Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.6, No.10, 2016

Sediment Yield Modeling of Dedissa Sub Basin, Abay Basin, South-Western Ethiopia

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Abstract
The effects of land use land cover change have an impact on sediment yield on the Dedissa sun basin. The study mainly focused on predicting the amount of sediment yield and stream flow of the sub basin. A physical-based, semi-distributed hydrological model, SWAT was used to simulate hydrological response (sediment and stream flow) of Didessa sub-basin. The simulated Stream flow and sediment yield results were utilized to analyze seasonal variability of sediment and stream flow of the sub basin. The performance of SWAT model was evaluated through sensitivity analysis, calibration, and validation. Both the calibration and validation result shows good agreement between observed and simulated stream flow and sediment yield. Sensitivity analysis using the SWAT model has pointed out some crucial parameters that control the stream flow and sediment yield in the catchment. The model evaluation statistics of sediment yield prediction and stream flow gave good result with NSE and R^2 values having greater than 0.7 for the calibration and validation of the model. Therefore, SWAT model is good predictor of stream flow and sediment yield for Dedissa sub basin.
Keywords: SWAT, Dedissa sub basin, sediment Yield

1. Background

Soil resource degradation by accelerated water induced erosion is the most series in the Ethiopian high lands. Nearly 1.9 billion tons of fertile soil is lost from highlands annually through water erosion. According to McColl (2007), an average soil loss of 130 ton per hectare per year from cultivated land is eroded. It is also estimated that there is an average annual land productivity decline of 2.2% due to soil erosion.

Rapidly increasing population, deforestation, over cultivation, expansion of cultivation at the expense of lands under communal use rights (grazing and woody biomass resources), cultivation of marginal and steep lands, overgrazing, and other social, economic and political factors have been the driving force to a series of soil erosion in the basin in general and in the watershed in particular (Richard, 1998).

One of the possible solutions to alleviate the problem of land degradation (soil erosion) is therefore, to understand the processes and cause of erosion at a micro watershed level and to implement watershed management interventions. Effective watershed planning requires understanding of runoff and erosion rates at the plot, on hill slopes, and at small watershed scale and how these vary across the landscape. Deforestation, soil and water erosion, sedimentation, increasing demand for water, flooding, pollution, and climate change become a challenge to attainment of the social and economic developmental goals of the country. The lack of decision support tools and limitation of data concerning weather, hydrological, soil and land use are the factors that significantly hinder research and development in the area. To solve the existing soil erosion problems there is a need to identify the most erosion sensitive areas in the region, so that effective conservation measures can be taken. Appropriate tools are needed for the better assessment of the hydrology and soil erosion processes as well as decision support system for planning and implementations of appropriate measures (Shimelis G. *et al*, 2009).

This study tries to characterize the watershed in terms of sediment yield using physically based SWAT model. The main objective of this study is to predict the amount of sediment yield in the sub basin. Moreover it tries to address the following specific objectives: to determine the amount of sediment yield, to characterize the Dedissa watershed in terms of sediment yield, and to identify spatial and temporal variability of sediment in Dedissa Sub Basin. Therefore, this study will provide enough information about the sediment variability and erosion status of each sub watershed which will be very essential for watershed development and management options, and decision makers will be beneficiaries on decision making based on scientific results.

2. Description of the study area

Didessa Sub Basin contributes a quarter of the total flow of the Blue Nile as measured at the Sudan border. Didessa River is the largest tributary of the Blue Nile in terms of volume of water, which is located in the South Western part of Ethiopia, having a vast number of tributaries that has drainage area of nearly 9979 km2. The topography or elevation of the watershed ranges from 1274 to 3145m above mean sea level.

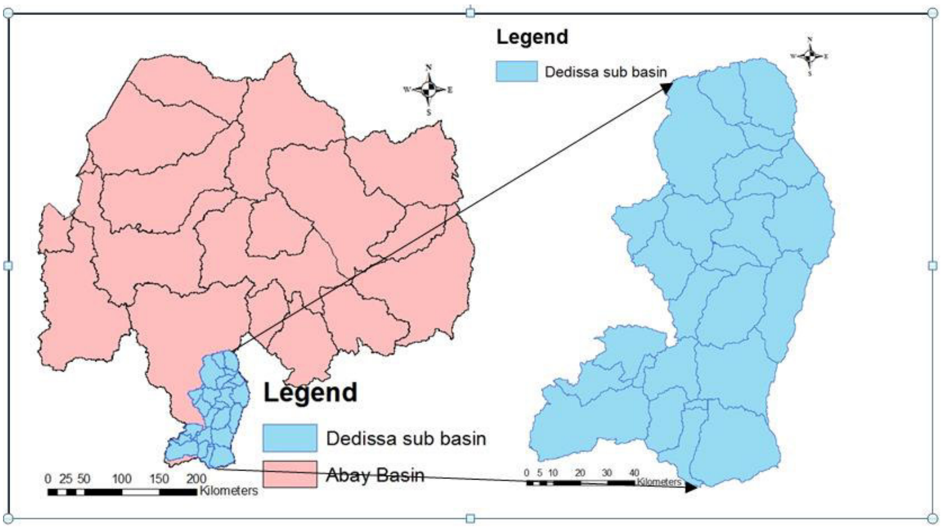

Figure 1. Location of study area

Generally the Didessa sub-basin is geographically located between 36^0 02' and 36^0 46' East longitude, and between 7^0 43' and 8^0 13' North latitude. The majority of the area is characterized by a humid tropical climate with heavy rainfall and most of the total annual rainfall is received during one rainy season called kiremt. The maximum and minimum temperature varies between 21.1 – 36.5^0c and 7.9 -16.8^0c, respectively. The mean annual rainfall in the study area ranges between 1509 mm in the southern to 2322 mm in the northern catchments. The altitude ranges between 1720m and 2088m above sea level.

The sub basin is mainly formed from Haplic Alisols, Eutric Vertisols, Halpic Nitisols and Haplic Acrisol type, but the riverbed has a loam and sandy-loam type of soil. From these soils Haplic Alisols covers the largest prtion at about 65.36%, Eutric Vertisols and Haplic Acrisols covers 12.01% and 10.31% respectively and the remaining 12.31% covered with others types of soils.

The methodology mainly focuses on addressing the impact of land use /cover change on stream flow by using ERDAS imagine2014 and arc SWAT models. ERDAS imagine2014 used for image processing by maximum likelihood supervised classification algorism. SWAT is used for stream flow simulation and analysis.

3. Methodology

In this study physically based SWAT model were used for stream flow analysis and prediction of sediment yield from Dedissa Sub basin. Through the study different data were collected from respective organizations and prepared based on the model requirements.

3.1 Description of SWAT Model

Soil and Water Assessment Tool (SWAT) is a model developed by US Department of Agriculture – Agriculture Research Service (USDA-ARS). It is a conceptual, physically based, basin scale, daily time step, semi-distributed model that functions on a continuous time step. Model components include weather, hydrology, erosion/sedimentation, plant growth, nutrients, pesticides, agricultural management, channel routing, and pond/reservoir routing (Neitsch et al., 2002). Among the many advantages of this model are; it has incorporated several environmental processes, it uses readily available inputs, it is user friendly, it is physically based and distributed, and it is computationally efficient to operate on large basins in a reasonable time.

The model calculations are performed on HRU basis and flow and water quality variables are routed from HRU to sub-basin and subsequently to the watershed outlet. The SWAT model simulates hydrology as a two-component system, comprised of land hydrology and channel hydrology. The land portion of the hydrologic cycle is based on a water mass balance. SWAT estimates soil erosion using the Modified Universal Soil Loss Equation (Arnold et al, 1998).

3.2 Hydrological Component of SWAT

The Simulation of the hydrology of a watershed is done in to two separate divisions. One is the land phase of the hydrological cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. The second division is routing phase of the hydrologic cycle that can be defined as the movement of water, sediments, nutrients and organic chemicals through the channel network of the watershed to the outlet. In the land phase of hydrological cycle, SWAT simulates the hydrological cycle based on the water balance equation (equation).

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

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

Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating surface runoff: the SCS curve number procedure (USDA-SCS 1972) and the Green & Ampt infiltration method (Green and Ampt, 1911). Using daily or sub daily rainfall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. In this study, the SCS curve number method was used to estimate surface runoff because of the unavailability of sub daily data for Green &Ampt method.
The SCS curve number equation is:

$$Q_{surf} = [(R_{day} - 0.2S)]^2/(R_{day} + 0.8S \qquad (2)$$

In which, Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), S is the retention parameter (mm). The retention parameter is defined by the equation:

$$S = 25.4 * \left[\left(\frac{100}{CN}\right) - 10\right] \qquad (3)$$

3.3 SWAT input data

3.3.1 Digital Elevation Model (DEM)

The topography is defined by DEM, which describes the elevation of any point in a given area at a specific spatial resolution, which is used for watershed delineation. A 30 by 30 meter resolution DEM was taken from Ministry of water, Irrigation and Energy of Ethiopia.

3.3.2 Soil data

Soil data is one of the major inputs for SWAT model with inclusive and chemical properties. The soil map of the study area was also obtained from Ministry of Water, Irrigation and Energy of Ethiopia. According to FAO classification, eight major soil groups were identified in the Dedissa sub basin. To integrate the soil map with SWAT model, user soil data base which contains textural and chemical properties of soils was prepared for each soil layers and added to the SWAT user soil data bases.

3.3.3 Meteorological data

Meteorological data is needed by the SWAT model to simulate the hydrological conditions of the basin. The meteorological data required for this study were collected from National Meteorological Agency of Ethiopia. The meteorological data collected were precipitation, maximum and minimum temperature, relative humidity, solar radiation, wind speed and sunshine hours for six stations (Nekemt, Jimma, Arjo, Chora, Limugenet and Denbi) from the year 1985 -2011.

A. Filling Missing Data

Data were missing from a particular gauge site or representative precipitation is necessary at a point of interest. There are different methods for filling the missing data from those methods station average and normal ratio method were used for the rainfall in this study (Richards, 1998).

$$\% \text{ difference} = \left(\frac{N_X - Ni}{N_X}\right) * 100 \qquad (4)$$

N_x–N_i must be positive. If $N_i > N_x$ the numerator will become $N_i - N_x$. Then, the mean of the nearby stations' differences is determined.

$$P_X = \frac{1}{n} * [\left(\frac{N_X}{N_1}\right) * P_1 + \left(\frac{N_X}{N_2}\right) * P_2 + \cdots + \left(\frac{N_X}{N_n}\right) * P_n \qquad (5)$$

Where P_X is the missing data at station x, N_x is the missing data stations normal annual rainfall, N_i is normal annual rainfall at station i, and n is number of nearby gauges

The station-average method for estimating missing data uses n gages from a region to estimate the missing point rainfall, P_X, at another gage:

$$P_x = \frac{1}{n}\sum_{i=1}^{n} p_i \qquad (6)$$

In which Pi is the rainfall at gage i (Equation 6) is accurate when the total annual rainfall at any of the n regional gages when the mean of percent difference is less than 10%. This method gives equal weight to the rainfall at each of the regional gages. The value 1/n is the weight given to the rainfall at each gage used to estimate the missing rainfall.

Most of the rainfall recorded from the stations has missing data ranging about 10 %.Therefore before using the data to runoff modeling it was first essential to apply a gap filling techniques. The other station which has greater than 10% is filling by weather generator.

B. Consistency

Double mass curve (DMC) was used to check the consistency of rainfall for adjustment of inconsistent data. This technique is based on the principle that when each recorded data comes from the same parent sample, they are consistent. A group of six base stations in the neighborhood of the station was selected.

A double-mass curve is a graph of the cumulative catch at the rain gage of interest versus the cumulative catch of one or more gauges in the region that has been subjected to similar hydro meteorological occurrences and is known to be consistent. If a rainfall record is a consistent estimator of the hydro meteorological occurrences over the period of record, the double-mass curve will have a constant slope.

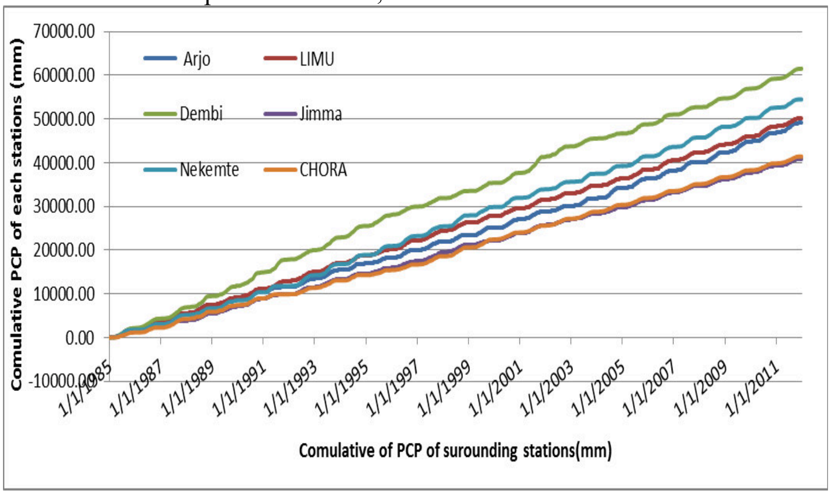

Figure 2. Double mass curve of the selected station

The collected weather data were also arranged as per the requirement of SWAT model. Wgn user weather parameters were developed by using the weather parameter calculator pcpSTAT and dew point temperature calculator DEW02.

3.3.4 Flow and Sediment data

River flow and sediment data were required for performing sensitivity analysis, calibration and validation of the model. These data were also collected from Ministry of Water, Irrigation and Energy of Ethiopia. The flow data at Arjo gauged station were collected and arranged as per the requirement of SWAT model. The homogeneity of flow data were also checked using RAINBOW (a software package for hydro meteorological frequency analysis and testing the homogeneity of historical data sets). The sediment data were too small so that a rating curve was developed between the collected sediment and flow data. This was used for calibration and validation of sediment yield simulations.

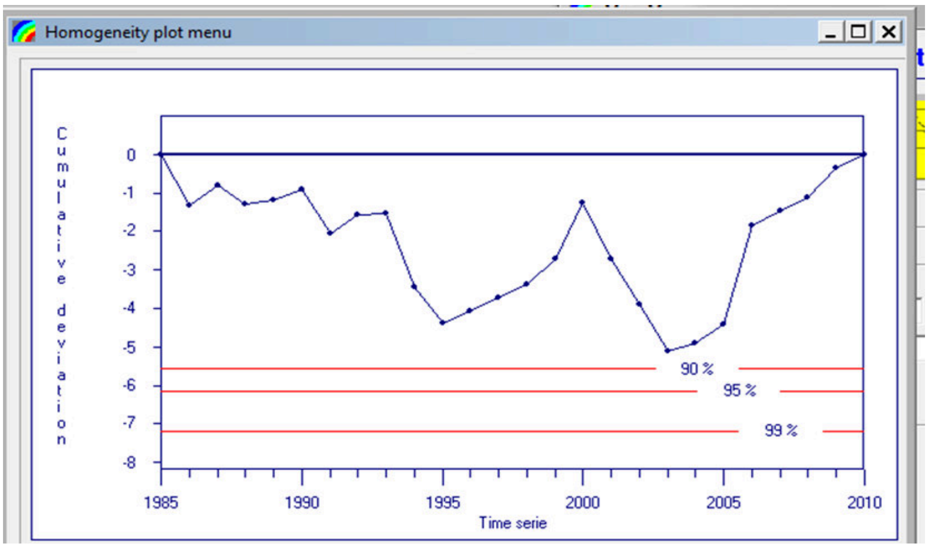

Figure 3. Homogeneity test of flow data

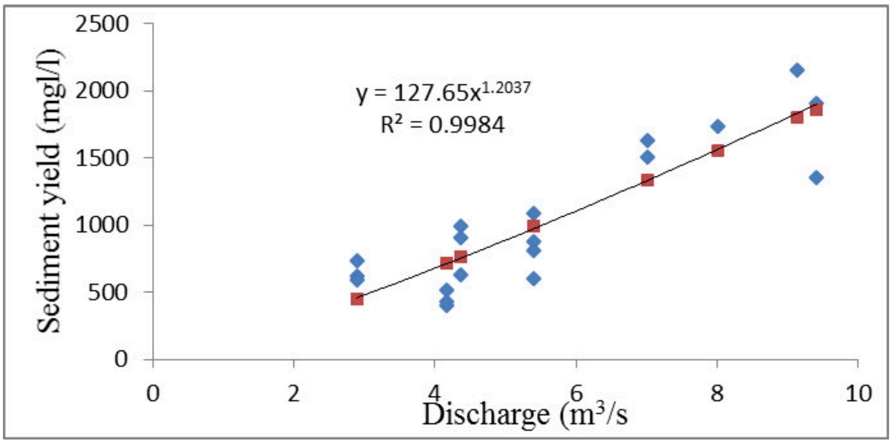

Figure 4. Rating curve

3.3.5 Land use land cover data

Land use is also another most important factor that affects runoff, evapotranspiration and surface erosion in a watershed. The Land use and land cover data of the year 2010 for the sub basin was downloaded from USGS Glovis website and classified using ERDAS Imagine 2014 for further analysis of the watershed properties like sediment simulations.

3.4 Model set up

Physically based Soil and Water Assessment Tool (SWAT) were used for watershed delineation, HRUs, weather write up, sensitivity analysis, calibration and validation of stream flow and sediment yield. HRUs were done using land use, soil and slope with threshold levels of 10%, 10%, and 5% respectively.

3.4.1 Sensitivity Analysis

Sensitivity analysis is a method of identifying the most sensitive parameters that significantly affects the model calibration and validation. Sensitivity analysis describes how model output varies over a range of a given input variable (Gessese, 2008). So that twenty-six flow parameters were checked for sensitivity using simulated and observed flow data.

3.4.2 Model Calibration and Validation

Stream flow and sediment yield of the model simulations were calibrated at Arjo gauging station in order to make the simulation result more realistic for independent calibration period. The period from 1991 to 1999 was used as a calibration period since the data for this period was with little missing data. After calibrating and getting acceptable results the model was validated for four years period from 2001 to 2004.

3.4.3 Model performance evaluation

Model evaluation is an essential measure to verify the robustness of the model. In this study, two model evaluation methods were used, which were Nash-Sutcliffe efficiency (NSE) and coefficient of determination (R^2) (Moriasi, 2007).

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n}(X_i^{obs} - X_i^{sim})^2}{\sum_{i=1}^{n}(X_i^{obs} - X^{mean})^2} \quad (7)$$

where, X_i^{obs}=observed variable X_i^{sim}= simulated variable X^{mean} =mean of n values and n=number of observations

The coefficient of determination (R^2) describes the proportion the variance in measured data by the model. It is the magnitude linear relationship between the observed and the simulated values. R^2 ranges from 0 (which indicates the model is poor) to 1 (which indicates the model is good) with higher values indicating less error variance, and typical values greater than 0.6 are considered acceptable (Santhi, 2001). The R^2 is calculated using the following equation:

$$R^2 = \frac{\sum[X_i - X_{av}] * [Y_i - Y_{av}]}{\sqrt{\sum[X_i - X_{av}]^2} * \sqrt{\sum[Y_i - Y_{av}]^2}} \quad (8)$$

where, X_i – measured value, X_{av} – average measured value, Y_i – simulated value and Y_{av} – average simulated value.

4. Result and Discussion

4.1 Stream flow modeling

4.1.1 Sensitivity analysis

Sensitivity analysis of simulated stream flow result indicated four flow parameters were sensitive and used for further calibration of the model (Table 1).

Table 1. Sensitive parameters and their rank with RMS value for stream flow

Parameter name	Parameter value range	RMS	Calibrated value	Sensitivity	Significance
CN2	±25%	0.571	47.08	1	High
ESCO	0 – 1	0.568	0.82	2	High
SOL_AWC	0-1	0.374	1.0	3	High
GWQMN	0 – 5000	0.307	4500	4	High

From those parameters SCS runoff curve number (CN2), Soil evaporation compensation factor (ESCO), Soil available water capacity (SOL_AWC), and Threshold depth of water in the shallow aquifer required for return flow (GWQMN) were sensitive parameters and ranked from 1 to 4 respectively. The remaining parameters were not considered during model calibration as the model simulation result was not sensitive to the sub basin.

4.1.2 Flow calibration and validation

The result of calibration using the average monthly stream flow showed good agreement between observed and simulated stream flow (Figure 5) with Nash –Sutcliffe efficiency of 0.76 and coefficient of determination (R^2) of 0.80. The validation of model simulation also showed a good agreement between simulated and measured monthly flow with the NSE value 0.70 and R^2 0.79 respectively (Table 2).

Table 2 Average monthly stream flow for calibration and validation

Period	Average monthly flow(m^3/s)		R^2	NSE
	Observed	simulated		
Calibration (1991-1999)	101.53	110.42	0.80	0.760
Validation (2001-2004)	110.77	114.63	0.79	0.70

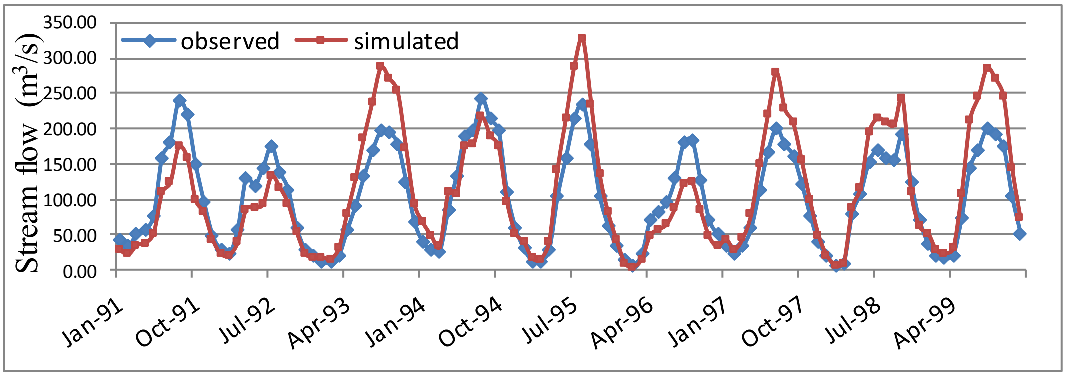

Figure 5. Calibrated average monthly stream flow (1991 to 1999)

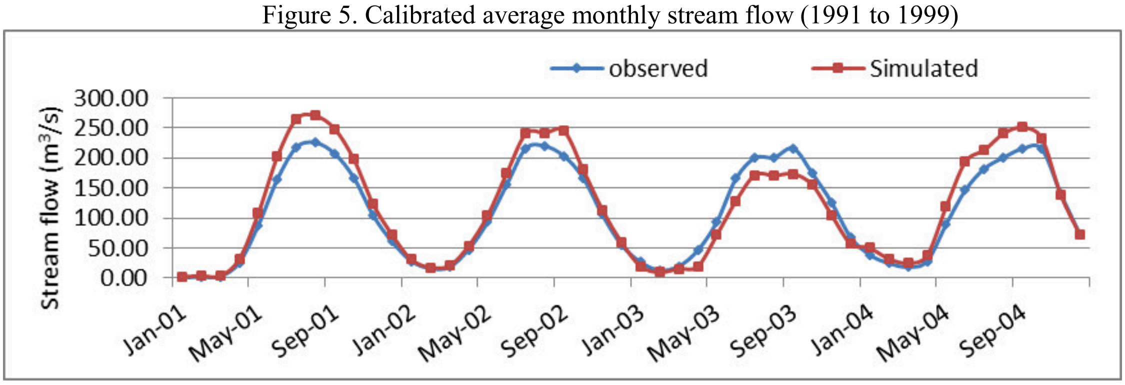

Figure 6. Validated average monthly stream flow (2001 to 2004)

Therefore the results of stream flows indicate that SWAT model is a good predicator for stream flow of Dedissa sub basin. Different studies conducted in the upper Blue Nile basin also showed similar result. For example, Assmamaw, (2013) reported that SWAT model showed a good match between measured and simulated flow of Gumera watershed both in calibration and validation periods with (NSE = 0.76 and R^2= 0.87) and (NSE =0.68 and R^2= 0.83), respectively. Through modeling of Lake Tana basin, Shimelis et al, (2008) indicated that the average monthly flow simulated with SWAT model were reasonably accurate with NSE =0.81 and R^2=0.85 for calibration and NSE = 0.79 and R^2 = 0.80 for validation periods. This indicates that SWAT cans sufficiently reasonable result in the upper Blue Nile basin and hence the tool can be used in similar watershed.

4.2 Sediment Yield Modeling

4.2.1 Sensitivity analysis

Six sediment yield parameters were tested and only three parameters were identified significance effect on sediment inflow in the sub basin. These are Usle_p (usle support practice factor), Spcon (Linear parameters for calculating the maximum amount of sediment that can be re-entering during channel sediment routing) and Spexp (exponential factor for channel sediment routing) with the rank of ascending order respectively.

4.2.2 Calibration and validation of sediment

The model sediment yield calibration for the period of 8 years from 1987 to 1994 revealed good agreement between observed and simulated average monthly sediment inflow with NSE of 0.78 and R^2 of 0.83. The validation of the model from 1995 to 1998 also indicated good agreement between simulated and measured monthly flow with the NSE value 0.73 and R^2 0.81(Table 3).

Table 3 Comparison of observed and simulated sediment

Period	average sediment load (t/month)		modified efficiency	
	Observed	Simulated	R^2	NSE
Calibration (1987-1994)	6.6	6.98	0.83	0.78
Validation (1995-1998)	5.2	5.5	0.81	0.73

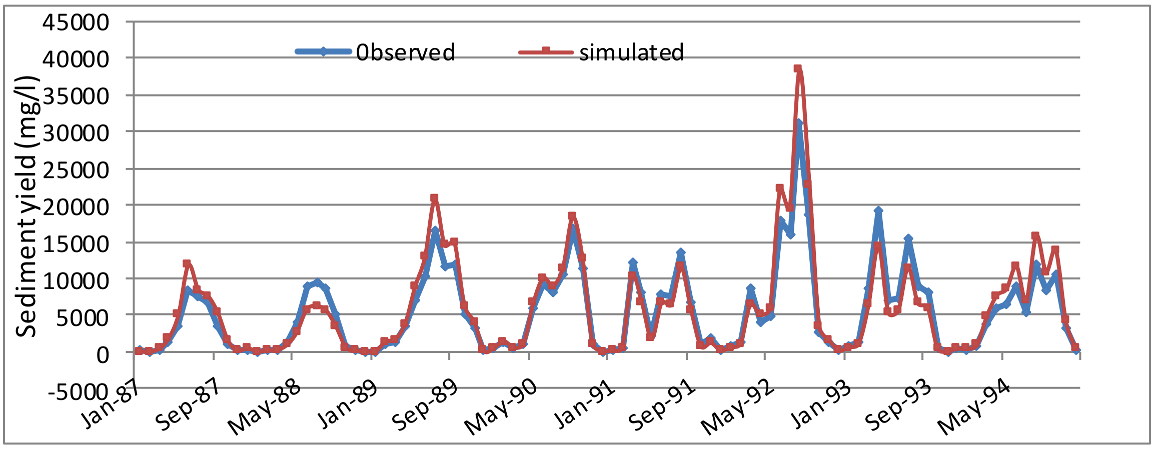

Figure 7. Calibration of average monthly sediment yield (1987 to 1994)

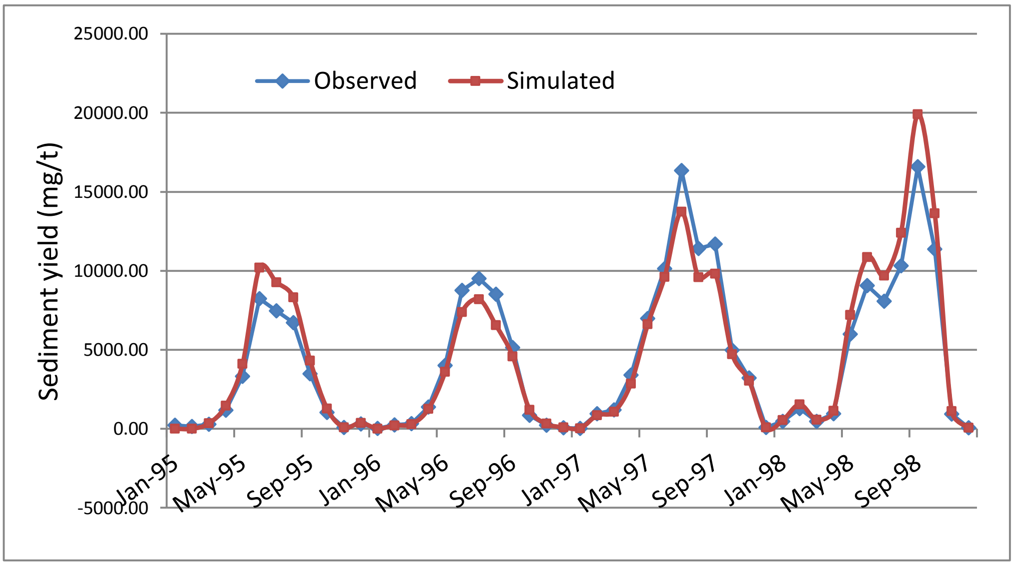

Figure 8. Validation of average monthly sediment yield (1995 to 1998)

Different studies conducted in different parts of the country also showed similar result. For example Shemels (2009) reported that in Giligl Abay watershed the statistical comparison between the measured monthly sediment yield and monthly simulated sediment yield was a good agreement with R^2=0.85 and NSE=0.81 for calibration and R^2=0.8 and NSE=0.79. Dereje (2010) reported that at Karadobi the comparison between the measured monthly sediment load and simulated sediment load was a good agreement with R^2=0.79 and NSE=0.74 for calibration and R^2=0.89 and NSE=0.85 for validation period.

5. Conclusion and Recommendation

5.1 Conclusion

During this study the sediment yield from the sub basin was determined using spatially semi-distributed SWAT model. The model evaluation statistics of sediment yield prediction and stream flow gave a good result since NSE and R^2 of the model were greater than 0.7. The sediment yield from the sub basin were high due to high population growth, overgrazing and deforestation practices in the area. The sediment yield from the sub basin was very high in wet seasons which have a direct relationship with the river discharge. Some sub watersheds showed very high erosion which needs best sediment management practices in this sub basin.

5.2 Recommendation

Generally the following recommendations are drawn

- ❖ In order to improve the performance of the model more hydrological and meteorological stations shall be installed to improve quality of flow, sediment and meteorological data.
- ❖ Best soil and water conservation practices shall be highly encouraged to reduce due to sediment from the sub basin.
- ❖ Reforestation of shrub lands, steep slope lands and some parts of agricultural lands mainly at upper parts of the watershed with other soil conservation measures should have to be implemented for further reduction of sediment
- ❖ Further researches like sedimentation effects on Dedissa sub basin with reservoirs including development of BMPs with detail land use survey could be better.

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Acknowledgement

I would like to express my sincere appreciations to Dr. Ing Adane Abebe and Dr.Ing Bogale G/mariam for their advice in the commencement of the study and valuable suggestions, encouragement and guidance starting from the class up to the end of my research work.

I would like to thank the Ministry of Water, irrigation and Energy of Ethiopia and National Meteorological Service Agency for providing the hydrological and meteorological data.

I would like to express my deep thanks all my friends especially commonly known by FAO members Mamuye Tebebal, Girum Getachew, and Demelash Ademe for their wonderful social atmospheres and appreciations.