ampt infiltration method (Green and Ampt, 1911).

The SCS curve number equation is (SCS, 1972):

$$\mathbf{Q_{surf}} = \frac{(\mathbf{R_{day}} - \mathbf{I_a})^2}{(\mathbf{R} - \mathbf{I_a} + \mathbf{S})}$$

Where: Qsurf: is the accumulated runoff or rainfall excess, Rday is the rainfall depth for the day, Ia is the initial abstractions which includes surface storage, interception and infiltration prior to runoff, and S is the retention parameter.

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

Where, CN- is the curve number for the day.

The initial abstractions, Ia, is commonly approximated as 0.2S and becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)}$$

Erosion

Transport of sediment, nutrients and pesticides from land areas to water bodies is a consequence of weathering that acts on landforms. Soil and water conservation planning requires knowledge of the relations between factors that cause loss of soil and water and those that help to reduce such losses.

Erosion caused by rainfall and runoff is computed with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978).

MUSLE: The modified universal soil loss equation (Williams, 1995) is:

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

Where: sed- is the sediment yield on a given day (metric tons), Qsurf is the surface runoff volume , qpeak is the peak runoff rate (m3/s), areahru is the area of the HRU (ha), KUSLE is the USLE soil erodibility factor (0.013 metric ton m2 hr/(m3-metric ton cm)), CUSLE is the USLE cover and management factor, PUSLE is the USLE support practice factor; LSUSLE is the USLE topographic factor and CFRG is the coarse fragment factor.

The maximum amount of sediment that can be transported from a reach segment is calculated:

$$conc_{sed,ch,mx} = c_{sp} \cdot v_{ch,pk}^{\ spexp}$$

Where: concsed,,ch,,mx is the maximum concentration of sediment that can be transported by the water (ton/m3 or kg/L), C sp is a coefficient defined by the user, V ch,pk is the peak channel velocity (m/s), and spexp is an exponent defined by the user.

Data availability and analysis

DEM data: The Digital Elevation Model of 90m by 90m resolution has been used. The DEM was in the format of STRM and this was processed on 3 DEM, Global Mapper Software's and imported to Arc view GIS environment.

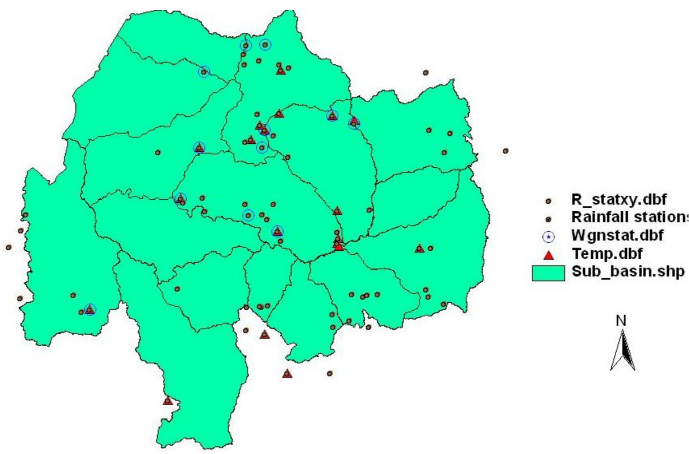


Figure3: Climate and weather generating stations in the catchment of the Blue Nile

Hydrological data: Daily flow data is required for SWAT simulated result calibration and validation.
Sediment data: There are few sites which has measured suspended sediment data in Blue Nile which is not long year recorded data. So, it is generated by regression analysis arranged as per the SWAT model and used for calibration.

Climate data: The climate data is among the most prerequisite parameter of SWAT model. These are Rainfall Data, Temperature data, Wind speed, Relative humidity and sunshine hours (solar radiation).

Materials and methodology

Materials for the study: Topographic map, DEM of the basin, Soil type map, Land use map.

Methodology

The applied methodology comprises five phases;

1) Preparation
2) Data acquisition
3) Modeling and data analyzing
4) Calibration, Validation, evaluation, and
5) Reporting.

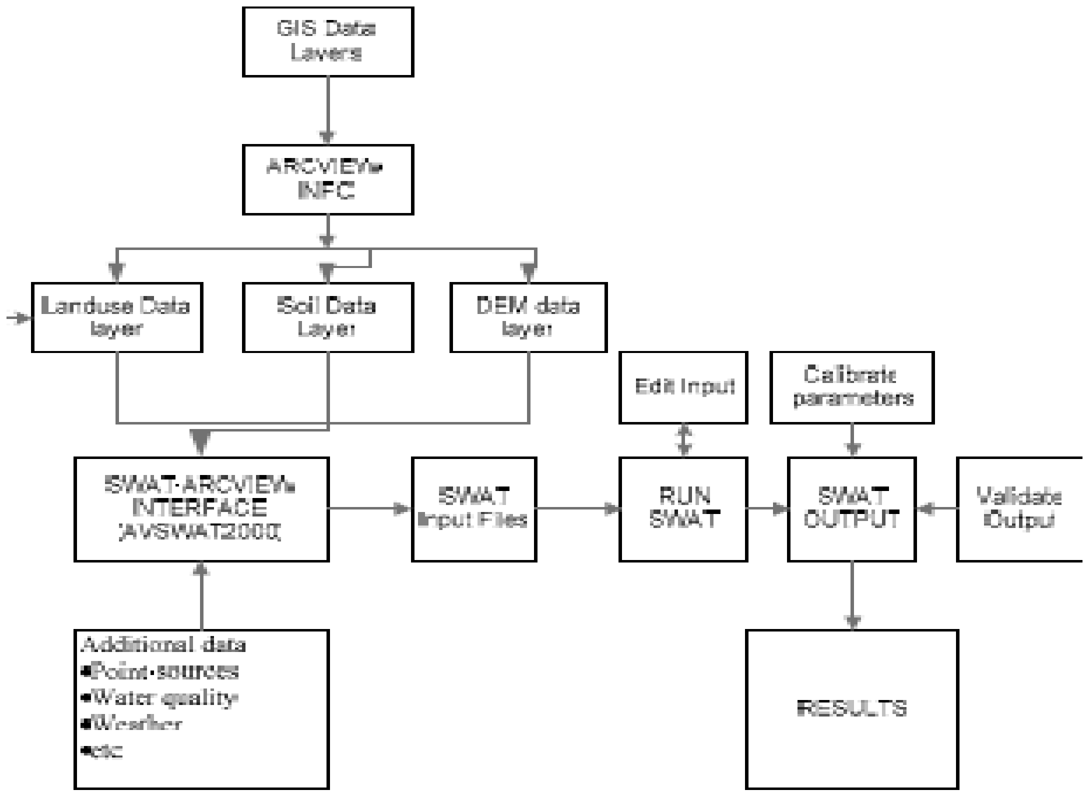


Figure 4: The general layout of Simulation diagram of SWAT model

Model Inputs

Inputs including basin area and main channel length were determined by AVSWAT (ArcView GIS interface for SWAT) from DEM of the study area. SCS curve number and overland Manning's n values were chosen based on suggested parameters by the SWAT interface from soil and land use characteristics.

Measured daily rainfall, temperature, solar radiation, wind speed and relative humidity for the study area were used in the model.

Digital elevation model (DEM)

Topography was defined by a Digital Elevation Model (DEM), which describes the elevation of any point in a given area at a specific spatial resolution as a digital file.

Land use/cover map and soil map

Once watershed topographic parameters have been computed for each sub basin, the interface uses land cover and soils data to generate multiple hydrologic response units (HRUs) within each sub basin by GIS overlay process to assign soil parameters and SCS curve numbers. SWAT has predefined land uses identified by four-letter codes and it uses these codes to link land use maps to SWAT land use databases in the GIS interfaces.

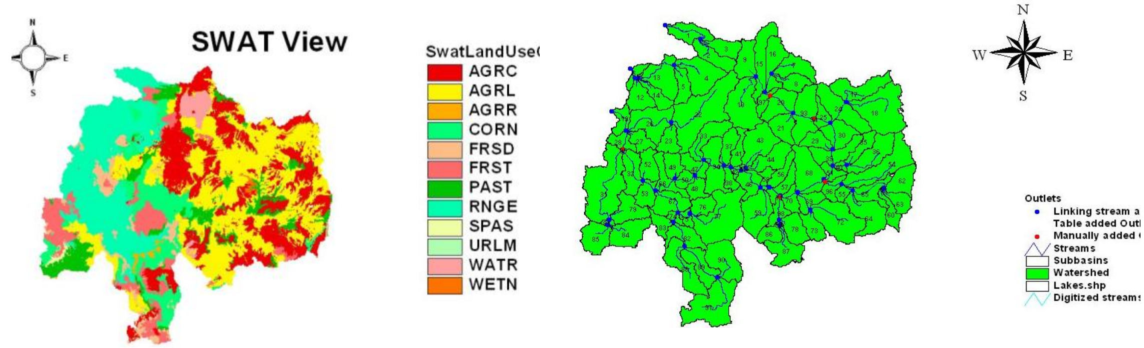


Figure 5: a) SWAT land use/cover classification & soil map of Blue Nile b) Watershed delineated & outlets

Watershed delineation

The subdivision of a watershed into discrete sub-watershed areas enables the modeling process to represent the heterogeneity of the watershed. SWAT works on a sub-basin basis and the interface delineates the watershed in to such sub-basins or sub-watersheds based on topographic information. The total Blue Nile basin area is 199810.98 Km^2, but the delineated area becomes 190347 Km^2.

Digitized stream networks

The digitized stream networks used in this study were found from the Ministry of Water Resources (MoWR) of Ethiopia. The streams were prepared in a shape file format and together with the DEM given as an input to the model to be “burnt” during the delineation process. The model superimposed the digitized stream networks into the DEM to define the location of the stream networks and safe the time of delineation.

Weather data

This data are in daily based long year data's of many stations as much as possible. They are precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation. On top of these data statistical analysis of monthly daily average, standard deviations, and probability of wet and dry days, skew ness coefficients and dew temperature were determined by FORTRAN program known as *WXGenParm* (J.R. Williams, 1991) and program *dew02.exe* (S. Liersch, 2003) for generating missing data (identified by -99) and predicting unmeasured and missing data in the basins.
SWAT takes data of each climatic variable for every sub basin from the nearest weather station measured from the centroid of the sub basin.

Evaporation data

It has two options, either loading measured evaporation data or choosing the methods for SWAT simulation. There are three methods of Evaporation determination by SWAT model itself: Prestily-Taylor method, Penman-Monteith method and Hargreve methods. For this study, since there is humidity, wind speed and solar radiation data limitation, Hargreve method was chosen for simulation of evaporation and evapotranspiration by SWAT model.

Sensitivity analysis

When a SWAT simulation is taken place there will be discrepancy between measured data and simulated results. So, to minimize this discrepancy, it is necessary to determine the parameters which are affecting the results and the extent of variation. Hence, to check this, sensitivity analysis is one of SWAT model tool to show the rank and the mean relative sensitivity of parameters identification and this step was ordered to analysis. This

appreciably eases the overall calibration and validation process as well as reduces the time required for it. Besides, as Lenhart et al. (2002) indicated, it increases the accuracy of calibration by reducing uncertainty.
For streamflow of Blue Nile basin, it was checked at three points, (at outlet of Tana basin, near Kessie and at the Sudan Border.) In the entire study sub basin the sensitivity showed that 28 parameters were sensitive. The following are few of them which have significant effect on the results.

Table 1 Sensitivity results at Bahir Dar outlet

Parameter	**Rank**	**Relative mean sensitivity**	**Sensitivity Class**
CN2	1	3.04	Very high
SOL_AWC	2	1.00	Very high
ESCO	3	0.60	high
sol_z	4	0.582	high
sol_k	5	0.23	high
GE_DEALY	6	0.21	high
ALPHA_BF	7	0.059	medium
SMTMP	8	0.046	Small
canmx	9	0.0432	Small
TIMP	10	0.0417	Small
SMFMX	11	0.0172	Small

Evaluation of Model Simulation

Graphical display of simulated and observed flows is very important because the traditional method of evaluating model performance by statistical measures has limitations. Statistical indices are not effective in communicating qualitative information such as trends, types of errors and distribution patterns. In both calibration and validation processes both observed and simulated hydrographs were compared graphically.

Model Efficiency

Two methods for goodness-of-fit measures of model predictions were used during the calibration and validation periods in addition to graphical comparison for this study.
Model simulations efficiency were evaluated during calibration by using mean, standard deviation, regression coefficient (R^2), and the Nash-Sutcliffe simulation efficiency (E_{NS}) (Nash and Sutcliffe 1970).

$$r^2 = \frac{\left[\sum_{i=1}^{n}(q_{si} - \bar{q}_s)(q_{oi} - \bar{q}_o)\right]^2}{\sum_{i=1}^{n}(q_{si} - \bar{q}_s)^2 \sum_{i=1}^{n}(q_{oi} - \bar{q}_o)^2}$$

Where: q_{si} is the simulated values of the quantity in each model time step, q_{oi} is the measured values of the quantity in each model time step , $\bar{q}_s$ is the average simulated value of the quantity in each model time step. $\bar{q}_o$ is the average measured value of the quantity in each model time step.

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(q_{oi} - q_{si})^2}{\sum_{i=1}^{n}(q_{oi} - \overline{q}_o)^2}$$

After each calibration, the regression coefficient (R^2), and the Nash-Sutcliffe (1970) simulation efficiency (ENS) were also checked in accordance to Santhi et al. (2001) recommendation (R^2 >0.6 and ENS > 0.5).

Model calibration and validation

Model calibration is a means of adjusting or fine tuning model parameters to match with the observed data as much as possible, with limited range of deviation accepted. Similarly, model validation is testing of calibrated model results with independent data set without any further adjustment (Neitsch, 2002) at different spatial and temporal scales.

Calibration of sediment was at locations of Tana basin (Gilgel Abbay, outlet number 10 and Addis Zemen at Ribb, outlet number 7) and at Kessie (outlet number 51).

Results and discussion

The basin has been divide in to 98 sub basins with threshold area of 100, 000 ha as specified in section and 392 HRU.

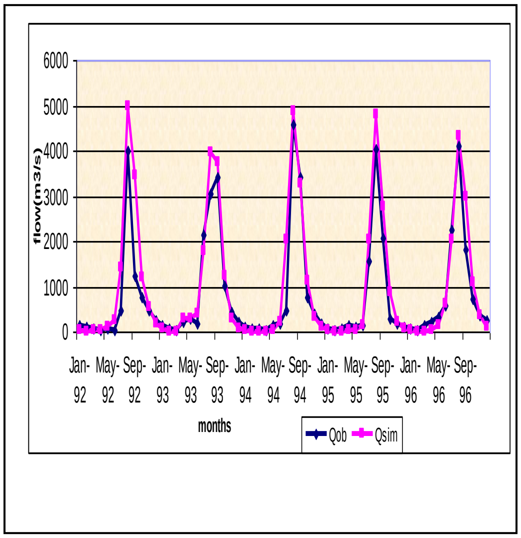
Table 2 Parameters set before and after calibration of SWAT for streamflow calibration at Bahirdar station

SWAT PARAMETER	RECOMMENDED RANGE BY SENSITIVITY	INITIAL VALUE	CALIBRATED VALUE
CN_2	±50%	DEFAULT *	-40.6%
SOL-AWC	±50%	**	-25%
ESCO	0.0 -1.0	0.95	0.1
SOL-Z	±50%	**	-44%
SOL-K	±50%	**	+50%
GW_DELAY	0-100	31	40
ALPHA_BF	0-1	0.048	0.5

** Default value assigned by SWAT itself*
*** Value initially assigned by users, but it may not depends on accurate data*

Flow calibration

After sensitivity analysis has been carried out, the calibration of SWAT 2003 model simulated streamflow at the mentioned sites were done manually. The analysis of simulated result and observed flow data comparison was considered monthly and annually. Until the best fit curve of simulated versus measured flow was satisfied, the sensitive parameters were tuned in the allowable range recommended by SWAT developers.



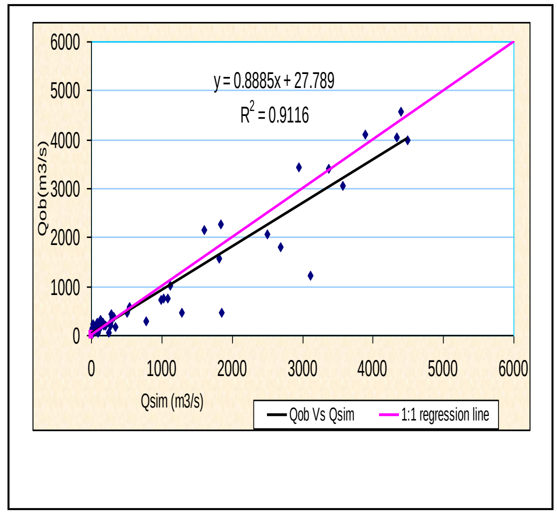
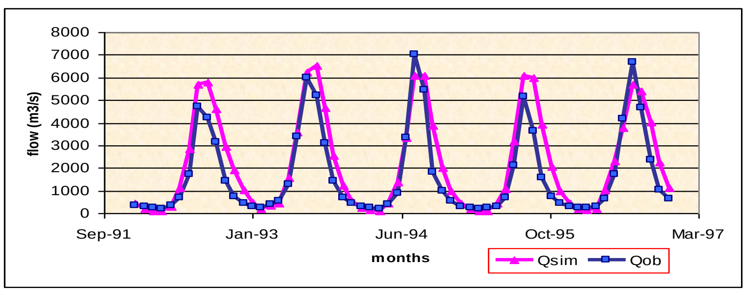


Figure 6: Simulated Vs. measured streamflow at Kessie outlet b) Regression analysis line and 1: 1 fit line



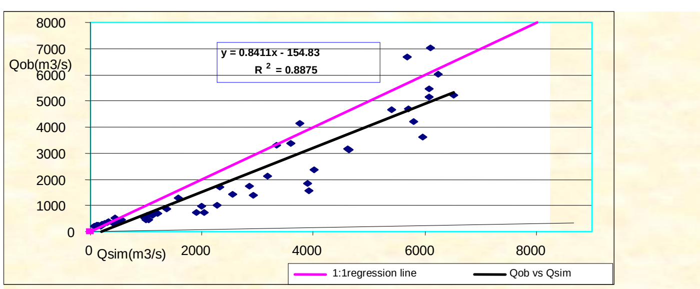


Figure 7: Simulated Vs. measured streamflow at Border outlet b) Regression analysis line and 1: 1 fit line

Table 3 Summary of calibrated and observed flow (m3/s) at the three sites

site	year	1992	1993	1994	1995	1996	Average (m3/s)	Yearly efficiency		Monthly efficiency	
								R^2	E_{NS}	R^2	E_{NS}
Bahirdar	calibrated (m3/s)	139.3	140.7	175.9	131.7	127.4	156.2	0.86	0.8	0.71	0.65
	Measured (m3/s)	138.31	153.58	188.2	57.13	135.39	145.16				
Kessie	calibrated (m3/s)	921.44	923.41	923.89	922.84	880.12	889.34	0.93	0.87	0.91	0.84
	Measured (m3/s)	638.69	931.46	989.93	658.93	912.59	818.01				
Border	calibrated (m3/s)	1811.47	2003.5	1750.7	1702.4	1849.63	1823.53	0.9	0.82	0.89	0.78
	Measured (m3/s)	1502.12	1920.3	1797.68	1299.72	1908.43	1774.42				

Flow validation

In this study the validation period is from year jan, 1998 to dec, 2000. One year from jan 1997 to dec 1997 is considered as warm-up period for model. Like as calibration, the three above-mentioned goodness-of-fit measures were calculated and model-to-data plots were inspected.

Table 4 Summary of validated and observed flow (m3/s) at the three sites

site	year	1998	1999	2000	Average (m^3/s)	Yearly efficiency		Monthly efficiency	
						R^2	E_{NS}	R^2	E_{NS}
Bahirdar	validated (m3/s)	182.1	186.2	157.9	175.4	0.89	0.75	0.78	0.69
	Measured (m3/s)	197.6	178.9	176.6	184.36				
Kessie	validated (m3/s)	1283.8	1261.8	1289.7	1278.4	0.9	0.81	0.79	0.76
	Measured (m3/s)	1129	1136.9	862.5	1087.24				
Border	validated (m3/s)	2186.6	2360.5	2140.4	2229.16	0.9	0.78	0.88	0.75
	Measured (m3/s)	2247.7	2206.2	1657.8	2037.23				

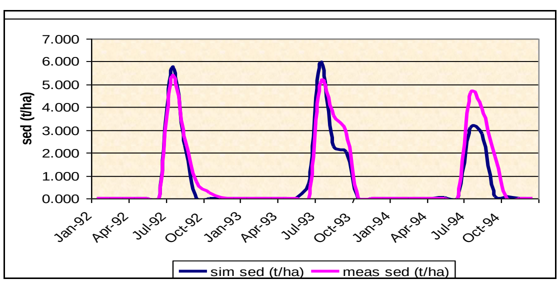
Sediment calibration and validation

In this paper the physically based SWAT 2003 model was applied to Blue Nile gauged watershed for prediction of soil erosion and sediment yield/concentration for the whole basin. SWAT model was first calibrated to flows, then to sediment. SWAT model was calibrated for sediment by comparing monthly model simulated sediment yield against monthly measured sediment yield at sites Gilgel Abbay (outlet 10), Addis Zemen at Ribb (outlet 7) and near Kessie (outlet 51).

The sediment discharge curve is derived and by using this curve monthly data for the site of calibration has been generated. To minimize the discrepancy the discharge sediment curve was derived as wet season and dry season curve separately

Table 5 SWAT model calibration and validation statistics for monthly sediment yield comparison at selected sites

Watersheds		Simulation Period	Monthly Average efficiency	
			R^2	E_{NS}
Addis Zemen	Calibration	1992-1994	0.89	0.88
	Validation	1997-2000	0.81	0.75
Gilgel Abbay	Calibration	1992-1994	0.71	0.66
	Validation	1997-2000	0.71	0.65
Kessie	Calibration	1992-1994	0.86	0.85
	Validation	1997-2000	0.82	0.77



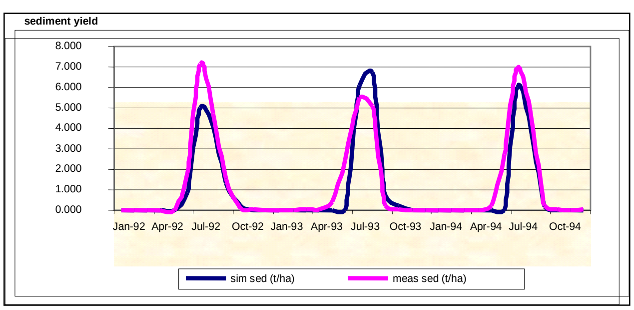
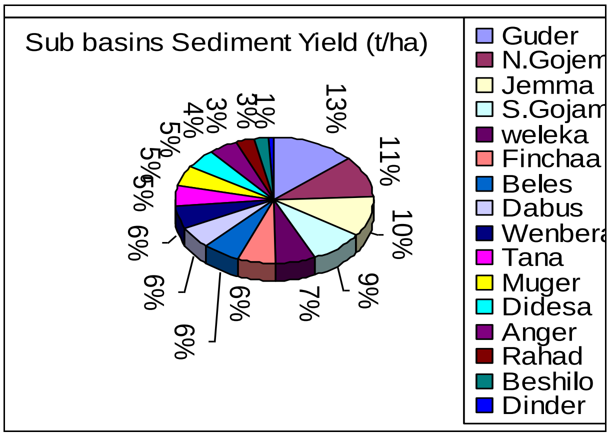


Figure 8: Observed vs simulated sediment yield at a) Addis Zemen b) at Kessie

Discussion of model output

Simulation was performed for the whole Blue Nile in Ethiopia from the year 1991 -1996 as calibration period and from 1997-2000 as validation time for runoff result and from 1991-1994 as calibration period and from 1995-2000 as validation period for sediment results. From these calibration and validation results and sites, it is possible to generalize the model work for other sub basins in the watershed of simulation since the SWAT model is distributed model and predict the same result in the calibration region for the similar HRU. For different sub basin the annual sediment yield is shown in the following chart:



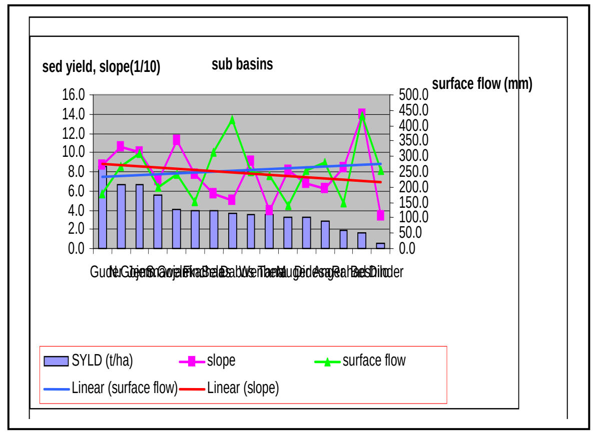


Figure 9: a) Sediment yield from different sub basin

b) The graphical comparison of the effect of surface runoff and slope steepness on sediment yielding

From this diagram, the Guder, N.Gojam and Jemma are the highest sediment yielding sub basin in the mentioned order, cover 13%, 11% and 10% respectively of the whole Blue Nile basin in Ethiopia. 34% of sediment of the Blue Nile basin is eroded from these three sub basins. The amount of soil erosion or sediment yield that occurs in given watershed related to five factors: the rainfall and runoff, the soil erodibility, the slope length and steepness, the cropping and management of the soil, and any support practices that are implemented to prevent erosion (Dilnesaw A., Bonn 2006).

The land use/cover of the three highest sediment yielding sub basins are dominated by Agriculture; (Guder: (Agriculture=95.66%, and pastoral land=4.34%), N.Gojam (Agriculture=95.41% and pastoral land=4.59) and Jemma (Agriculture=93.89%, pastoral land= 3.42% and Corn=2.69%)). This is a key factor for erosion in these sub basins.

The slope of these three highly eroded sub basins (Guder, N.Gojam and Jemma) are stands 3rd, 4th and 6th compared to other sub basins of Blue Nile basins. This is also one of the main factors affecting soil erosion in the watershed.

Similarly, the slope of those three high sediment yielding sub basins are relatively high compared to the least sediment yielding sub basin, even though, they are not the highest compared to other medium sediment yielding sub basin (see figure 9. b above).

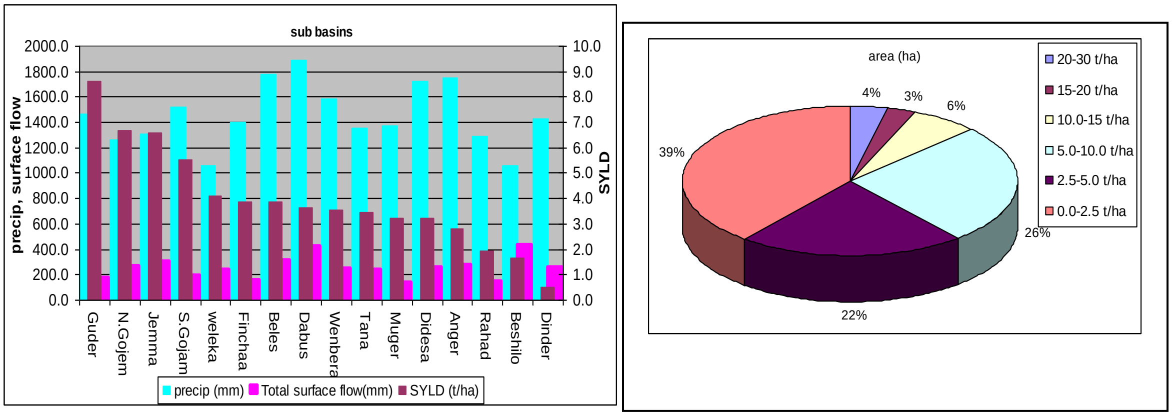


Figure 10: a) Relationship between sediment yield, precipitation and surface runoff ; b) Sediment yield percentage distribution in Blue Nile basin

As shown above on figure 9, the precipitation and surface runoff alone have no direct impact on sediment yield. From this, we can observe that, the land use/cover is the most influential parameter for soil erosion and sediment yield from a given watershed in Blue Nile basin.

Relation between Rainfall-Runoff and Sediment Yield

The relation between rainfall and runoff is a very long history as they have direct relation with some effects of watershed characteristics. But the relation of sediment with runoff and rainfall is not as such common to predict manually or empirically, but with help of recent models like SWAT, it gives the relation between the three phenomena as it considers all parameters that influence sediment yield, sediment concentration and sediment transport.

Depending on the output of SWAT model result, the relation between rainfall, runoff and sediment yield/concentration is shown, rainfall peak is come first, with sediment concentration peak the next and the peak of runoff is at the end.

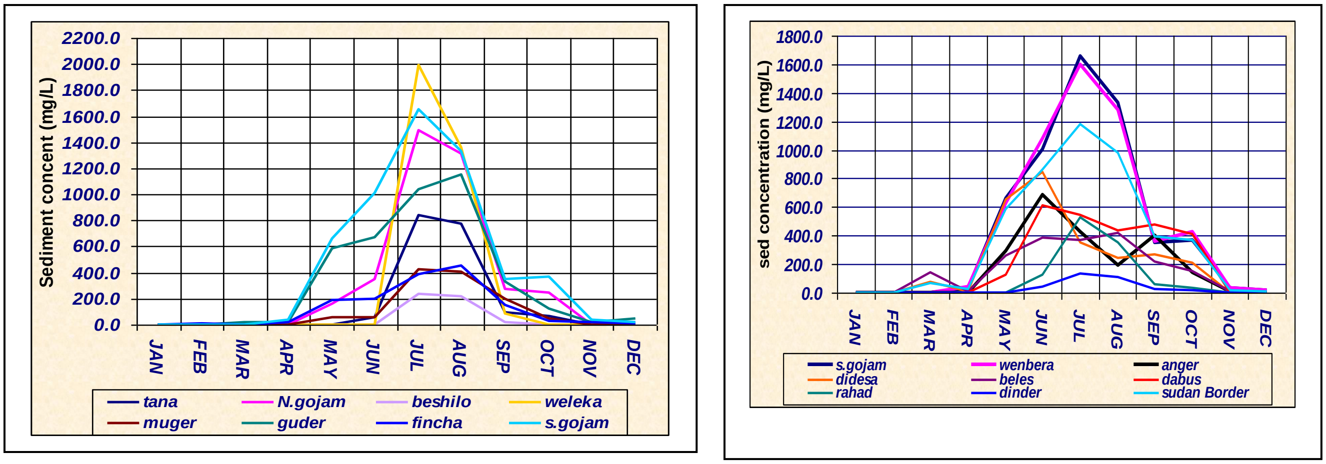


Figure11: a & b Comparisons of sediment concentration at the outlet of each subbasins

Conclusion and recommendation

Conclusion

The main objective of this thesis is to determine sediment yield in the different sub basin of Blue Nile in Ethiopia, sediment load and sediment concentration in the main rivers of the tributaries and in the Abbay River. In addition to this, the aim is to look spatial and temporal variation of sediment yield/ concentration in the basin.

As it is looked from the model performance efficiency indicator, regression coefficient (R^2) and the Nash-Sutcliffe (E_{NS}) are in the range of 0.71 to 0.91 in calibration and 0.78 to 0.88 in validation for flow analysis. Similarly, sediment model efficiency by regression coefficient evaluation is in the range of 0.71 to o.89 for calibration and 0.71 to 0.86 in validation. This shows that, the SWAT model simulates well both for streamflow and sediment yield/load in Blue Nile basin.

As looked in result and discussion part, the 34% of soil is eroded from three sub basins, Guder, N.Gojam and Jemma (in between 6-9 t/ha per average per year) that cover an area of 18.6% of total Blue Nile. In similar manner, more than 50% of soil is eroded from an area of around 16% of the whole basin (ranging from 15-30 t/ha sediment yield). The actual annual soil loss rate in the study area exceeds the maximum tolerable soil loss rate 18t/ha/y at some sub basins. But the average annual sediment yield of the whole Blue Nile basin is around 4.26 t/ha/yr and 4.58 t/ha/yr with and excluding Rahad and Dinder sub basins respectively. The total soil eroded from the Blue Nile is 91.24 Million tones and 88.96 Millions tones with and without Rahad and Dinder respectively.

When we look from the result of sediment concentration (mg/L) in the main streams of Blue Nile, Weleka, S.Gojam and Wenbera have the greater amount of concentration (in the range of 1600 to 2000mg/L) peak monthly sediment concentration compared to other sub basins. But the sub basins that have least peak monthly concentration of sediment are Dinder, Beshilo and Muger from lowest to up and the monthly peak concentrations in these sub basins are in the range of 400 to 800 mg/L.

The sediment concentration in these sub basins become peak in the month of July, next to peak of runoff mostly in August except Finchaa, Anger, Dabus and Didesa which have peak in the month of September. Coming to annual concentration, S.Gojam, Wenbera and Sudan border are taking the lead ranging from 350 to 900 mg/L annually, and Dinder, Beshilo and Rahad are those which have least concentration ranging from 25 to 90mg/L annually.

Recommendation

The results of this model out put of areal rainfall, runoff and sediment yield/ concentration/load should be considered as an attempt to predict with SWAT model and used carefully for further study and potential project works study. We suggest that the SWAT model is a very powerful tool to fill the gap we have in area of sediment data and even on an un-quality and scarce streamflow data. we hope this result give initial information for any researchers, projects on the basin and policy makers, but it may not be remain the same result in the future as land use, management practice, weather changes are some factor which alter the present situation rapidly.

It is better for the Ethiopian situation use SWAT model for sediment data prediction prior to potential project study and plan commencement.

As a mitigation measure for prevention of severs erosion and conservation mechanism, it is recommended to cover the mountainous and hilly area with plantation and control further degradation by erosion. Further study is required in different scenarios to decide a type of coverages and extent of application on different sub basins.

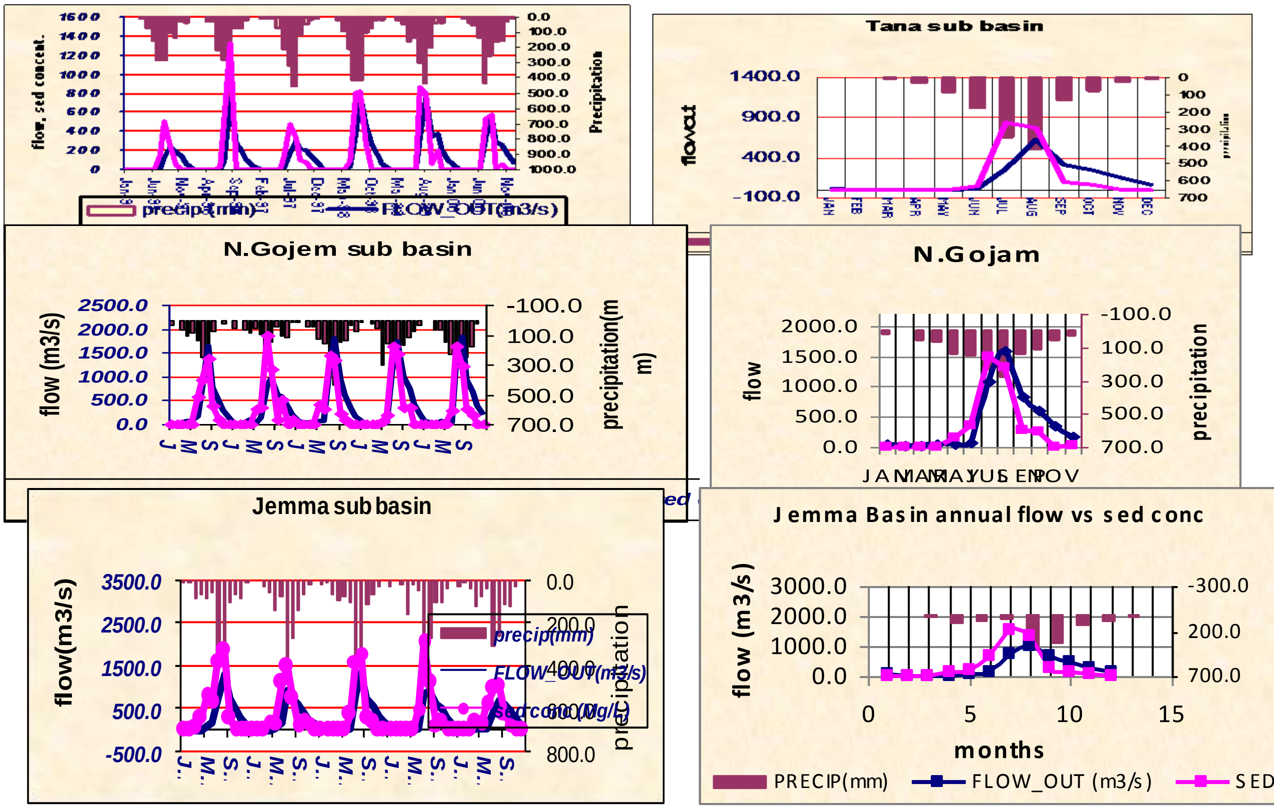


Figure12: Graphical presentation of flow versus sediment concentration relation

References

Anderson, M. P., and Woessner, W. W., (1992), Applied groundwater modeling: Academic Press, Inc., San Diego.

Arnold, J.G., P.M. Allen, and G. Bernhardt, (1993), A comprehensive surface groundwater flow model. J. Hydrol. 142:47-69

BCEOM, BRGM, ISL (1998a), "The Federal democratic Republic of Ethiopia, Ministry of water Resources, Abbay River Basin Integrated Development Master Plan Project", Water Resources, Volume III, Part I & II

Beck, M. B. 1987. Water quality modeling: A review of the analysis of uncertainty. *Water Resources Res.* 23(8): 1393-1442.

Chow, V. T., Maidment, D. R., and Mays, L. W. (1988) Applied hydrology, McGraw-Hill, New York

Conway. D. (2000), "The Climate and Hydrology of the Upper Blue Nile River." The Geographical Journal 166(1): 49-62.

DeCoursey, D. G. (1985) Mathematical models for non-point water pollution control. Journal of Soil and Water Conservation 40:408–413

DILNESAW Alamirew, (2006), Modelling of Hydrology and Soil Erosion of Upper Awash River Basin. PhD Thesis, University of Bonn: 233pp.

Dooge, J.C.I., (1968) The hydrologic cycle as a closed system. Bull. Int. Ass. Scient. Hydrol., 13. (1).

Eppink, L.A.A.J. (1993). Processes and models in erosion and soil and water conservation. Water erosion models: an overview. Lecture notes, Wageningen.

Garde R J, Ranja Raju K G, (1985), Mechanics of Sediment Transportation and Alluvial Stream Problems, second edition, Roorkee, India

Hurni H (1988) Degradation and conservation of the resources in the Ethiopian highlands JSTOR, pp. 123-130.

Leonard, R.A., W.G. Knisel., and D.A. Still. (1987). GLEAMS: Groundwater loading effects of agricultural management systems. Trans. ASAE. 30:1403-1418.

Leo C. van Rijn (1993) principles of sediment Transport in Rivers, Estuaries and Coastal seas, University of Utrecht, The Netherlands.

Neitsch (a), S.L., J.G. Arnold, J.R. Kiniry, J.R. Williams, K.W. King , 2002. Soil and Water Assessment Tool (SWAT) Theoretical Documentation, Version 2000, Grassland Soil and Water Research Laboratory, Blackland Research Center, Texas Agricultural Experiment Station, Texas Water Resources Institute, Texas Water Resources Institute, College Station, Texas, 506pp.