Estimation of Runoff and Sediment Yield Using Soil and Water Assessment Tool Model in Dedeba Watershed, Rift Valley Lake Basin of Ethiopia

Dulo Husen*, Ayub Jelde, Anbase Ambomsa and Zelalem Shalemew

Oromia Agricultural Research Institute, Adami Tulu Agricultural Research Center, P. O. Box 35, Batu, Ethiopia.

*Corresponding Author: dulohusen196@gmail.com

Abstract

Runoff and sediment yield estimation is important in the watershed to alleviate soil erosion and identify hotspot area for intervention strategies. The objectives of this study is to estimate runoff and sediment yield in sub watershed and prioritize and map the watershed in terms of sediment yield rate and runoff potential using SWAT model. From the result of the Global sensitivity analysis, fourteen highly sensitive parameters identified and used for calibration and validation. The model was calibrated manually by adjusting sensitive parameters using observed data from 1990 to 2001, and validation was done using observed data from 2002 to 2007. The model performance was checked by statistical model performance evaluators such as the coefficient of determination (R^2) and Nash–Sutclife model efficiency (ENS) and it shows that the model has a high potential in the estimation of runoff and sediment yield. Statistical model performance evaluator of calibration result shows a satisfactory agreement between the observed and simulated stream flow and sediment yield parameters. Whereas, statistical model performance evaluator of validation result shows a good agreement between the observed and simulated stream flow and sediment yield parameters. Among 29 sub-watersheds, nine sub watersheds were more vulnerable/hotspot area to soil loss and potentially prone to erosion risk. Based on the hydrological simulation integrated watershed management plan should be implemented for effective land and water resource development. Hence, the outputs of this study will be used by decision maker to plan and implement appropriate soil and water conservation strategies in the hot spots area.
Keyword: Calibration, Runoff, Sediment Yield, SWAT model, Watershed and Validation
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Introduction

Each year, in Ethiopia it is estimated that 1.5 billion tons of top soil is washed away from their original location (Hurni, 1987) and degradation of land through soil erosion is increasing. The Central Rift Valley (CRV) of Ethiopia is greatly affected by soil erosion, sediment transport and land degradation. The CRV is one of the environmental vulnerable areas in the country. The land and water resources of the area are adversely affected by the rapidly growing population, deforestation, absences of SWC, over cultivation, overgrazing and rising demand for cultivated land have been the driving force to a series of soil erosion in the basin in general and in Dedeba watershed in particular (MOARD, 2004).

In order to reverse soil erosion, several efforts have been exerted since the 1970s (Menale et al. 2009; Nigussie et al. 2012). However, past soil conservation efforts did not bring significant changes to the ongoing soil degradation problems (Menale et al. 2009). Most recently, watershed management is an approach followed by the government of Ethiopia to protect soil from erosion in particular and to reverse land degradation in general (Desta et al. 2005; Gete 2006; Nigussie et al. 2012). Although dramatic reduction has been made in arresting soil erosion (AgWater Solutions 2012; Nigussie et al. 2012; Tongul and Hobson 2013), the approach has not been supported with intervention prioritizing techniques that identify highly susceptible areas using geospatial analysis.

The rift valley river watersheds suffer severe land degradation and soil erosion due to extended dry seasons in some parts of the Basin, torrential rain and geological nature, bringing large quantities of sediment in the drainage systems (Mengist, 2017). Human occupation of the rift valley has placed extreme pressure on the natural flora and fauna, which is rapidly disappearing. During the last three decades there has been large-scale clearing of natural vegetation for agriculture, overgrazing of natural grasslands, and clearing of forests for construction material and fuel. Moreover, intensive cultivation of annual crops and deforestation of forest has caused serious erosion problems in the Dedeba watershed, resulting in soil nutrient depletion or soil fertility reduction. In addition, steeper slopes are cultivated without protective measures against land erosion and degradation in the study area. Land degradation due to soil erosion by water not only reduced the productivity of the land in this watershed, but also causes siltation at the downstream of watershed. This process has aggravated degradation in the area resulting in on-site soil erosion and off-site heavy sedimentation. Unless the magnitude of the erosion–sedimentation problem is understood and appropriate watershed management intervention implemented, the increasing amount of soil erosion suggests that lakes in the CRV face a similar fate to the reservoirs of northern and eastern Ethiopia. Thus, estimations of soil loss and identifications of hotspot regions are important to in order to preserve naturally balanced watershed. Dedeba watershed has been under intensive commercial and public use over the past decade, leading to rapid decline in the natural vegetation, water availability and productivity.

One of the possible solutions to alleviate the problem of land degradation (soil erosion) is to understand the processes and cause of erosion at a micro watershed level and to implement watershed management interventions. The estimation of soil erosion loss and evaluation of soil erosion risk has become an urgent task before implementing soil conservation practices in the study area. Identification of the hotspot areas that are significantly affected is essential to prioritize problem-oriented and site–specific watershed management efforts. However, there is no sufficient research work on this issue before in the watershed. The total amounts of surface runoff volume and sediment yields annually leaving the watershed are not easily quantified. Therefore, surface runoff and sediment yield estimation is important for future watershed management by knowing the amount of losses. SWAT model is important to predict reliable quantity and rate of sediment transport from land surface and identify erosion prone areas within a watershed. Hence, identifying and prioritizing erosion susceptible areas for soil conservation measures are quite essential. Therefore, the objectives of this study is to estimate runoff and sediment yield in sub watershed; and prioritize and map the watershed in terms of sediment yield rate and runoff potential using SWAT model.

Materials and Methods

Description of study area

The study area is found in the Ziway shala sub basin and darins to Lake Shala. Geographical, it situated between UTM zone of 778000 meter N to 820000 meter N ($7^0$20'N - $7^0$25'N) and 460000 meter E to 495000 meter E ($38^0$38'E - $38^0$57'E) as shown in the Figure 1 below. The catchment covered three woredas administrations; these are Shashemene, Negele Arsi and Kofal. From this, most part of watershed was fallen in kofale woreda, which accounts 88.073 Km^2. Moreover, the small watershed was fallen in Shashemene woreda, which accounts 22.127 Km^2 and 26.45% was fallen in Negele Arsi woreda. The total land area is estimated about 141.64Km^2.

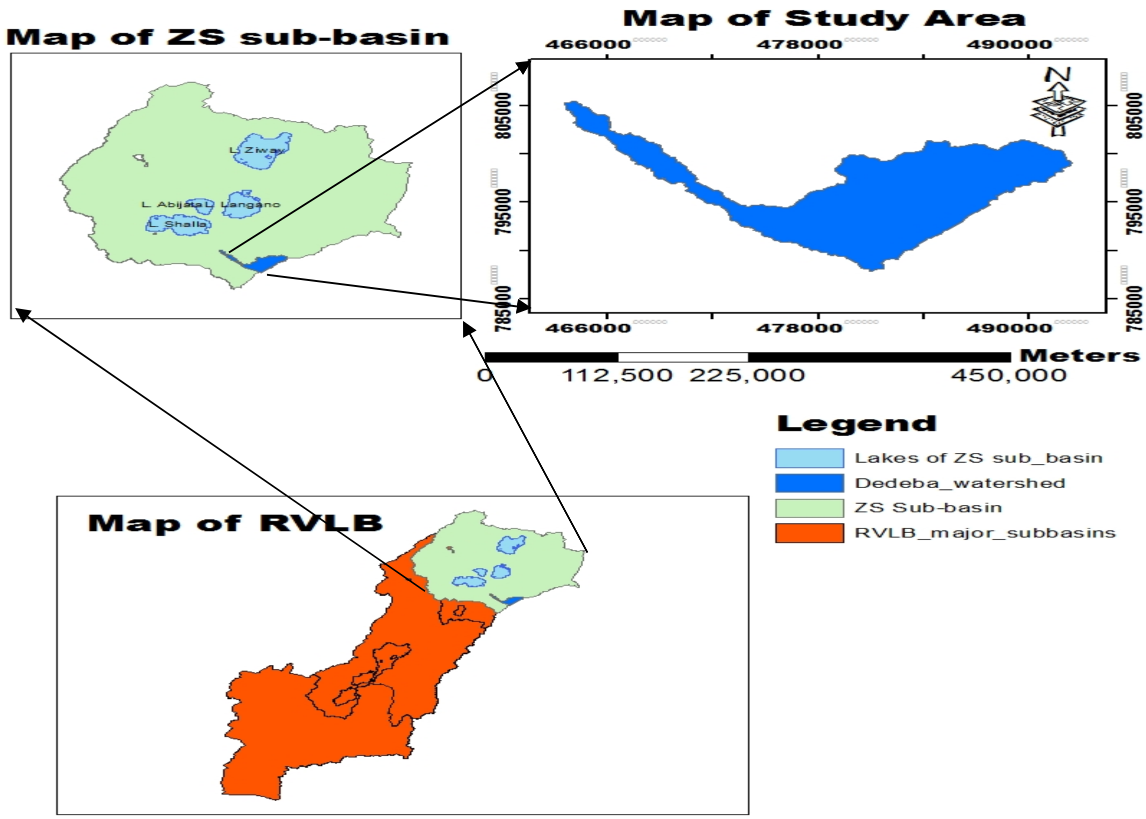

Figure 1: Study watershed

Hydro meteorological data

The three meteorological data obtained from the National Meteorological Agency (NMA) and one from National Centre for Environmental Prediction's (NCEP) Climate Forecast System Reanalysis (CFSR) grid stations (Global Weather, 2014) for the time range from 1988 to 2014 for this study watershed. The meteorological data collected daily value for precipitation, maximum and minimum air temperature, wind speed, relative humidity and solar radiation. The data was prepared on daily basis and organized using the Microsoft Excel program and formatted as note pad, which is the required format by SWAT model. To manipulate and use point rainfall in SWAT, the missing weather data were filled by negative (-999) and saved in notepad format. Daily precipitation data was used by the weather generator of the SWAT model (Userwgn.dbf) and calculated using pcpSTAT.exe computer program for each station using daily precipitation data. The stream flow data were collected from Ministry of Water, Irrigation and Energy from the hydrology and water quality directorate department in the time series data (1988–2014) for Dedeba River at near Kuyera (No. 081003) gauging station with a catchment area of 141.71Km^2.

Sediment data

The sediment data collected from Ministry of water, Irrigation and Energy (MOWIE) is not data of all monthly days rather it was sample taken in different seasons within different years. On other hand, due to discontinuous time series sediment record data measured using stream flow and measured suspended sediment data, sediment load data was generated in the continuous time step by developing sediment-rating curve. Suspended sediment flux estimation was calculated using a relation of discharge to suspended sediment discharge known as a sediment-rating curve (SRC) (Khassaf and Hassan, 2014)

$$Qs = aQ^b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . Eq. 1$$

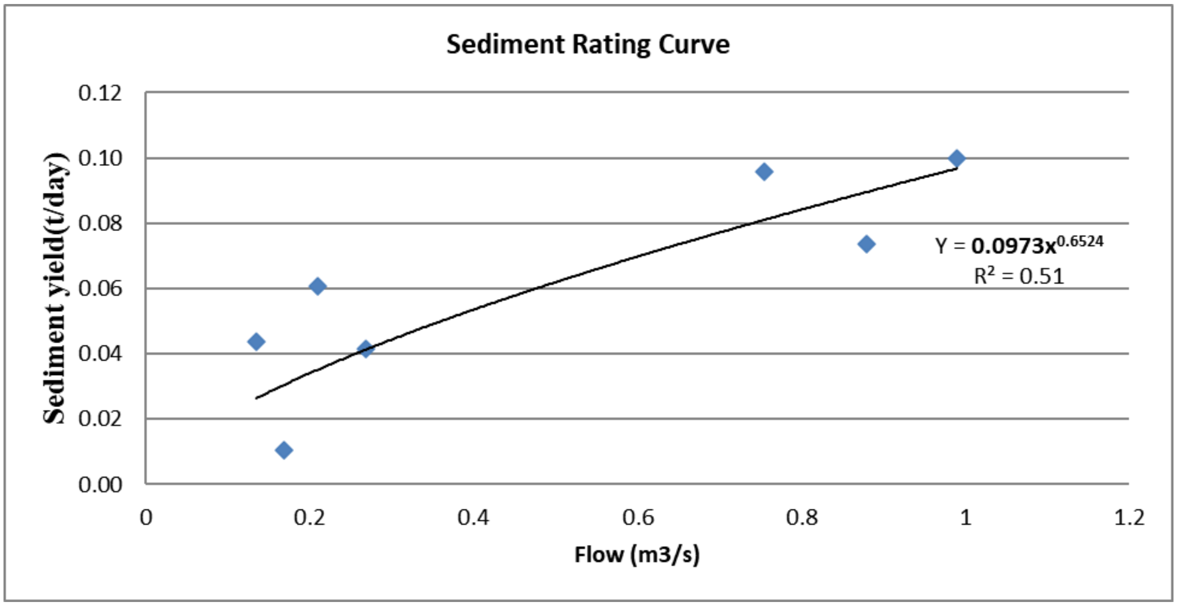

Figure 2. Sediment rating curve at Dedeba watershed gauging station (Dedeba Nr. Kuyera)

The relation of sediment load and discharge at the gauging station with R^2 value of 0.51 was derived as

$$Qs = 0.0973Q^{0.6524} \dots\dots\dots Eq. 2$$

Model Inputs

Digital Elevation Model (DEM)

The DEM 30 x 30 m used in this study was obtained from Ministry of Irrigation, Water and Energy (MOIWE). Arc SWAT was used Digital Elevation Model (DEM) data to automatically delineate the watershed into several hydrologically connected sub-watersheds. After the DEM grid was loaded and the stream networks superimposed, the DEM map grid was processed to remove the non-draining zones. The initial stream network and sub-basin outlets were defined based on drainage area threshold approach. From this, 3170 and 2059 m.a.s.l is highest and lowest elevation respectively (Fig.3). According to MOARD, (2005), slopes of study area were classified into 5, namely slopes from 0-3, 3-8, 8-15, 15-30 and 30 % (Fig.3). The slopes ranges from 3-8% of slope is covered more area (34.51%) of watershed and >30% of slope is covered least area (3.10 %) of watershed.

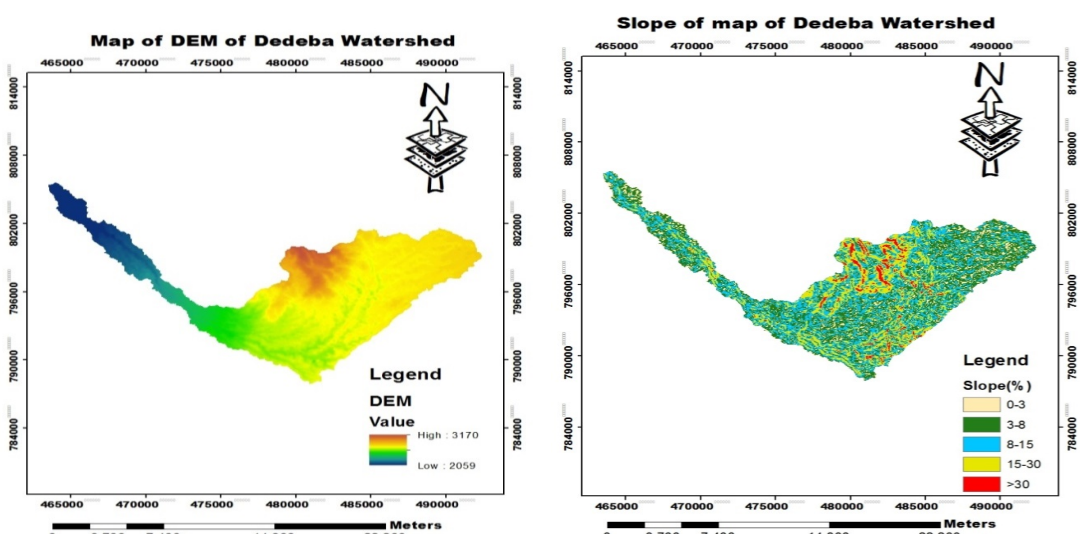

Figure 3: Map of DEM (left) and slope (right)

Table 1: Slope classes and the area occupied in ha and percent (ha & %) of the study area

Slope range (%)	Kater Watershed		
	Land form	Area (ha)	Area Coverage (%)
0-3	Flat or almost flat	1258.90	8.88
3-8	Gentle slopping, undulating plain	4892.64	34.51
8-15	Rolling plain	4718.03	33.28
15-30	Hilly plain	2868.46	20.23
>30	Steep hilly, very steep slopes, ridges and mountains	440.22	3.10
Total		**14178.25**	**100**

Land use/Land cover

The digital land use and land cover of the Dedeba watershed was obtained from Ethiopian Rift Valley Lake Basin Master Plan study (2010). On the basis of land use and land cover map of Ethiopia, the extracted land use and land cover (LU/LC) map of the study watershed was reclassified using the SWAT model in order to correspond with the parameters in the SWAT database (Fig. 4). For successful reclassification, a look up table that identifies the 4-letter SWAT code was prepared in notepad format to relate the grid values to SWAT land use/land cover classes for the different categories of land use/land cover.

Table 2: Area coverage by each land use/Land cover in ha and percent (ha & %) of the study area

	Dedeba Watershed	
Major LULC	**Area (ha)**	**Area (%)**
Intensively Cultivated	9619.02	67.84
Moderately Cultivated	2616.62	18.46
Distributed Forest	1942.61	13.70
Total	**14178.25**	**100.00**

Soil data

The digital soil map of the Dedeba watershed was obtained from Ethiopian Rift Valley Lake Basin Master Plan study (Master plan of MOWIE, 2010). The physio-chemical properties were analyzed in Ethiopia Water Works, Design and Supervision Enterprise soil laboratory. The SWAT model requires soil property data such as the texture, chemical composition, physical properties, and available moisture content, hydraulic conductivity, bulk density and organic carbon content for the different layers of each soil type. Therefore, these soil laboratory results were obtained from Rift valley lake basin Master Plan study document Halcrow, G. (2010). And some SWAT soil parameters were calculated by using Pedo Transfer Function (PTF) developed by Saxton and Rawls (2006).

Table 3: Slope classes and the area occupied in ha and percent (%) of the study area

Major soil	Dedeba Watershed	
	Area (ha)	Area Coverage (%)
Haplic Luvisols	14003.72	98.77
Eutric Vertisols	431.26	1.23

Hydrologic response unit analysis

The sub watersheds were subdivided, after watershed delineation into areas having unique land use, soil and slope so called hydrologic response unit (HRUs). The reclassifications of the soil type and land use were done to represent the soil and land use according to the specific soil types and land uses and overlaid to obtain a unique combination of land use, soil and slope within the watershed to be modeled. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. Most of the time the default of SWAT recommends that 10% soil, 20% LULC and 20% slope thresholds have been used (Neitsch *et al*., 2005).

Sensitivity analysis

The sensitivity analysis of this study was done using Global sensitivity analysis methods. This was done to identify the influential parameters on the modeled stream flow. It is important to identify sensitive parameters for a model to avoid problems known as over parameterization (van Griensven, 2005). The sensitivity analysis can be categorized into four classes

Table 4: Sensitivity analysis index

Class	Index (I)	Sensitivity
I	$|I|\geq 1.00$	Very high
II	$0.2\leq|I|<1.00$	High
III	$0.05\leq|I||<0.2$	Medium
IV	$0.00\leq|I|<0.05$	Small to neglible

(Source: Lenhart, 2002)

Model performance evaluation

The performance of the model was evaluated by assessing the correlation between simulated and observed values. SWAT-CUP 20012 version was used to calibrate the model using Sequential uncertainty fitting (SUFI ver2) (Abbaspour et al., 2007). In this study, during both calibration and validation periods, the goodness of-fit between the simulated and measured runoff was evaluated using the coefficient of determination (R^2) and the Nash-Sutcliffe coefficient of efficiency (Nash and Sutcliffe,1970).

Table 5. General performance evaluation for stream flow on monthly time step (Moriasi et al., 2007 and Nash et al., 1970):

Objective functions		
R^2	ENS	Performance Rating
$0.7< R^2< 1.00$	$0.75 <ENS\leq 1.00$	Very Good
$0.6 < R^2< 0.7$	$0.65 <ENS\leq 0.75$	Good
$0.50 < R^2 <0.6$	$0.50 <ENS\leq 0.65$	Satisfactory
$R^2 <0.50$	$ENS \leq 0.50$	Unsatisfactory

The R^2 is the magnitude of the linear relationship between the observed and the simulated values, and calculated as:-

$$R^2 = \left\{ \frac{\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(S_i - \bar{S})^2}} \right\}^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq.3}$$

Where: Oi is the observed flow, Si is the modeled flow, and O is the mean of the observed flow and *S* is of the simulated flows.

The Nash–Sutcliffe efficiency proposed by Nash and Sutcliffe (Nash et.al,1970) is related to the deviation from unity of the sum of the absolute squared differences between the predicted and observed values normalized by the variance of the observed values. The normalization of the variance of the observation series results in relatively higher and lower values of NSE in catchments with higher and lower dynamics, respectively

$$ENS = 1 - \left[\frac{\sum_{i=1}^{n}(Q_m - Q_s)^2}{\sum_{i=1}^{n}(Q_m \quad Q_s)^2} \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eq. 4}$$

Where: Q_m is the observed flow, Q_s is the simulated flow of the simulation.

Results and Discussion

Sensitive Parameters for Stream flow and Sediment yield

The first step in the calibration and validation process in the SWAT model is the identification of the most sensitive parameters for a given watershed that have a significant impact on specific model outputs such as stream flow and sediment yields (Lenhart, 2002). The results of the sensitivity analysis indicate that, twenty parameters viz, Curve Number (CN2), Base flow alpha factor (ALPHA_BF), Soil Evaporation Compensation coefficient (ESCO), Plant Evaporation Compensation Coefficient (EPCO), Soil Available Water Capacity (SOL_AWC), Soil Hydraulic conductivity (SOL_K), Hydraulic conductivity in main channel (CH_K2), Surface runoff lag coefficient SURLAG, Average slop steepness (HRU_SLP), Groundwater "revap" coefficient (GW_REVAP), Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN), Deep aquifer percolation fraction(RCHRG_DP), Depth of soil (SOL_Z), Bulk density (SOL_BD), Average slope length (SLSUBBSN),Manning's "n" value (CH_N2), Baseflow alpha factor for bank storage (ALPHA_BNK), Manning's "n" value for overland flow (OV_N), Maximum canopy storage(CANMX), Temperature lapse rate (TLAPS)and Ground water Delay (GW_DELAY) are the most essential parameters for the studied watershed. The sensitivity analysis indicated the overall importance of the twenty parameters in determining the stream flow and fifteen (15) parameters were found to be the highly sensitive parameters than others at the study area (Table 6). Therefore, attention was given to most twelve highly sensitive parameters during model calibration. From twenty parameter, two and three parameters were medium and small sensitive to the stream flow for the study watershed (Table 6).

Table 6**:** Dedeba watershed stream flow parameters, sensitivity index, degree of sensitivity and Rank

Descriptions	SWAT-Code	Sensitivity index	Rank	Degree of sensitivity
Groundwater "revap" coefficient	GW_REVAP	$9.7*10^{-1}$	1	High
Plant uptake compensation factor	EPCO	$9.6*10^{-1}$	2	High
Average slope length	SLSUBBSN	$9.2*10^{-1}$	3	High
Depth of soil	SOL_Z	$8.1*10^{-1}$	4	High
Manning's "n" value	CH_N2	$7.9*10^{-1}$	5	High
Effective hydraulic conductivity	CH_K2	$7.4*10^{-1}$	6	High
Temperature lapse rate	TLAPS	$7.0*10^{-1}$	7	High
Treshold depth of water	GWQMN	$6.3*10^{-1}$	8	High
Deep aquifer percolation fraction	RCHRG_DP	$6.2*10^{-1}$	9	High
Available water capacity of the soil layer	SOL_AWC	$5.7*10^{-1}$	10	High
Manning's "n" value for overland flow	OV_N	$5.2*10^{-1}$	11	High
Soil evaporation compensation factor	ESCO	$5.1*10^{-1}$	12	High
Curve Number	CN2	$5.0*10^{-1}$	13	High
Base flow alpha factor(days)	ALPHA_BF	$4.5*10^{-1}$	14	High
Average slope steepness	HRU_SLP	$3.9*10^{-1}$	15	High
Ground water delay	GW_DELAY	$1.8*10^{-1}$	16	Medium
Maximum canopy storage.	CANMX	$1.1*10^{-1}$	17	Medium
Surface runoff	SURLAG	$2.7*10^{-2}$	18	Small
Saturated hydraulic conductivity	SOL_K	$1*10^{-3}$	19	Small
Bulk density	SOL_BD	$4.5*10^{-34}$	20	Small

Table 7**:** Dedeba watershed calibrated flow parameters and fitted values

Descriptions	SWAT-Code	Range	Initial Value	Fitted Value
Curve Number	CN2	± 25%	-1.759776	-2.182975
Base flow alpha factor(days)	ALPHA_BF	0–1	0.490839	0.486471
Deep aquifer percolation fraction	RCHRG_DP	0-1	0. 022748	0. 022784
Treshold depth of water	GWQMN	0-5000	212.929062	231.367264
Depth of soil	SOL_Z	± 25%	0.390929	2.502454
Available water capacity of the soil layer	SOL_AWC	± 25%	0.408060	0.420958
Manning's "n" value	CH_N2	-0.01-0.3	0.402341	0.345006
Effective hydraulic conductivity	CH_K2	-0.01-500	4.713148	4.718277
Groundwater "revap" coefficient	GW_REVAP	0.02-0.2	0. 059279	0. 059368
Average slope length	SLSUBBSN	10-150	37.82249	45.544811
Manning's "n" value for overland flow	OV_N	0.01-30	0.355081	0.357971
Soil evaporation compensation factor	ESCO	0.01–1	0.655509	0.682006
Plant uptake compensation factor	EPCO	0.01–1	0.463488	0.466515
Temperature lapse rate	TLAPS	-10-10	-0.490839	-0.829824
Average slope steepness	HRU_SLP	0-1	0.402341	0.444549
Ground water delay	GW_DELAY	0-500	26.264736	-26.151794
Maximum canopy storage.	CANMX	0-100	7.748510	7.761445

Also, sensitivity analysis was done for sediment yield and found that the parameters such as Exponential factor for channel sediment Routing; SPEXP, Linear factor for channel sediment Routing; SPCON, Channel erodibility; CH_EROD, USLE_P support practice factor and Channel cover factor-CH_COV were the most highly sensitive parameters for sediment yields in the study watershed (Lenhart 2002) (Table 8). And USLE_C Cover and management factor and CN2_ Initial SCS value were small sensitivity in the sediment yield in the study watershed (Lenhart 2002). Hence, the most (highly) significant parameters were considered for further model calibration and validation (Tables 8)

Table 8: Dedeba watershed stream flow parameters and sensitivity index and Rank

Descriptions	SWAT-Code	Sensitivity index	Rank	Degree of sensitivity
Exponential factor for channel sediment Routing	SPEXP	$8.32*10^{-1}$	1	High
Linear factor for channel sediment Routing	SPCON	$7.64*10^{-1}$	2	High
Channel erodibility factor	CH_EROD	$7.37*10^{-1}$	3	High
USLE support Practice factor	USLE_P	$4.23*10^{-1}$	4	High
Channel cover factor	CH_COV	$3.36*10^{-1}$	5	High
Cover and management factor	USLE_C	$9.8*10^{-3}$	6	Small
Initial SCS CN II value	CN2	$3.95*10^{-27}$	7	Small

Table 9: Final calibrated parameters and fitted values of sediment yield for Dedeba watershed

Descriptions	SWAT-Code	Range	Initial Value	Fitted Value
Exponential factor for channel sediment Routing	SPEXP	1.0–1,5	1. 0321	1.4223
Linear factor for channel sediment Routing	SPCON	0.0001–0.08	0. 000811	0. 0029
Channel erodibility factor	CH_EROD	-0.5-0.6	0.1734	0.7246
USLE support Practice factor	USLE_P	0.0–1.0	0.0	0.7900
Channel cover factor	CH_COV	-0.001-1	-0. 001	0.3469

Model Performance Evaluation

Model calibration for stream flow

The first two years (1988-1989) data were used for stabilization of model runs (warm up period). Therefore, the calibration performed for 12 years from Jan/1/1990 to Dec/31/2001 for stream flow and sediment yields of the Dedeba watershed. The calibration process was done manually until the acceptable agreement happens between observed and simulated data (Neitsch et al,.2005). Moreover, the fit between observed and simulated stream flow and sediment yield data was checked by statistical techniques provided below in Table 10. Stream flow and sediment yield hydrographs were developed to compare observed and simulated stream flow and sediment yield values for the calibration periods in monthly time step (Fig. 4 and 6). Statistical model performance evaluator of calibration result shows a satisfactory agreement between the observed and simulated stream flow and sediment yield parameters (Van Liew et al, 2005) (Table 10) and the model recommended for the monthly time basis (Moriasi et al, .2007). Moreover, previously SWAT was not applied in the study area; following this fact, the calibrated results indicate that the model recommended for predicting watershed process of Dedeba watershed. As indicated in Fig 5 &7, the model results in most months of the year; under estimated for both simulated stream flow and sediment yield result.

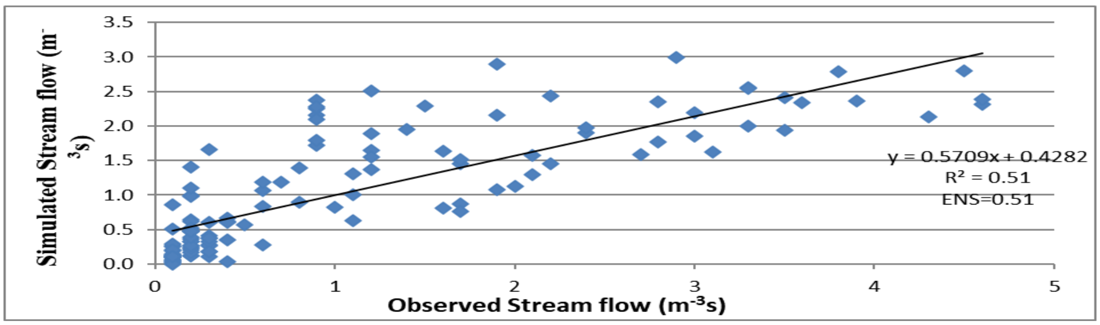

Figure 4. Comparison between observed and simulated Stream flow Calibration period (1990–2001) at Kuyera gauging station

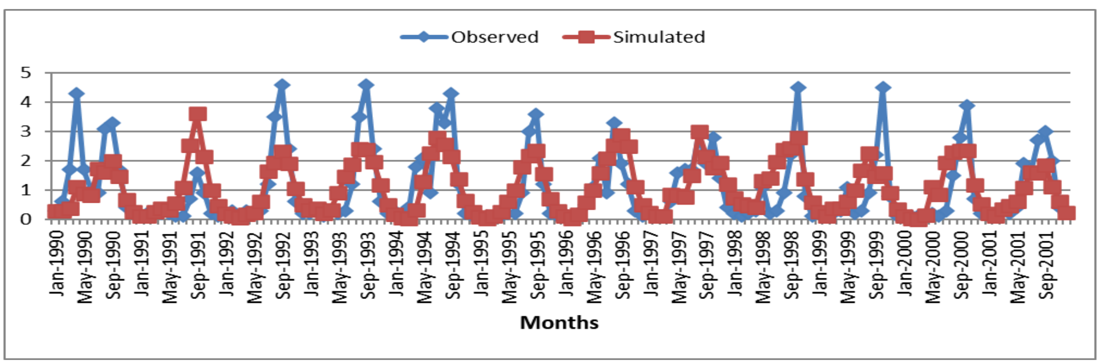

Figure 5. Simulated and observed monthly Stream flow during Calibration period (1990–2001) at Kuyera gauging station

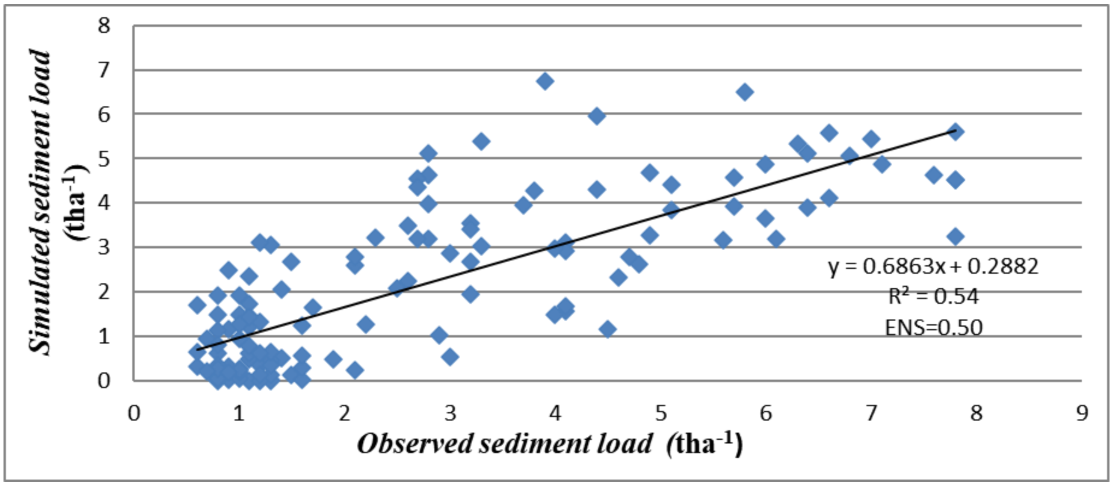

Figure 6. Comparison between observed and simulated sediment yield Calibration period (1990–2001) at Kuyera gauging station

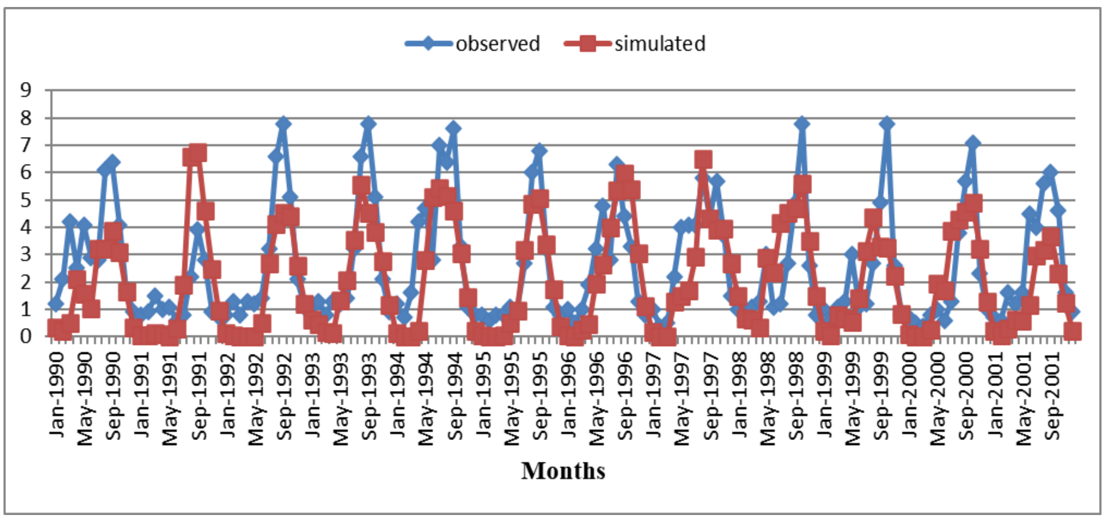

Figure 7. Simulated and observed monthly sediment yield during Calibration period (1990–2001) at Kuyera gauging station

Table 10: Monthly calibration statistical results

Parameter	Stream flow	Sediment yield
	Calibrated (1990-2001)	Calibrated (1990-2001)
R^2(coefficient of determination)	0.51	0.54
NSE(Nash-Sutcliffe model efficiencies)	0.51	0.50

Model validation for stream flow

Model validation was carried out for 6 year period (Jan/1/2002 to Dec/31/2007) for both stream flow and sediment yield parameters. An agreement between measured values (stream flow and sediment concentration) and simulated outputs (stream flow and sediment concentration) on monthly time steps as shown by R^2 and ENS (Table 11), the model parameters represent the processes happen in the Dedeba watershed. Figures 9 and 11 clearly show a reasonably good agreement between observed and simulated stream flow and sediment yield hydrographs for monthly time steps during the validation period. The long-term results of the flow a seasonal variation (Fig. 9) show that there was a good agreement between observed and simulated average values of stream flow; even though the model overestimates stream flow. This shows that there was a low measured flow value which less than the simulated results Fig.9). The long-term results of the sediment load a seasonal variation (Fig. 11) show that there was a good agreement between observed and simulated average values of sediment load; even though the model underestimates sediment load in most months of the year.

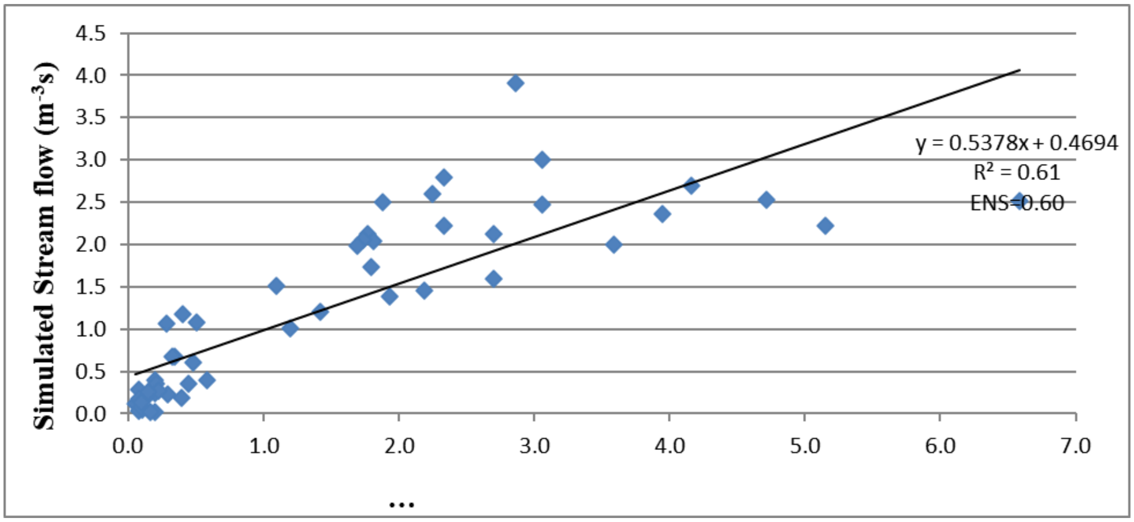

Figure 8. Comparison between observed and simulated stream flow Validation period (2002-2007) at Kuyera gauging station

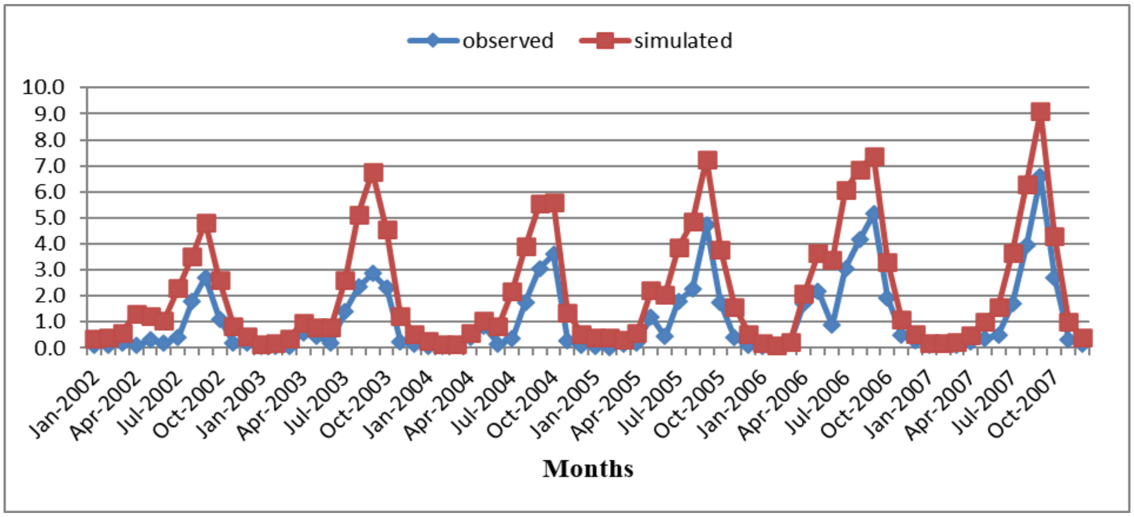

Figure 9. Simulated and observed monthly Stream flow during Validation period (2002-2007) at Kuyera gauging station

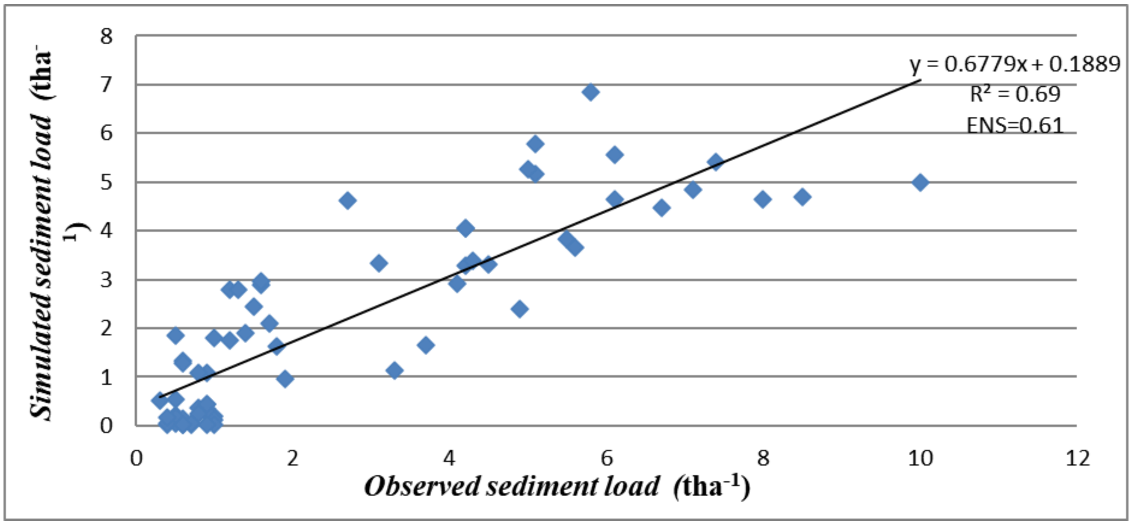

Figure 10. Comparison between observed and simulated sediment yield Validation period (2002-2007) at Kuyera gauging station

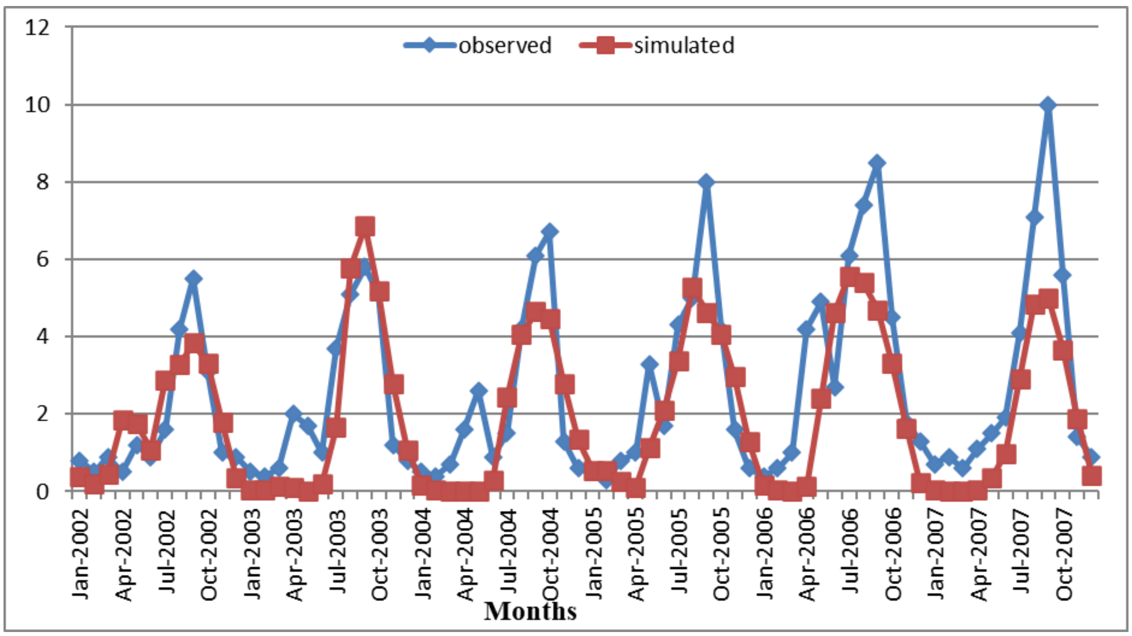

Figure 11. Simulated and observed monthly sediment yield during Validation period (2002-2007) at Kuyera gauging station

Table 11: Monthly validation statistical results

Parameter	Stream flow	Sediment yield
	Validated(2002-2007)	Validated(2002-2007)
R^2(coefficient of determination)	0.61	0.69
NSE(Nash-Sutcliffe model efficiencies)	0.60	0.61

Spatial Distribution of Sediment Yield and Runoff in Dedeba sub Watershed

From this result, the highest average annual sediment losses was 4 22. $tha^{-1}yr^{-1}$ and generated from cultivated land use system, Haplic Luvisols and slope ranges from 3-8% (undulating slope) (Fig 12). Besides to this, the cultivated land use system facilitated the surface runoff to wear out the top soil in a higher rate. Whereas, the lowest sediment yield loss is 1 $tha^{-1}yr^{-1}$ (Fig.12) and this sediment loss generated from forest land and slope ranges from 8-15%. In this case even though the slope increased, the land use land cover plays the major role in reducing surface runoff and sediment loss.

Table 12: Sediment yield losses and Severity classes of Dedeba Watershed

Sub basin	Sediment yield loss(t/ha/yr)	Area	Area (%)	Severity classes	Rank
1,3,4,5,6,8,10,11,15,17,18,20,21,26	1-2	6678.7	47.12	low	4
7,13,14,16,19,22	3-4	3696	26.00	Medium	3
2,9,12,25,27	5-18	2057	14.51	High	2
23,24,28,29	>18	1743.3	12.30	Very High	1
Total		**14175**	**100**		

According to this study, sub watershed 2, 9,12,25,27 and 23,24,28,29 $tonha^{-1}year^{-1}$ were categorized under high and very high sediment yields and covered an area of 12.3 and 14.51 % from the total watershed of study area respectively (Table 12). Highest sediment yield loss was correlated with Haplic Luvisols with cultivated land use system and gradient of 3-8, 8-15 and 15-30 %. The sediment loss from four sub watershed (23, 24, 28, 29) were above tolerable soil loss rate (>18 $tonha^{-1}year^{-1}$) (Hurni 1985) and the sediment losses from five watersheds were above the range of soil formation rate in the study area ranges from 6-10 tha-1yr-1 (Hurni, 1983) (Table 12). Hence, these sub watersheds was identified as highly vulnerable to sediment loss and potentially prone to erosion risk area in Dedeba watershed (Table 12). This study agreed with the study of Hurni (1985), who stated that range of the tolerable soil loss level for the various agro-ecological zones of Ethiopia, was found from 2 to 18 $tonha^{-1}year^{-1}$. The result is consistent with the finding of Bekele et al. (2019) in the Karesa watershed south west Ethiopia who found a comparable result ranging from 0 to 25 $tonha^{-1}year^{-1}$. In addition, this result agreed with the finding of Dulo Husen, Brook Abate (2020) in the Katar watershed rift valley basin of Ethiopia who found that sediment loss ranges from 0 to 37.6 $tonha^{-1}year^{-1}$.

Among 29 sub watershed, six sub-watersheds (7, 13, 14, 16, 19 and 22) were fallen under medium sediment losses with area coverage of 26% from total area of watershed, which were given medium priority class and the annual soil loss from this watershed ranges from 3 to 4 $tonha^{-1}year^{-1}$ (Table 12). The rest 21 sub-watershed classified under low soil loss were covered an area of 47.12% from total watershed (Table 12). However, higher/steep slopes are found along the boundaries of the watersheds and had less impact on the soil loss because it has been covered by forest. Actually, good land use land covers have positive effect on the reduction of runoff and sediment yield. Several studies prevail that, land use land cover can be controlled erosion by covering the soil surface by the canopy and reduce the mechanical action happen at the soil surface by intercepting the raindrop (Francis CF and Thornes JB 1990). A report from China (Luo, 2014) indicated that, land with lower vegetation cover implying the extent of soil erosion. Similarly, a Nigerian study by (Oruk, 2012) reported greater soil erosion in lands with poor vegetation cover. Hence, land cover plays a major role in reducing soil erosion and runoff potential by increasing infiltration capacity.

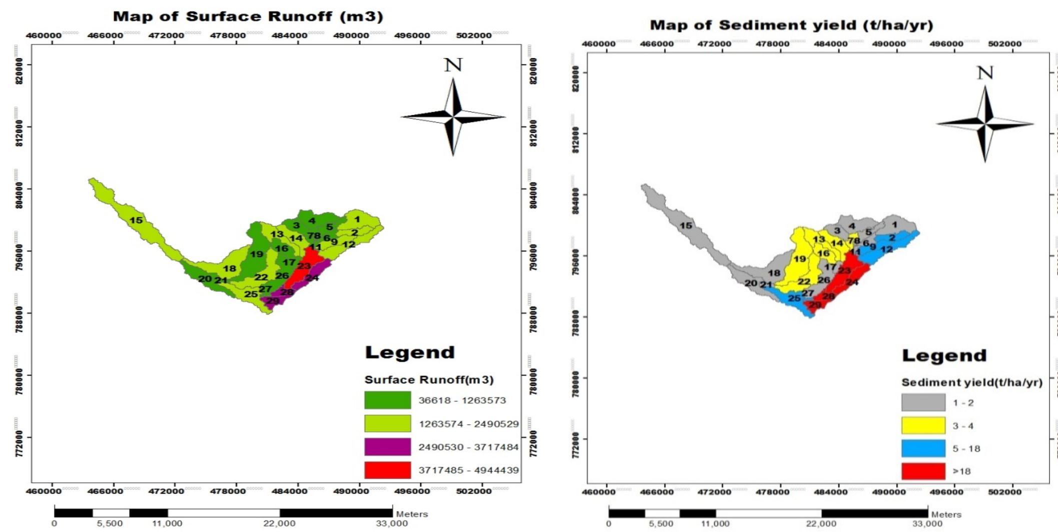

Figure 12. Map of sediment loss (left) and Runoff (right) of Dedeba watershed.

Prioritization for Intervention Planning

Reasonable assessment of soil erosion is the core of any decision making. Because of resource limitations, implementing of soil conservation measures or watershed management in the entire watershed at a time is impractical. Thus, prioritization of intervention based on the severity and risks of soil erosion is imperative. The Dedeba watershed was classified and ranked into four priority classes indicated in Table 14 and Figure 18. Hence, based on the results, sub watersheds 2,9,12, 25 and 2, 9,12,25,27 were hotspot erosion area and prioritized for intervention (Table 12**).** These sub watersheds implies that, the soil erosion rate from this sub watershed is above the soil formation (6-10 tonha^{-1}year^{-1}) (Hurni, 1983). In addition, similar studies stated that, undertaking soil conservation measures based on the given priority is a better option as also suggested by Bewket and Teferi,. (2009), Abate, (2011), Amare et al, (2014) and Gizachew, A. (2015) for their respective study sites.

Therefore, priorities for intervention should be focused on high and very high eroded sub watershed to keep natural balance and minimized the effects siltation at downstream of the study area. On flat slopes, deposition of sediments is the major constraint that can affect the down watershed mainly small irrigation project and hydrology of watershed, and this constrains can be improved by applying integrated watershed management.

Conclusions and Recommendations

From the result of the Global sensitivity analysis, 15 highly sensitive parameters identified and used for calibration and validation. The model was calibrated manually by adjusting sensitive parameters using observed data from 1990 to 2001 and validation was done using observed data from 2002 to 2007. The model performance was checked by statistical model performance evaluators such as the coefficient of determination (R^2) and Nash–Sutclife model efficiency (ENS) and it showm that the model has a high potential in the estimation of runoff and sediment yield. Statistical model performance evaluator of calibration result (R^2=0.51 and NSE=0.51 for stream flow and R2=0.54 and NSE=0.50 for sediment yield) shows a satisfactory agreement between the observed and simulated stream flow and sediment yield parameters. Whereas, statistical model performance evaluator of validation result (R^2=0.61 and NSE=0.60 for stream flow and R^2=0.69 and NSE=0.61for sediment yield) shows a good agreement between the observed and simulated stream flow and sediment yield parameters.

The developed SWAT model also helped in identifying erosion prone area of the watershed and also estimate runoff and soil loss from watershed. Accordingly, the nine (2, 9, 12,25,27,23, 24, 28 and 29) sub-watersheds were highly exposed to soil erosion among the 29 sub watershed and more attention has to be given to sub watersheds. The estimated soil loss rate from 29 sub-watershed ranges from 1t/ha/year to 22 t/ha^{-1}yr^{-1}. According to reclassification of SWAT model sediment yield output about 47.12% of the watershed area is under low, 26 % under medium, 14.51% under high and 12.30% under very high degree of soil erosion respectively. The main reason for eroding more sediment yield from these sub-watersheds could be land degradation, poor land cover, improper land management (lack of soil and water conservation) and intensive cultivation without conservation. These factors were responsible for aggravating the soil loss and facilitated the surface runoff to wear out the top soil in a higher rate from watershed. Therefore, the study watershed needs conservation measures for the future sustainable uses and infrastructure development.

On the gentle slopping and undulating plain, agricultural practice with conservation measure will be recommended in the study area. On the other hand, on slope greater than 30% (3.1% of entire watershed) no need of conducting any agricultural activities, rather the area should be protected and conducting rehabilitation. There is a lot of work to improve in the future for this study area regarding suspended sediment data at outlet. Therefore, responsible bodies should give due attention to took sampling of sediment at the time of flow measurement for further testing the model. The model could be further tested for calibration and validation of sediment yield when suspended sediment data is available.

Therefore, appropriate watershed management policies be put in place in order to promote a more sustainable environment, and future study will be focused on further analysis of the impacts of climate and land use change as well as management scenarios on the stream flow flows and sediment yield in the study watershed. Generally, the output of this study may support planners and decision makers to take relevant soil and water conservation measures and thereby reduce the alarming soil loss and land degradation problems in the watershed.

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Conflict of interest

There is no conflict of interest regarding this research work.

REFERENCES

Abate, 2011. Estimating soil loss rates for soil conservation planning in the Borena woreda of South Wollo highlands, Ethiopia. J Sustain Dev Afr 13(3):87–106.

Abbaspour, K.C.(2007). Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. J. Hydrol. 333, 413–430.

Ag Water Solutions (2012). Watershed management in Ethiopia. Agriculturalwater management learning and discussion brief.

Amare S, Nega C, Zenebe G, Goitom T, Alemayoh T (2014) Landscape–scale soil erosion modeling and risk mapping of mountainous areas in eastern escarpment of Wondo Genet watershed, Ethiopia. Int Res J Agric Sci Soil Sci 4(6):107–116

Bekele B, Muluneh A, Wondrade N (2019). Geographic Information System (GIS) based soil loss estimation using Universal Soil Loss Equation Model (USLE) for soil conservation planning in Karesa Watershed, Dawuro Zone, and South West Ethiopia. Int J Water Resour Environ Eng 11(8):143–158.

Bewket and Teferi, (2009). Assessment of soil erosion hazard and prioritization for treatment at the watershed level: case study in the Chemoga watershed, Blue Nile basin, Ethiopia. Land Degrad Dev 20:609–622

Desta L, Carucci V, Wendem-Ageňehu A, Yitayew A (eds) (2005). Community based participatory watershed development: A guideline. Ministry of Agriculture and Rural Development, Addis Ababa, p 62.

Dulo Husen, Brook Abate (2020). Estimation of Runoff and Sediment Yield Using SWAT Model: The Case of Katar watershed, Rift Valley Lake Basin of Ethiopia. *International Journal of Mechanical Engineering and Applications*. Vol. 8, No. 6, pp. 125-134

Francis CF, Thornes JB (1990) Runof hydrographs from three Mediterranean vegetation cover types. In: Thornes JB (ed) Vegetation and erosion. Wiley, Chichester, pp 363–384

Gete Z (2006). Integrated management of watershed experiences in Eastern and Central Africa: Lessons from Ethiopia. In: Shiferaw B and Rao KPC (eds): Integrated management of watersheds for agricultural diversifcation and sustainable livelihoods in Eastern and Central Africa: lessons and experiences from semi arid South Asia. Proceedings of the international workshop held at ICRIS at Nairobi, 6–7 December 2004, p 120

Gizachew A (2015). A geographic information system based soil loss and sediment estimation in Zingin watershed for conservation planning, Highlands of Ethiopia. World Appl Sci J 33(1):69–79

Halcrow, G. Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project; the Federal Democratic Republic of Ethiopia-Ministry of Water Resources (MOWR): Addis Ababa, Ethiopia, 2010.

Hassan, S. I. Khassaf and A.A. (2014.). Suspended sediment rating curve for tigris river upstream al-amarah barrage.

Hurni, H. (1983). "Soil Formation Rates in Ethiopia" Ethiopian High lands Reclamation Study, Hydrologic modeling .USDA ARS-S-9.76 pp.

Hurni, H. 1985. Soil conservation in Ethiopia; Guideline for development agents. CFSCDD. Ministry of Agriculture. Addis Ababa, Ethiopia

Lenhart, T., K. Eckhardt, N. Fohrer and H.G. Frede, (2002). Comparison of two different approaches of sensitivity analysis. Physics and Chemistry of the Earth, 27: 645–654.

Luo, Z, Deng, L, Yan, C. 2014. Soil erosion under different plant cover types and its influencing factors in Napahai Catchment, Shangri-La County, Yunnan Province, China, International. J Sustain Dev World Ecol.

Menale K, Mahmud Y, Köhlin G (2009). The role of production risk in sustainable land-management technology adoption in the Ethiopian Highlands. Working papers in economics, No 407. Gothenburg: University of Gothenburg, p 25

Mengist. (2017). Estimation of Catchment Sediment Yield Using Swat Model (Case Study Gelana Reservoir, Rift Valley Basin, Ethiopia). University of Addis Ababa.

Ministry of Agriculture and Rural Development (MoARD). (2005). Ethiopia's Agricultural Sector Policy and Investment Framework (PIF) 2010–2020. Draft Final Report, p 39.

Moriasi et al,.(2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE 50(3): 850-900.

Nash, J.E.; Sutcliffe, J.(1970). River flow forecasting through conceptual models: Part I. A discussion of principle. J. Hydrol. 10, 282–290.

Neitsch et al,.(2005). Soil and Water Assessment Tool, Theoretical Documentation: Version 2005. Temple, TX. USDA Agricultural Research Service anti Texas A&5I Black land Research Center.

Nigussie H, Ademnur B, Atsushi T, Mitsuru T, Derege T (2012) Integrated watershed management as an effective approach to curb land degradation: a case study of the Enabered watershed in northern Ethiopia. Environ Manage 50:1219–1233

Oruk EO, Eric NJ, Ogogo AU (2012). Influence of soil textural properties and land use cover type on soil erosion of a characteristic ultisols in Betem, Cross River Sate, Nigeria. J Sustain Dev 5(7):104–110

Saxton K.E., Rawls W.J. (2006). Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. Soil Science Society of Agronomy Journal 70(5):1569-1578

Tongul H, Hobson M (2013). Scaling up an integrated watershed management approach through social protection programmes in Ethiopia: the MERET and PSNP schemes

Van Griensven, A. (2005). Sensitivity, auto-calibration, uncertainty and model evaluation in SWAT2005