sciendo

Journal of Environmental Geography 12 (3–4), 21–31.

DOI: 10.2478/jengeo-2019-0009
ISSN 2060-467X

CALIBRATION, VALIDATION AND PERFORMANCE EVALUATION OF SWAT MODEL FOR SEDIMENT YIELD MODELLING IN MEGECH RESERVOIR CATCHMENT, ETHIOPIA

Abebe Tarko Assfaw*

Civil Engineering Department, College of Engineering, Debre Berhan University, PO Box 445 Debre Berhan, Ethiopia
*Corresponding author, e-mail: abe4tar@gmail.com

Research article, received 2 September 2019, accepted 18 November 2019

Abstract

Intensive agricultural practice in Ethiopian highlands results in increasing rates of soil erosion and reservoir sedimentation. The estimation of sediment yield and prediction of the spatial distribution of soil erosion on the upper Megech reservoir catchment enables the local governments and policymakers to maximize the design span life of the Megech reservoir through implementing appropriate soil conservation practices. For this study, the sediment yield was estimated and analyzed through hydrological modeling (SWAT). The simulated outputs of the model show that the mean annual surface runoff was 282 mm and the mean annual streamflow was 153 m^3/s. Similarly, 12.33 t/ha mean annual total sediment load gets into the Megech reservoir. The model performance standard used to evaluate the model result indicates that the model was superior in performing the trend of runoff and sediment yield in both calibration and validation periods. Finally, the most erosion vulnerable sub-basins that could have a significant impact on the sediment yield of the reservoir were identified. Based on this, sub-basin 7, 25, 27, 18 and 29 were found to be the most erosion sensitive areas that could have a significant contribution to the increment of sediment yield in the Megech reservoir. Considering the land use, soil type, slope, and relief of erosion vulnerable sub-basins cut off drains, fallow land, contour ploughing, Fanya juu terraces, soil bunds combined with trenches and trees could be the possible management strategies to reduce the sediment yield in the catchment.

Keywords: calibration, validation, Megech Reservoir, sediment yield, SWAT

INTRODUCTION

Sediment yield fluctuates greatly because of natural or man-induced factors. Climate, soil, topography, land use/land cover and management practices are the most common factors that affect the soil erosion process and sediment yield from the catchment. These factors have a dynamic role in the erosional behavior of soil (Wainwright and Brazier, 2011). There are mainly three types of soil erosions namely sheet erosion, rill erosion, and gully erosion. Sheet erosion is the first phase of the erosion process that is characterized by the uniform removal of soil from the surface. As the severity of the erosion increases rill erosion begins to develop and finally deep gully erosion is formed. It is reported that more than 2/3rd of farmland degradation in Africa is caused by soil erosion (Tully et al., 2015). Soil erosion is a natural and dynamic process that occurs when the force of wind, raindrops or runoff on the soil surface exceeds the cohesive agent that binds the soil together (Ifabiyi, 2004). Soil erosion caused by water is a serious problem in many parts of the world which causes most of the degradation of agricultural lands. However, the extent and magnitude varies from one part of the country to another depending on the farming practices, population pressure, type and susceptibility of the soils to erosion, local climate, the general terrain formation, and variations in agroecological setting of the area (Tebebu et al., 2010; Monsieurs et al., 2015). All this implies that location-specific soil erosion studies are still substantial in Ethiopia for arresting the problem of soil loss.

The availability of large amounts of water resources and adequacy of topography enables Ethiopia to be the most beneficiary of water resource development projects such as dams and reservoirs (Setegn et al., 2007). On the contrary poor land use practice and improper management make the reservoirs be in a serious problem of sedimentation even beyond their dead storage capacity. In Ethiopia Poor land-use practices, improper management systems and lack of appropriate soil conservation measures have been major causes of soil erosion and land degradation problems (Tamene et al., 2006). A quantitative expression of soil erosion is a fundamental phase for any watershed management (Prasannakumar et al., 2012; Khadse et al., 2015). Even though different researches (such as Haregeweyn et al., 2017; Gashaw et al., 2018; Miheretu and Yimer, 2018; Woldemariam et al., 2018; Zerihun et al., 2018) have been done so far to estimate soil erosion in the Ethiopia highlands, the problem has been increasing (EfD, 2010) and it could be worse in the future (Niang et al., 2014).

Intensive agricultural practice in the upper Blue Nile basin causes land use to be changed rapidly which results in increased rates of soil erosion and sedimentation. This was manifested by the significant downstream impacts and the storage capacity reduction of reservoirs. Specifically, the silting of reservoirs is the most challenging problem in the upper Blue Nile basin. The benefits gained by the construction of micro-dams in the upper Blue Nile basins were threatened by the rapid loss of storage volume due to excessive sedimentation (Tamene, 2006). In Megech reservoir catchment the existing land and water resources system of the area is adversely affected by the rapid growth of population, deforestation, surface erosion and sediment transport. Many farmers in the area cultivate mountainous and steeper slope land without protective measures against soil erosion and degradation, causing topsoil to be washed out during the heavy rain season.

The construction of a dam and the creation of an impounded river reach area usually change the stream natural conditions. The dam reservoir causes a reduction in the flow velocity and decreases turbulence thus causing the gradual deposition of those sediments carried by the stream and finally diminishing the reservoir storage capacity. Sedimentation also affects the surface area of the reservoir by reducing water depth and favoring the development of aquatic plant growth. Angerb reservoir constructed in early 1980, to supply water for Gondar town people could not be serving up to the expected design period because of siltation (Admasu, 2005). This implies that the Megech reservoir which is going to be constructed around the same area is expected to face such sedimentation problems. From this experience, it has become a serious concern to determine the trends of streamflow and sedimentation on Megech reservoir catchment for planning, design, and implementation of numerous national water resource development projects in the area.

There is also a knowledge gap concerning the interdependence between the sediment production and watershed treatments on different temporal and spatial scale in the study area. Due to the above reasons, there is a need for hydrological research of Megech reservoir catchment which could support improved catchment management programs to safeguard the alarming degradation of soil and water resources. Since the Megech dam is currently under construction phase, determining the spatial distribution of sediment yield is essential to have efficient reservoir water resource management as per the design life span of the reservoir by improving catchment management practices.

The overall objective of the research was to calibrate, validate and evaluate the performance of the SWAT model for sediment yield modeling and to predict the total sediment load entering to Megech reservoir. The research was also intended to evaluate the spatial distribution of soil erosion for identifying and ranking erosion vulnerable sub-basins of Megech reservoir catchment and to recommend management strategy.

STUDY AREA

Megech reservoir catchment area at the dam site is 394.2 km^2 which is fully gauged. Megech catchment upstream of the dam site is characterized as a steep mountainous watershed with a relative elevation difference of 1075 m. The elevation in the catchment has its maximum value in the north-east direction which is 2953 m above mean sea level. The lowest topography land is at the dam site, which is at an altitude of 1878 m above mean sea level. Megech reservoir catchment is presently covered with six types of land covers namely bare land, cultivated land, grassland, shrubland, urban and plantation forest. Cultivated land covers the highest portion of the catchment as it could be seen from the land use map. According to FAO (2002) soil classification system, the major and dominant soil identified in the Megech reservoir catchment are Eutric Leptosols, Eutric Vertisols, Urban, Chromic Luvisols and Haplic Nitosols. As it could be seen from the soil map most of the watershed area is covered with Eutric leptosols. The Megech reservoir catchment area is characterized by severe land degradation situations indicated with excessive soil erosion in the form of sheet, rills, gullies, and land sliding, high deforestation, low vegetation cover, the decline of soil fertility and low land productivity. Gullies are a frequent and permanent phenomenon everywhere, particularly on steep cultivated, grazing and open shrublands. It is evident in almost all slope classes of the catchment area that are kept under cultivation; grazing and open shrublands are exceedingly affected due to soil erosion and land degradation problems. Out of the total study area close to 50% is under this threat.

The climate of the Megech catchment is marked by a rainy season from May to October, with monthly rainfall varying from 67 mm in October to 306 mm in July. The mean annual precipitation is about 1,100 mm in the upper part and about 1,000 mm in the lower part. Rainfall over the Megech catchment is mono-modal with nearly 79 % of the annual rainfall occurring in the period June – September. Maximum temperatures vary from 23 ºC in July to 30 ºC in March, whereas minimum temperatures range from 11.5 ºC in January to 15.6 ºC in April & May. Humidity varies between 39% in March and 79% in August. Wind speed is low, thus minimizing potential evapotranspiration values between 101 mm/month in July and 149 mm/month in March (WWDSE, 2008).

The Megech River, which is about 75 km long, has an average annual discharge of 5.6 m^3/s. Eighty-five percent of the annual runoff occurs from July to September. The daily minimum river flow record is 4 m^3/s whereas the daily maximum river flow is 160 m^3/s. The total mean annual sediment load entering the Megech reservoir is estimated as 461,214 t, which corresponds to 1,170 t/km^2/year. Megech reservoir capacity is about 182 M m^3 of water. The dam is currently under construction phase and it is rock fill embankment type with a crest length of 890 m and height of 76.5m above the river bed level. The dam would allow developing around 7,311 hectares of land using irrigation, besides securing water demand for Gondar town. The dam is provided with side-channel spillway and chute to discharge 662 m^3 of water per second without overtopping the dam. The location map of Megech reservoir catchment is shown in Fig. 1.

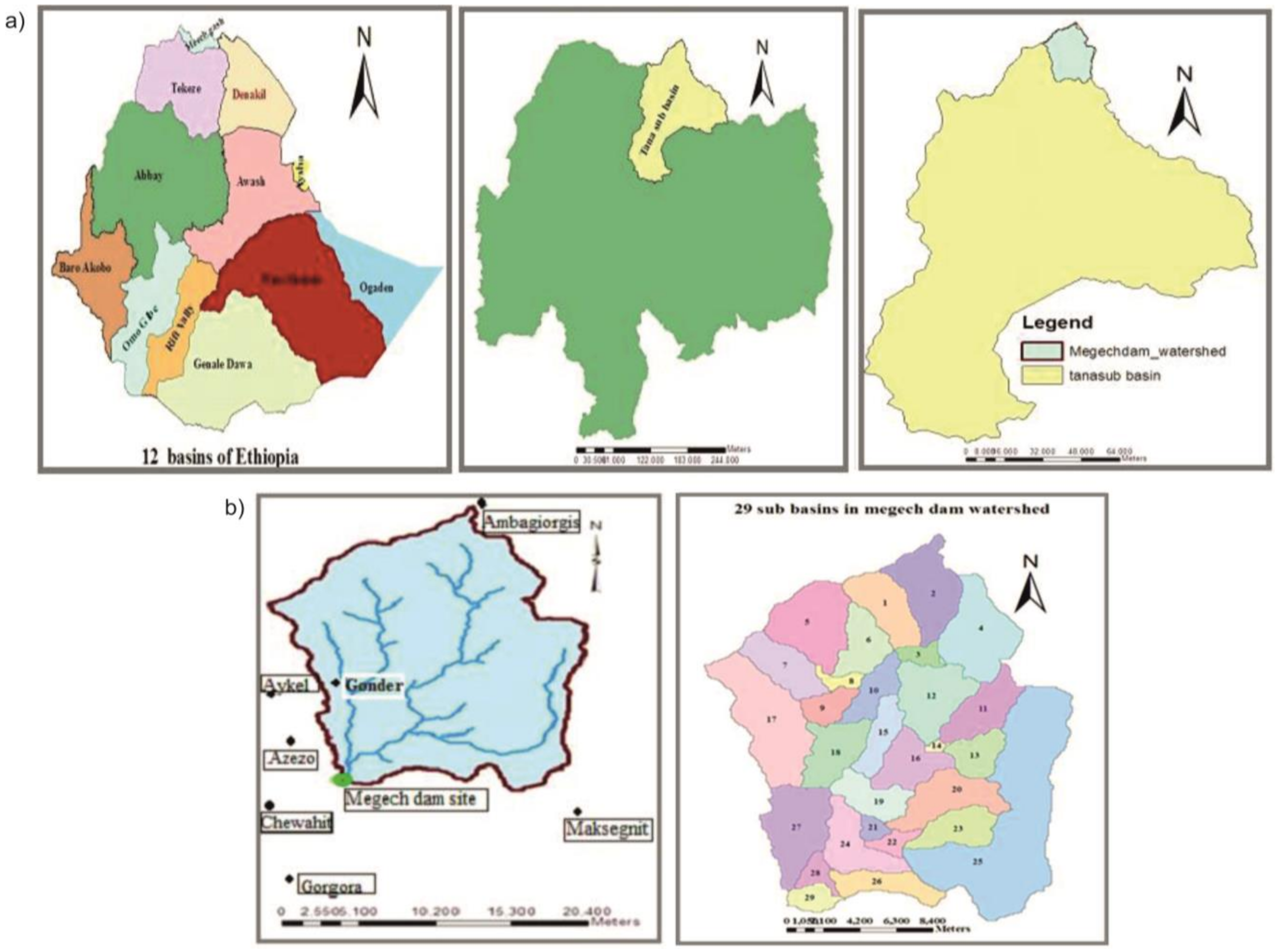

Fig. 1 Location of Megech reservoir catchment in Ethiopia (a) Gauging stations near the study area and the location of the 29 sub-basins in the Megech reservoir catchment (b)

METHODS

There are a wide variety of models used to estimate soil erosion. These models can be physical-based, empirical, and conceptual (Farhan and Nawaiseh, 2015). Arc GIS software and its extension, the Arc SWAT model were used for input data preparation, analysis and modeling purpose of the research. In general, three types of data namely spatial, meteorological and hydrological data were collected for this study. The spatial data (Digital Elevation Map, land use/cover and soil map) have 90m*90m resolution. Fifteen year's daily time series meteorological data (precipitation, air temperature, solar radiation, wind speed, and relative humidity) and hydrological data (streamflow and sediment flow) were also collected starting from Jan 1-2001 to 2015. The data collected were processed until they become an input to the model used. The data processing started by defining all spatial data with the same projection and the watershed delineation. The overlay operation of the land cover map, soil map, and slope map was performed once after the slope classification was made based on the DEM data. Then the hydraulic response unit analysis was done for the spatial input data and the weather/meteorological data table. For the weather generator/ synoptic station all the required values were computed both manually and using helping software such as WGNmaker4.xlsm and dew02.exe program. Finally, the model was parameterized by converting the results of data analysis into model parameters, then model sensitivity analysis, calibration, validation, and simulation were conducted.

Spatial data collection and analysis

A digital elevation map was collected by the Ministry of Water, Irrigation, and Energy (MoWIE). Flat, undulating plains, rolling plains, Hills and mountainous landforms are the major topographic features of the Megech dam watershed (FAO, 2002). The elevation of the study area ranges from 1878 m to 2953 m a.s.l. The source of land use map shown in Fig. 2 was the Ministry of Agriculture and rural development, a rural land management directorate. Spatial distribution and specific land use parameters were required for modeling. 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 interface. Therefore, for the study land uses to be configured by the SWAT lookup table have been prepared and land use types were made compatible with the input needs of the model. Finally, the land uses were reclassified by 4-letter SWAT code and their spatial distribution was prepared. The soil textural and physicochemical properties required by the SWAT model include soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for each soil type. These data were obtained from FAO (2002) and the Ministry of Water Resources, Irrigation and Energy. The shape file which describes the distribution of soil in the study area was obtained from the baseline maps available at MoWIE as shown in Fig. 3.

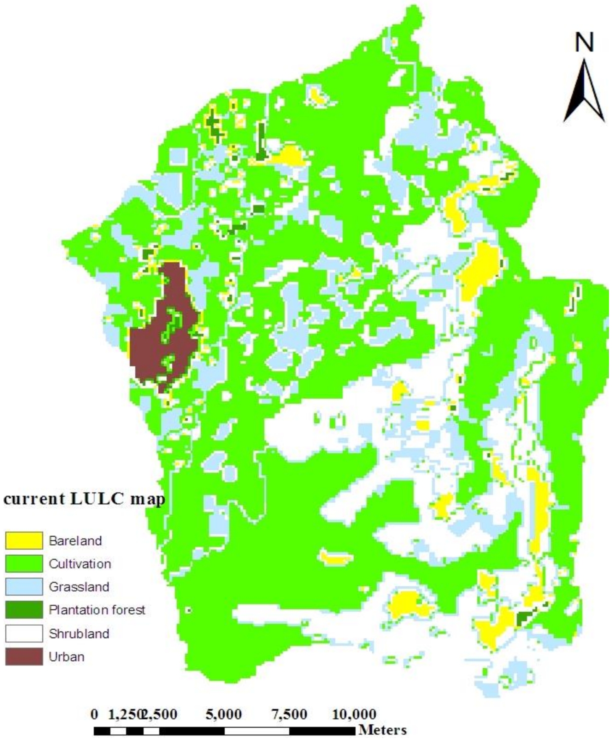

Fig. 2 Land use map of the catchment

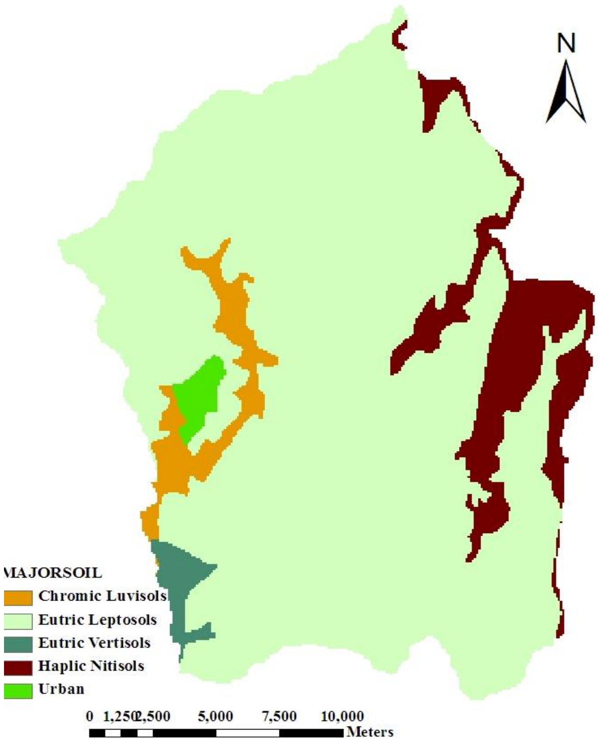

Fig. 3 Soil map of the catchment

Meteorological data collection and analysis

There are six meteorological observation stations within and around the Megech watershed namely Aykel, Gondar, Ambagiorgis, Chewahit, Gorgora, and Maksegnit. For each gauging station, the required daily meteorological data (daily precipitation, daily maximum, and daily minimum air temperature, daily solar radiation, daily wind speed, and daily relative humidity) were collected from the National Meteorological Agency of Ethiopia (NMA) from 2001 to 2015. Checking the availability, quality, consistency, and homogeneity of hydro-meteorological data is imperative for any hydrological model study like SWAT. For this study detail, discussion of both spatial and temporal analysis was made on rainfall, streamflow, and sediment yield. Due to its low impact on the SWAT application, only a simple graphical plot and visual examination was made for the remaining meteorological data.

Rainfall data analysis

Failure of the observer to make the necessary visit to the gage, destruction of recording gages or instrument failure (by mechanical or electrical malfunctioning) may result in missing data. For Hydrological analysis, these missed rainfall data should be first filled with an appropriate method. For this study, missing values were estimated from other stations around the missed record station by using both normal ratio method and simple arithmetic mean method. The normal ratio method was used when the mean monthly rainfall of one or more of the adjacent stations differs from that of the missed record station by more than 10%. Whereas, the simple arithmetic mean method was used when the mean monthly rainfall of all the adjacent stations is within 10% of the station under consideration. Homogeneity of the selected rainfall stations had been checked by using Non-dimensional values of the monthly precipitation. The homogeneity test plot shows that all of the rainfall stations used for this particular study were homogenous and their rainfall pattern was found to be monomodal with high rainfall season from July to September and low rainfall season from February to March. In this study double mass curve, spatial consistency test method is used to check the consistency of rainfall data for the research period.

The spatial analyses of rainfall for all gauging stations were made for the research period (2001-2015) and its result is located in Fig 4. As could be seen from the graph comparisons of the two principal stations were made and Gonder station was found to be the best representative of the catchment than Aykel. Hence, using Gonder station as a weather generator provides better output than using Aykel. Rain gauges represent point sampling of the areal distribution of a storm. In practice, hydrological analysis requires knowledge of the rainfall over an area. Due to its simplicity, the Thiessen polygon method is used to calculate areal rainfall and is given by:

$$P_{ave} = \sum_{i=1}^{n} \left(\frac{Pi * Ai}{At}\right)$$

where p_{ave} is average areal rainfall (mm), P_1, P_2, $P_3 \ldots P_n$ is precipitation of station 1, 2, 3…n, respectively and A_1, A_2, $A_3 \ldots A_n$ is area coverage of station 1, 2, 3…n respectively in the Thiessen polygon.

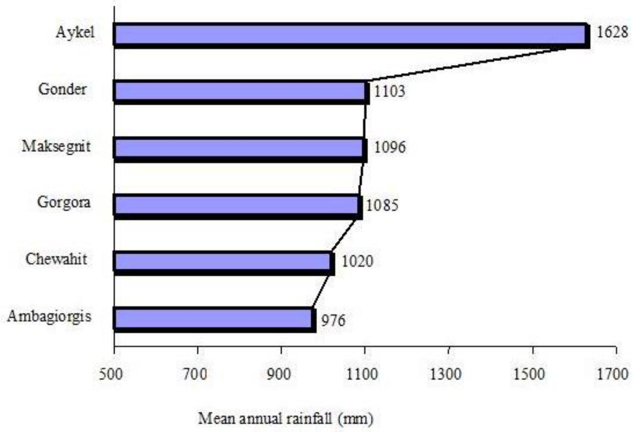

Fig. 4 Mean annual rainfall of stations in the catchment (2001-2015)

Hydrological data collection and analysis

Both the daily streamflow and sediment data were collected from the Ministry of Water, Irrigation, and Energy (MoWIE), from 2001 to 2015 (starting on Jan 1-2001) at Azezo gauging station. Unlike streamflow data, sediment data records exhibit several jumps. Due to the lack of continuous-time step suspended sediment records, the sediment rating curve was developed for this particular study by using the measured sediment records as a function of the corresponding streamflow values. The sediment rating curve is a widely applicable technique for estimating the suspended sediment load being transported by a river through signifying a relationship between the stream discharge and sediment concentration or load (Clarke, 1994).

The general relationship of suspended sediment rating curve can be written as:

$Qs = a*Q^b$

where: Qs is sediment load in t/day, Q is the stream discharge in m^3/s and a & b are regression constants. To work on the above formula the first task was the conversion of the measured suspended sediment concentration (mg/l) records that were collected from the MoWIE into sediment load (t/day) by using the following conversion formula:

$S = 0.0864 \times Q \times C$

where: S is sediment load in (t/day), Q is streamflow (m^3/s), C is sediment concentration (mg/l) and 0.0864 is conversion factor.

$Qs = 28.46*Q^{1.213}$

where: Q is streamflow (m^3/s) and Qs suspended sediment load (t/day). The relationship is known as the suspended sediment rating curve and is shown in Fig. 5.

SWAT simulation is based on the total sediment load (suspended + bed load). However, there was no measured data on bedload material. Hence considering the mountainous nature of Megech River it was decided that the bedload for the Megech catchment would be estimated as being 10% of the suspended load (WWDS, 2008).

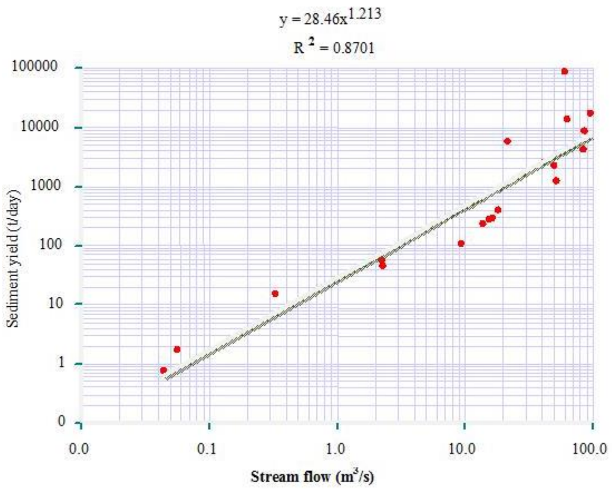

Fig. 5 Sediment rating curve of Megech River (Nr. Azezo)

SWAT model set up

The Megech reservoir catchment modeling was done by the SWAT model that is compiled using the AVSWATX interface (ArcView GIS interface for SWAT). The first step in the SWAT model setup was watershed delineation and stream network determination (Neitsch et al. 2009) using the Megech reservoir catchment DEM and taking the center of the Megech dam axis at the river bed level as an outlet point. Next, the study catchment was divided into sub-watersheds based on the concept of flow direction and accumulation; and sub-watersheds were further subdivided into smallest unit called hydraulic response units which consist of unique combinations of homogeneous soil, land use properties, and slope range (Arnold et al., 2012). The runoff and sediment yield is estimated separately for each hydraulic response unit and routed to obtain the total value for the watershed (Winchell et al., 2007). Finally, weather data definition and simulation were followed by sensitivity analysis and calibration.

Sensitivity analysis, calibration, and validation

The default simulation output in the SWAT model run can not be directly used for further analysis. Instead, the ability of the model to sufficiently predict the constituent streamflow and sediment yield should be evaluated through sensitivity analysis, model calibration, and validation (White, 1992). Performing the calibration process for all model parameters becomes complex and computationally far-reaching. In such cases, sensitivity analysis is helpful to identify and rank parameters that have a significant impact on specific model outputs of interest. The flow and sediment parameters considered by the model for sensitivity analysis are shown in Table 1 and Table 2 respectively. The sensitivity analysis method implemented in the SWAT model is called the Latin Hypercube One-At –a-Time (LH-OAT) design (van Griensven and Srinivasan, 2005). After running sensitivity analysis, the sensitive parameters were categorized into four classes based on their mean relative sensitivity (MRS). The four classes are Small to negligible ($0 \leq MRS < 0.05$), Medium ($0.05 \leq MRS < 0.2$), High ($0.2 \leq MRS < 1$) and Very high ($MRS \geq 1$) (Lenhart et al., 2002). Based on this classification, both flow and sediment parameters with mean relative sensitivity value of medium to very high had been selected for calibration.

For this study, the sensitivity analysis was performed from January 1, 2003, to December 31, 2009, in which the first two years (2001 and 2002) were taken as warm-up periods. Model calibration is the modification of parameter values and comparison of predicted output of interest to measured data until a defined objective function is achieved (James and Burges, 1982). Calibration of streamflow and sediment yield was carried out at the outlet of sub-basin 29 (near Azezo gauging station). Model validation is testing of calibrated model results with independent data set without any further adjustment (Neitsch, 2005) at different spatial and temporal scales. Table 3 shows both the calibration and validation periods.

Table 3 Calibration and validation periods for flow and sediment

Types of Simulation	Period of Simulation
flow calibration	2001 - 2009
flow validation	2010 - 2015
Sediment calibration	2001 - 2009
Sediment validation	2010 - 2015

Performance evaluation of the SWAT model

Three methods for performance evaluation of model predictions were used during the calibration and validation periods namely Regression coefficient (R^2), Nash and Sutcliffe simulation efficiency (ENS) and Relative Volume Error (RVE). R^2 value greater than 0.6 is acceptable (Santhi et al., 2001) and its value can be calculated by the following equation:

$$R^2 = \frac{\left[\sum_{i=1}^{n}(q_{si}-q_s)(q_{oi}-q_o)\right]^2}{\sum_{i=1}^{n}(q_{si}-q_s)^2\sum_{i=1}^{n}(q_{oi}-q_o)^2}$$

Table 1 Flow parameters for sensitivity analysis

Flow parameters used for sensitivity analysis	unit	SWAT_code
Alpha base flow recession constant	day	Alpha_Bf
Threshold depth of water required for return flow to occur	mm	Gwqmn
Initial SCS CN II value	%	Cn2
Soil evaporation compensation factor	_	Esco
Effective Channel Hydraulic Conductivity	mm/hr	Ch_K2
Available water capacity	mm water/mm soil	Sol_Awc
Threshold depth of water required for evaporation to occur	mm	Revapmn
Soil depth	mm	Sol_Z
Maximum Potential Leaf Area Index	_	Blai
Maximum Canopy Index	mm	Canmx
Groundwater evaporation coefficient	_	Gw_Revap
Soil conductivity	mm/hr	Sol_K
Ground water delay	day	Gw_Delay
Average slope steepness	m/m	Slope
Manning coefficient for channel	_	Ch_N2
Plant evaporation compensation factor	_	Epco
Surface runoff lag coefficient	_	Surlag
Soil Albedo	_	Sol_Alb

Table 2 Sediment parameters for sensitivity analysis

Sediment parameters used for sensitivity analysis	unit	SWAT_code
USLE support Practice factor	_	Usle_P
Average slope steepness	m/m	Slope
Linear factor for channel sediment routing	_	Spcon
Available water capacity	mmH2O /mm soil	Sol_Awc
Soil Albedo	_	Sol_Alb
Exponential factor for sediment routing	_	Spexp
Soil conductivity	mm/hr	Sol_K
Maximum Potential Leaf Area Index	_	Biomix
Channel Cover factor	_	Ch_Cov
Channel Erodibility factor	_	Ch_Erod
USLE cover factor	_	Usle_C

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, q_s is the average simulated value of the quantity in each model time step, q_o is the average measured value of the quantity in each model time step.

ENS value greater than 0.5 is acceptable (Nash and Suttcliffe, 1970) and its value can be calculated as follows:

$$ENS = 1 - \frac{\sum_{i=1}^{n}(q_{oi} - q_{si})2}{\sum_{i=1}^{n}(q_{oi} - q_{o})^2}$$

where: q_{si} is the simulated values of the quantity in each model time step, and q_{oi} is the measured values of the quantity in each model time step and q_o is the average measured value of the quantity in each model time step.

A relative volume error of less than +5 % or -5% indicates that a model performs well while relative volume errors between +5% and + 10% and – 5% and -10 % indicate a model with reasonable performance.

$$RVE = \frac{\sum(Qsim - Qobs)}{\sum Qobs} * 100\%$$

where RVE is relative volume error in %, Q_{sim} is simulated discharge and Q_{obs} is observed discharge in each model time step.

RESULTS AND DISCUSSION

Stream flow modeling

Eight flow parameters with a sensitivity class of very high to medium were selected for calibration as listed in Table 4. The simulated mean annual streamflow after calibration shows a good agreement with the observed data set as indicated in Fig. 6. Even though the pattern agreement was good for simulated and calibrated model the streamflow volume error was found to be -8.64 during the calibration period. The possible causes can be inefficient manual calibration, incorrect rainfall and streamflow record, error in estimating missed flow and precipitation data. R^2 = 0.71 and ENS= 0.63 were calculated.

During the validation period (2010-2015) the performance of the model was evaluated and gives a value of R^2= 0.79 and ENS = 0.83. Even though the relative volume error is somewhat large the (R^2) and (ENS) value lies in the acceptable range, hence it is possible to say that the SWAT model was successful to simulate realistic flow with a little deviation from observed streamflow for this particular research as shown in Fig. 7.

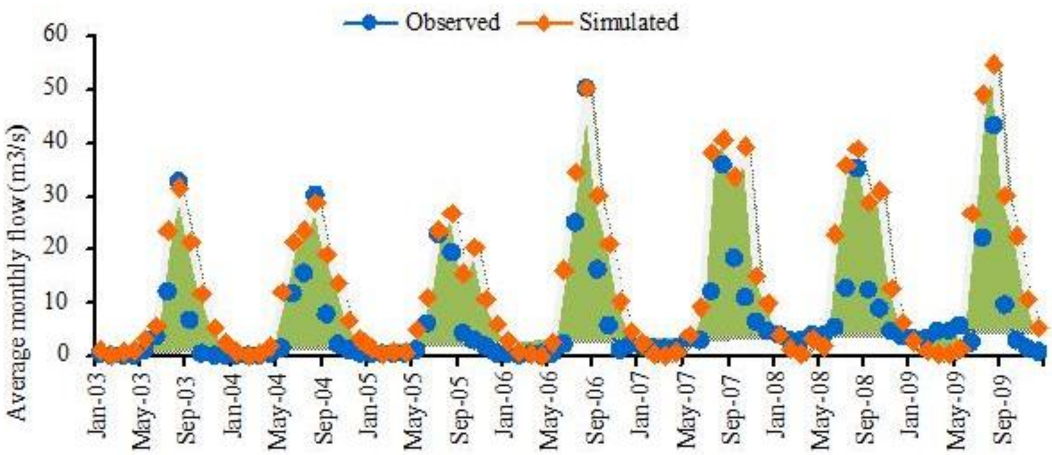

Fig. 6 Observed and simulated streamflow for the calibration period (2003-2009)

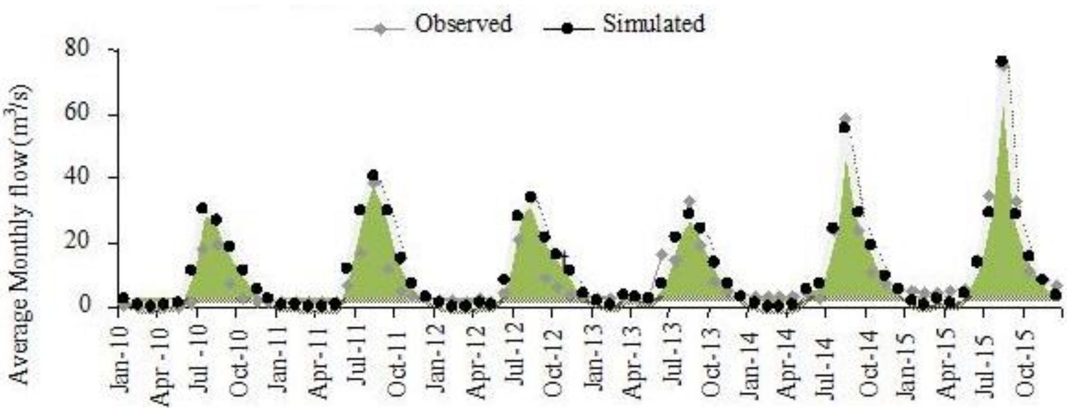

Fig. 7 Observed and simulated streamflow for the validation period (2010-2015)

Table 4 Calibrated values of sensitive flow parameters

Rank	Flow parameters	Sensitivity index (MRS)	Class of sensitivity	Allowable range of calibration	Calibrated values
1	Alpha_Bf	1.39E+00	very high	0-1	0.091
2	Gwqmn	2.56E-01	high	0-1000	360
3	Cn2	9.46E-02	medium	±25	11
4	Esco	9.22E-02	medium	0-1	0.91
5	Ch_K2	5.32E-02	medium	0-1	0.71
6	Sol_Awc	5.25E-02	medium	±25	5.8
7	Revapmn	5.24E-02	medium	0-1000	291
8	Sol_Z	5.10E-02	medium	±25	21

Sediment yield modeling

Six sediment parameters with a sensitivity class of very high to the medium were selected for calibration as listed in Table 5. Unlike streamflow simulation, the mismatch gap between measured and simulated sediment yield was found to be large for default simulation. The possible cause for this variation might be the lack of enough measured sediment data used during sediment rating curve development as most of the sediment samples were not representatives of the whole simulation periods. The sediment yield was initially calibrated manually for mean annual conditions until the simulated output coincides with the measured sediment load (t/ha/year).

Next to mean annual sediment yield calibration the monthly time step calibration was carried out by varying sediment sensitive parameters iteratively within the allowable ranges until a satisfactory agreement between observed and simulated sediment yield was obtained. Lastly monthly time step sediment yield hydrograph was developed to compare the observed and simulated sediment load values for the calibration period. The comparison between observed and simulated sediment flow for the calibration period was shown in Fig. 8. Disparate from calibration, the sediment yield hydrograph of measured and simulated output during the validation period shows a good agreement. This was mainly due to the availability of enough measured sediment samples taken during the validation period which later used for sediment rating curve preparation. This ensures that the observed sediment load data used for model input during the validation period were more representative and better approach to reality than the calibration period. The comparison between observed and simulated sediment flow for the validation period was shown in Fig. 9. Finally, measures of model performance values for sediment were summarized in Table 6. The model performance standard used to evaluate the model result indicates that the model was superior in performing the trend of runoff and sediment yield in both calibration and validation periods.

Table 5 Calibrated values of sensitive sediment parameters

Rank	Sediment parameters	Sensitivity index (MRS)	Class of sensitivity	Allowable range of calibration	Calibrated values
1	Usle_P	2.71E+00	very high	0-1	0.81
2	Slope	1.01E+00	very high	±25	6.1
3	Spcon	4.86E-01	high	0.0001-0.01	0.0041
4	Sol_Awc	3.11E-01	high	±25	15.3
5	Sol_Alb	5.62E-02	medium	±25	-3
6	Spexp	5.26E-02	medium	1-2	1.43

Table 6 Measures of model performance for sediment

Parameters	Calibration (2003-2009)	Validation (2010-2015)
R^2	0.82	0.9
ENS	0.77	0.81

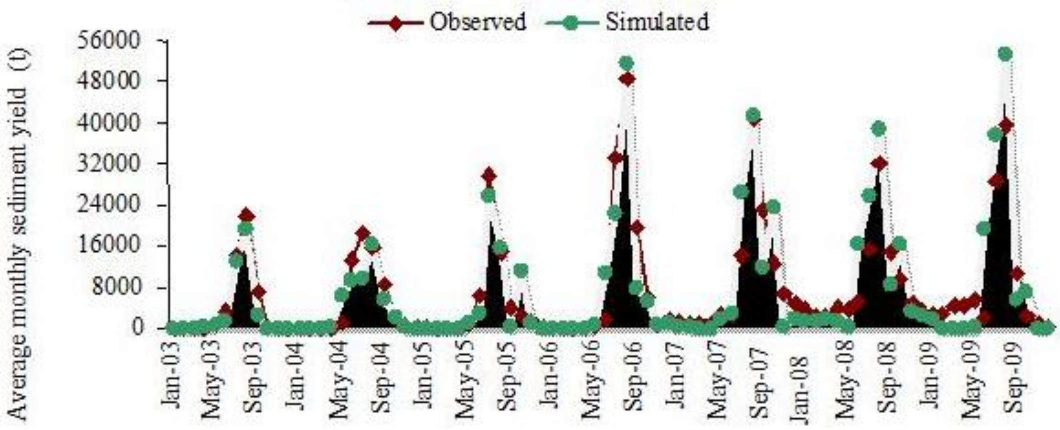

Fig. 8 Observed and simulated sediment flow for calibration period (2003-2009)

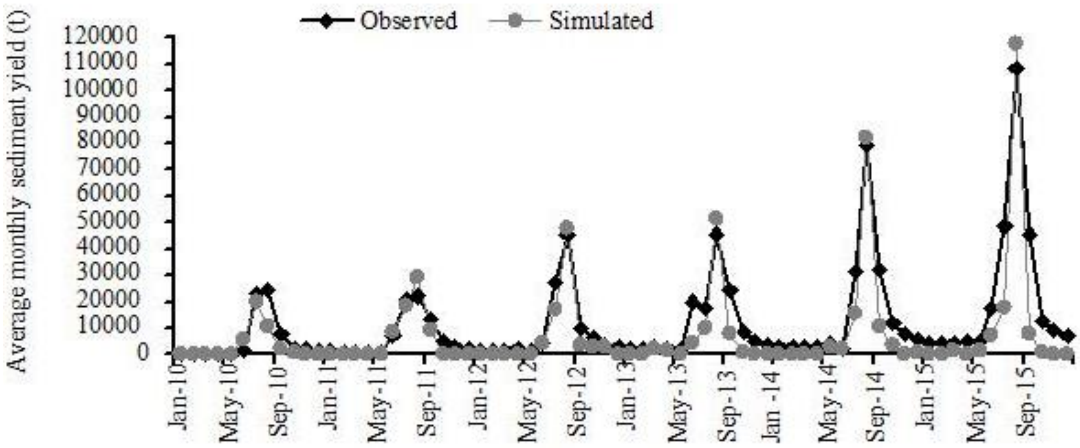

Fig. 9 Observed and simulated sediment flow for the validation period (2010-2015)

Spatial model responses to runoff and soil loss

Once sensitivity analysis, calibration, and validation of the model was done for both streamflow and sediment yield the next step was to simulate the model for the whole period of research baseline (2001-2015) and quantify the model response to runoff and soil loss as shown in Table 7. The catchment was subdivided into 29 sub-basins as shown in the location map. The erosion risk map was developed depending on the severity classes adopted from Haregeweyn et al. (2017). Based on Haregeweyn et al. (2017) recommendation the soil loss (t/ha/year) < 5 was very slight, 5-15 slight, 15-30 moderate, 30-50 severe and > 50 was very severe. The map showed that 33.25 % and 66.75 % of the catchment area was experienced slight and moderate soil erosion rate respectively. On average 12.33 t/ha mean annual sediment load gets into the Megech reservoir. The overall spatial distribution of the soil erosion on the catchment was summarized in Table 8. Sub-basin 7, 25, 27, 18 and 29 contribute the highest mean annual sediment load to the Megech reservoir and are identified as the most erosion vulnerable sub-basins of the Megech reservoir with 17.8, 16.86, 15.97, 15.91 and 15.74 t/ha/year soil loses respectively.

Table 7 Model response to runoff and soil erosion

Runoff (mm)	Sediment yield (t/ha)	Base flow (mm)	Total water yield (mm)
282	12.33	504	786

The land use/land cover map shows that the catchment is covered by 64.34 % of cultivated land, 1.19 % of plantation forest, 7.8 % of grassland, 20.59 % of shrubland, 2.95 % of bare land and 3.14 % of urban. Most of the erosion of vulnerable sub-basins are covered with cultivated/agricultural land uses. An agricultural land is exposed to pulverization of the soil during the frequent tillage practice in the study area and increases the erosion rate as it could be seen in the field visit. The soil map shows that the catchment is covered by 84.35% Eutric Leptosols, 9.47% Haplic Nitisols, 3.77% Chromic Luvisols, 1.04 Urban and 1.38% Eutric Vertisols.

Table 8 Spatial distribution of sediment yield in Megech reservoir catchment

Sub-basins	Area (ha)	Mean annual surface runoff (mm)	Mean annual soil loss (t)	Sediment yield (t/ha)	Rank
1	1419.8	233	14,354	10.11	23
2	1889.9	230	18,710	9.9	23
3	324.04	204	2,262	6.98	28
4	2272.4	207	25,224	11.1	22
5	2178.1	235	18,100	8.31	25
6	1109.1	221	10,159	9.16	24
7	1292	301	22,998	17.8	1
8	262.24	271	2,145	8.18	26
9	613.84	352	7,992	13.02	14
10	861.88	303	12,825	14.88	8
11	1307.8	216	15,471	11.83	19
12	1870.7	185	25,086	13.41	10
13	837.66	315	9,809	11.71	20
14	90.197	236	1,341	14.87	9
15	901.13	261	11,904	13.21	12
16	1216.8	253	8,652	7.11	27
17	3091.7	390	39,110	12.65	16
18	1332.1	262	21,194	15.91	4
19	1038.1	387	16,070	15.48	6
20	1631.1	271	21,824	13.38	11
21	238.85	328	3,580	14.99	7
22	345.75	311	4,522	13.08	13
23	1090.7	290	12,118	11.11	21
24	1393.9	327	17,717	12.71	15
25	6925.9	390	116,771	16.86	2
26	983.81	250	6,306	6.41	29
27	2047.8	322	32,703	15.97	3
28	379.16	296	4,489	11.84	18
29	472.7	331	7,440	15.74	5
Average basin value:		282	17,616	12.33	

Eutric Leptosols are the dominant soil type in these areas as it could be seen in the soil map of the study area and the relief is hills type, which could be also another reason for the increments of soil erosion. Considering the above land use, soil type, slope, and relief of erosion vulnerable sub-basins cut off drains, fallow land, contour ploughing, Fanya juu terraces, soil bunds combined with trenches and trees could be the possible management strategies to reduce the sediment yield in the catchment.

CONCLUSIONS

As per the objective of this particular research the spatial distribution of sediment yield was estimated and erosion vulnerable sub-basins were ranked and analyzed statistically by using a semi-distributed model called SWAT. The model performance criterion used to evaluate the model result indicates that the model was superior in performing the trend of sediment yield in both calibration and validation periods. The simulated output of the model shows that 12.33 t/ha/year sediment load gets into the Megech reservoir. But, Megech Dam design report shows as the dead storage capacity of the dam was designed by considering 11.7 t/ha/year sedimentation rates. Hence, the designers are recommended to revise the dead storage capacity of the reservoir to include the incremental rate of sedimentation. Beside this local governments and policymakers are highly recommended to implement appropriate management strategies such as cut off drains, fallow land, contour ploughing, Fanya juu terraces, soil bunds combined with trenches and trees on that erosion vulnerable sub-basins to maximize the design span life of the Megech reservoir through reducing the sediment yield generated from the catchment.

The major limitation during this research work was lack of bedload data and continuous measured suspended sediment data. Only a few sediment concentration measurements were available during different years. The best option for this problem was to generate the daily sediment data from sediment rating curves developed by using available measurements. Therefore, to get better-simulated sediment output that approaches the actual measured data responsible bodies are recommended to record frequent and reliable sediment data.

Finally, this study does not consider a scenario changes to compare the corresponding changes in streamflow and sediment yield. But, different variables such as land use land cover changes, climate changes, and management activities might have a significant impact on streamflow and sediment yield of the research area. Hence, future researchers are highly recommended to consider these variables for estimating the corresponding impacts on streamflow and sediment yield.

Acknowledgment

I would like to express my deep gratitude to the staff of the Ministry of Water, Irrigation, and Energy (MoWIE) and the National Meteorological Service Agency (NMA) for providing access to data on hydrology and meteorology respectively. International Water Management Institute (IWMI), Water Works Design and Supervision Enterprise (WWDSE) and Ministry of Agriculture and rural development (MoARD) of Ethiopia are duly acknowledged in availing the necessary spatial data. I am also thankful to Debre Berhan University staff for their all-rounded support and cooperation.

References

Admasu, A. 2005. Sediment yields from the watershed of Angerb reservoir. M.S.c thesis, Alemaya University.

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., Santhi, C., Harmel, R. D., Van Griensven, A., Van Liew, M. W., Kannan, N., Jha, M.K. 2012. SWAT Model Use, Calibration, and Validation. *Trans ASABE* 55, 1491–1508. DOI: 10.13031/2013.42256

Clarke, R.T. 1994. Statistical Modeling in Hydrology, 412 p.

EFD, 2010. Green accounting puts price on Ethiopian soil erosion and deforestation. Environment for Development. Online available at: http://efdinitiative.org/our-work/policy-interactions/green-accounting-puts-price-ethiopian-soil-erosion-and-deforestation

FAO, 2002. Major Soils Of The World. Land and Water Digital Media Series Food And Agricultural Organization of The United Nations, Rome.

Farhan, Y., Nawaiseh, S. 2015. Spatial assessment of soil erosion risk using RUSLE and GIS techniques. *Environ Earth Sci* 74, 4649–4669. DOI: 10.1007/s12665-015-4430-7

Gashaw, T., Tulu, T., Argaw, M. 2018. Erosion risk assessment for prioritization of conservation measures in Geleda watershed, Blue Nile basin, Ethiopia. *Environ Syst* Res 6(1), 1–14. DOI: 10.1186/s40068-016-0078-x

Haregeweyn, N., Tsunekawa, A., Poesen, J., Tsubo, M., Meshesha, D.T., Fenta, A.A., Nyssen, J., Adgo, E. 2017. Comprehensive assessment of soil erosion risk for better land use planning in river basins: a case study of Upper Blue Nile River. *Sci Total Environ* 574, 95–108. DOI: 10.1016/j.scitotenv.2016.09.019

Ifabiyi, A. 2004. Reduced rank model of drainage basin response to runoff in Upper Kaduna catchment of Northern Nigeria. *Geo studies forum* 2(1), 109–117.

James, L.D., Burges, C.T., Haan, H.P., Johnson, D.L. 1982. Selection, calibration, and testing of Hydrologic models. In: Hydrologic Modeling of Small Watersheds, ASAE Monograph, St. Joseph, Michigan, 437–472.

Khadse, G.K., Vijay, R., Labhasetwar, P.K. 2015. Prioritization of catchments based on soil erosion using remote sensing and GIS. *Environ Monit Assess* 187 (6), 333. DOI: 10.1007/s10661-015-4545-z

Lenhart, T., Eckhardt, K., Fohrer, N., Frede, H.G. 2002. Comparison of two different approaches of sensitivity analysis. *Physics and Chemistry of the Earth*, Parts A/B/C 27 (9-10), 645–654. DOI: 10.1016/s1474-7065(02)00049-9

Miheretu, B.A., Yimer, A.A. 2018. Estimating soil loss for sustainable land management planning at the Gelana sub-watershed, Northern Highlands of Ethiopia. *Int J River Basin Manag* 16(1), 41–50. DOI: 10.1080/15715124.2017.1351978

Monsieurs, E., Dessie, M., Adgo, E. 2015. Seasonal surface drainage of sloping farmland: a review of its hydrogeomorphic impacts. *Land Degrad Dev* 26(1), 35–44. DOI: 10.1002/ldr.2286

Nash, J. E., Sutcliffe, J.V. 1970. River flow forecasting through conceptual models. *Journal of Hydrology 13*, 297–324.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R. 2005. Soil and Water Assessment Tool (SWAT) Theoretical Documentation, Version 2005, Grassland Soil and Water Research Laboratory, Agricultural Research Service, Backland Research Center, Texas Agr. Experiment Station.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R, Williams, J.R. 2009. Soil and Water Assessment Tool Theoretical Documentation, Version 2009. USDA Agricultural Research Service And Texas A&M Blackland Research Center, Temple, TX.

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., Urquhart, P. 2014. Climate change 2014: Impacts, adaptation, and vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Prasannakumar, V., Vijith, H., Abinod, S., Geetha, N. 2012. Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation

(RUSLE) and geo-information technology. *Geosci Front* 3(2), 209–215. DOI: 10.1016/j.gsf.2011.11.003

Santhi, C., Arnold, J.G., Williams, J.R., Dugas, W.A., Srinivasan, Hauck, L.M. 2001.Validation of the SWAT model on a large river basin with point and non point sources. *JAWRA* 37(5), 1169–1188. DOI: 10.1111/j.1752-1688.2001.tb03630.x

Setegn, S. G., Srinivasan, R., Dargahi, B. 2007. Streamflow Calibration and Validation of SWAT2005/Arc SWAT in Anjani Gauged Watershed Northern Highlands of Ethiopia. In the proceedings of the 4th International SWAT Conference, July 02-06, UNESCO-IHE, Delft, The Netherlands. DOI: 10.1111/j.1752-1688.2010.00431.x

Tamene, L., Park, S. J., Dikau, R., Vlek, P. L. 2006. Analysis of factors determining sediment yield variability in the highlands of northern Ethiopia. *Geomorphology* 76(1-2), 76–91. DOI: 10.1016/j.geomorph.2005.10.007

Tebebu, T.Y., Abiy, A.Z., Zegeye, A.D., Dahlke, H.E., Easton, Z.M., Tilahun, S.A, Collick, A.S., Kidanu, S., Moges, S., Dadgar, F., Steenhuis, T.S. 2010. Surface and sub-surface flow effect on permanent gully formation and upland erosion near Lake Tana in the northern highlands of Ethiopia. *Hydrol Earth Syst Sci* 14(11), 2207–2217. DOI: 10.5194/hess-14-2207-2010

Tully, K., Sullivan, C., Weil, R., Sanchez, P. 2015. The state of soil degradation in sub-Saharan Africa: Baselines, trajectories, and solutions. *Sustainability* 7(6), 6523–6552. DOI: 10.3390/su7066523

van Griensven, A., Srinivasan, R. 2005. AVSWATX SWAT-2005 Advanced Workshop workbook. SWAT2005 3rd Int.conf. July 11–15, 2005, Zurich, Switzerland.

Wainwright, J., Brazier, R.E. 2011. Slope systems. In: Thomas D.S.G (ed) Arid zone geomorphology: process, form, and change in drylands. Wiley, Hoboken. ISBN 978-0-470-71076-0

WWDSE, 2008. Megech dam feasibility design report. Water Works Design & Supervision Enterprise, Addis Abeba, Ethiopia.

White, S.M. 1992. Sediment yield estimation from limited data sets: A Philippines case study: Ph.D. Thesis, University of Exeter, UK.

Winchel, M., Srinivasan, R., Di Luzio, M., Arnold, J. 2007. Arc-SWAT interface for SWAT users Guide. Blackland research center, Texas agricultural experiment station, and USDA agricultural research service.

Woldemariam, G.W., Iguala, A.D., Tekalign, S., Reddy, R.U. 2018. Spatial modeling of soil erosion risk and its implication for conservation planning: the case of the Gobele Watershed, East Hararghe Zone, Ethiopia. *Land* 7, 25. DOI:10.3390/land7010025

Zerihun, M., Mohammedyasin, M.S., Sewnet, D., Adem, A.A., Lakew, M. 2018. Assessment of soil erosion using RUSLE, GIS and remote sensing in NW Ethiopia. *Geoderma Regional* 12, 83–90. DOI: 10.1016/j.geodrs.2018.01.002