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Soil Erosion Modelling using SWAT and GIS Interface: Case of Weib Watershed

Tesfahun Addisu Messele, Golla Sreenivasu

Abstract: ***Soil wearing away is the slow process that occurs when effect of runoff detaches soil particles, causing the soil to remove within the natural channel. Catchment area of Weib River 7407.42km^2. The Watershed soil erosion and sedimentation is result of high intensity rainfall with generated runoff, steep slope channel, and inadequate conservation practices. The study was used to model by using simulated to calibrate against measured Sediment. From the result of simulated conditions of a fixed with only the measured land cover changes inserted, simulated sediment yield increased by 66.75%, 64.80%, 61.48%, 71.08%, and 55% respectively by using land cover year 1986 and 2010 of classified eight sub catchments. The analysis of Soil erosion has shown that sedimentation has increased from 41.27% to 61.58% between 1986 and 2010, with annual erosion of sediment to the Weib river from the watershed is 5.22ton/ha. The result of simulation by the model was checked based on R2 and NS values for monthly sediment was 0.94, 0.87 at Agarfa and Sof Omer stations during calibration, 0.89, 0.97 at Agarfa and Sof Omer during validation, respectively. The most sensitive parameters for erosion simulations were Average slope steepness (HRU_SLP), Average slope length (SLSUBBSN), Initial residue cover (RSDIN), Channel cover factor (CH_COV2), USLE equation soil erodibility (K) factor (USLE_K), SCS runoff curve number f (CN2), Linear parameter approach was used to quantify the highest amount of sediment that can be accumulated using channel sediment routing (SPCON)***

Keywords: ***SWAT Model, Sedimentation, Weib River Catchment, Calibration, Validation, Scenarios.***

I. INTRODUCTION

Land use change has direct relationship with changes in the hydrological cycles within watershed [1, 2]. After a change in land use, soil erosion will be resulted in the sediment yield within natural channel [3, 4]. Different previous studies around the globe indicated that erosion can be affected by land use with in change of duration spatially [1, 5]. Soil loss rate for different high ranges from 0 to 300 tonha-1yr-1 with an average loss of 70 tonha-1yr-1, which is not within threshold. The study report by the Soil Conservation Research Project of Ethiopia [6] Weib Watershed sedimentation is result of by high intensity of rainfall runoff, steep slope with poor soil and water mitigation measure. But due to financial constraints it is difficult to attain the effective management for reduction of sedimentation and erosion of soil within this watershed. Therefore those areas of vulnerable to erosion of soil with sedimentation assessment can be undertaken through the development of soil and water conservation practices. Hence the correct assessment with coupling of simulation of soil becomes now a day's quantitative assessment of soil erosion and runoff at large spatial coverage is undertaken by integrating remote sensing data and GIS technology with many different computers models. Among those models SWAT (soil and water assessment tool) is the one, which uses bulk spatially and temporally related data that are useful for modeling. Accordingly, in this study is required to integrate Remote Sensing, GIS and SWAT model to assess soil erosion and sedimentation due to land use change in the Weib Catchment

General Objective

The general aim is to assess change of soil erosion and river sedimentation using SWAT simulation Model

Specific objective

- To quantify the soil erosion at temporal scale.
- Categorize the catchment in terms soil erosion potential.
- To check the hydrological performance of the model

II. MATERIALS AND METHODS

Study Area Description

The watershed of Weib river covers 7407.42 Km2 with geographical range of coordinates between 7022' and 7043' N Latitude and 39058' and 41004' E Longitude. The highest precipitation is 1380mm and minimum average yearly value 547mm. The range average air temperature is between 6.6-16.4oC.

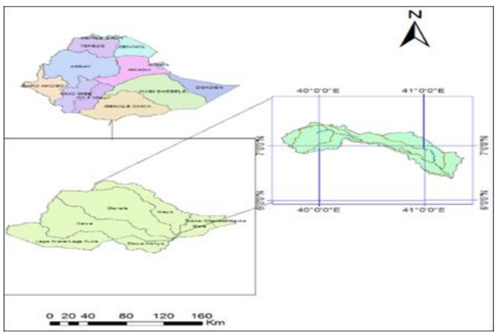

Figure II.1. Topographic map of Weib River

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Sediment component ArcSWAT model

SWAT can estimate erosion by using hydrologic response units instead of Modified Universal Soil Loss Equation (MUSLE). This approach used runoff to simulate erosion and sediment yield. Different studies showed that sediment movement in the natural channel system involved of two mechanisms working instantaneously, which are deposition and degradation [7]. To quantify the deposition and degradation development the maximum concentration of sediment is determined using equation below

$$ConcSed_{ch,mx} = C_{sp} * V_{ch,pk}^{sp\,exp} \qquad (1)$$

The maximum Vch,pk is determined by using the following equation

$$V_{ch,pk} = \frac{prf * q_{ch}}{Ach} \qquad (2)$$

(Conc sed,ch,mx) is determined from the previous equation is compared to the concentration of sediment in the reach at the beginning of the time step Conc sed,ch,i. If Concsed,ch,i > Concsed,ch,mx sed,ch,mx , deposition is the dominant process in the reach segment, Equation 1 used to calculate the net amount of sediment deposited in the reach.

$$Sed_{dep} = \left(Conc_{sed,ch,i} - Conc_{sed,ch,mx}\right) * Vch \qquad (3)$$

If Concsed,ch,i < Concsed,ch,mx Degradation is the most process in the reach segment and the net amount of sediment re-entrained is calculated by Equation 4.

$$Sed_{ch} = Sed_{ch,i} - Sed_{dep} + Sed_{deg} \qquad (4)$$

Once the amount of deposition and degradation is calculated, the above Equation is used to determine the final amount of sediment.

SWAT Model Input Parameters

Digital Elevation Data

Digital elevation Model used to process Raster grids to shape files and database to simulate along with input weather generator parameter and spatial data about the watershed as shown in fig below.

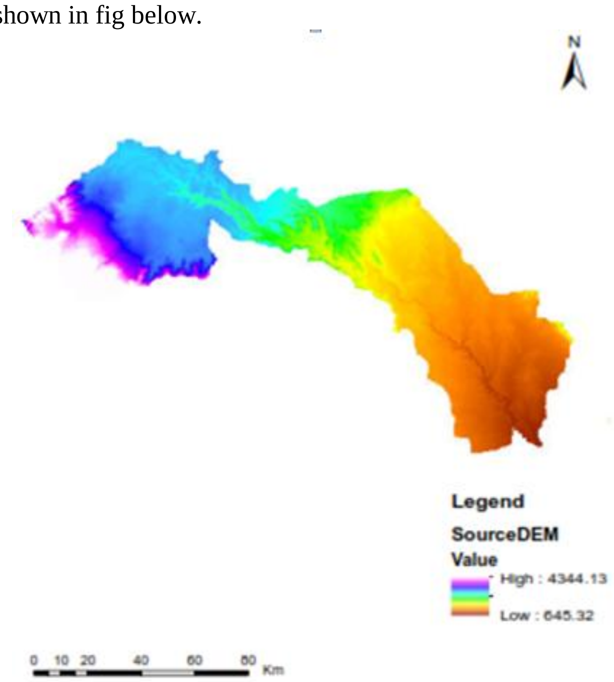

Figure II.2 Digital Elevation of watershed

Land Cover data

It is an existence natural cover on ground coverage. In other words, it is what is physically appearing on the surface of the ground as a natural or manmade entity [13].

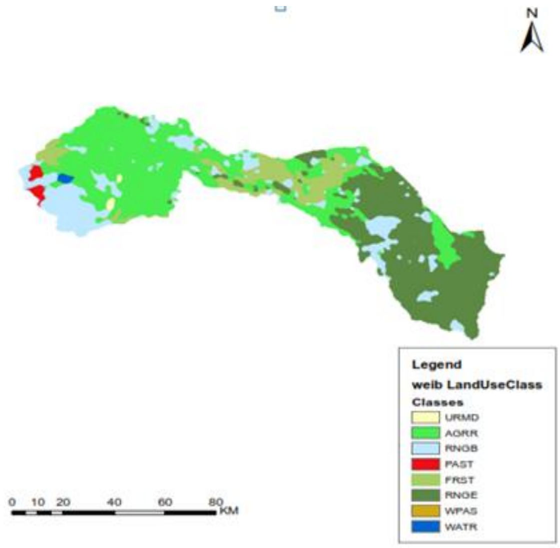

Figure II.3 classification of land cover

Soil Data

The soils data required in the simulation relating the average water holding capacity, active soil depth , textural, average hydraulic conductivity, curve number (CN), maximum impervious ,smaller impervious that is used for sub basin classification of the catchment in percentage [13].

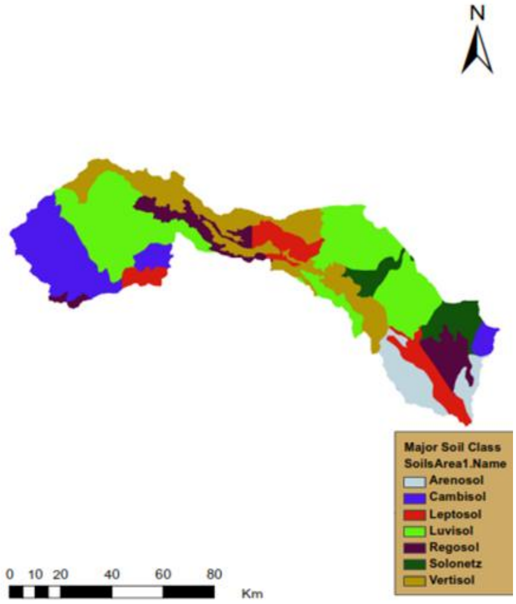

Figure II.4 Classification of Major Soil

Slope Data

Change in elevation is the best way of significant way of morphological classifications with land use for bringing up to form of land use amount which is indicated below [13].

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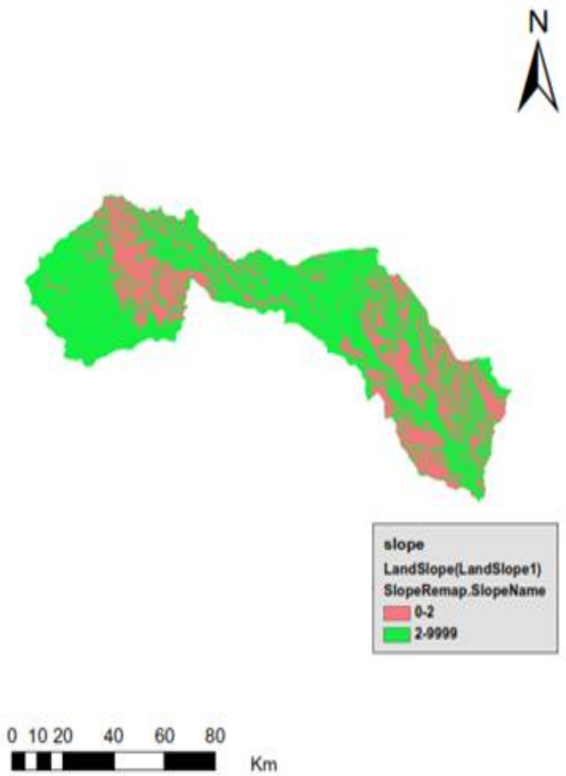

Figure II.5 Slope classification

III. RESULT AND DISCUSSION

Mechanism of Soil Erosion Formation

Erosion of sedimentation involves the processes of removal of soil particles of different size, movement, and accumulation of sediment by rainfall impact through runoff generated on ground surface [9, 10]. Figure 3.1 shows the mechanisms of soil erosion forms much material can move small rills and the rills make small channels. A few soils are very susceptible to rill erosion. Rills gradually join to form progressively larger channels, with excess runoff eventually proceeding to some established streambed. Topsoil wearing away may be unobserved on bare soil surface, but runoff are wear away bulky magnitudes of sediment, but erosion can be affected where intense flow creates wide rill and gully systems. The forms that are provided in the method were used for the survey.

Uncertainty analysis

The following are the most important uncertainity types of models that can be used for SWAT –CUP analysis.

1.Conceptual model uncertainty (or structural uncertainty) 2. .Input uncertainty is because of errors in input data such as precipitation, and more importantly, extension of point data to large areas in distributed models.
3. Parameter uncertainty
The packages like SWAT-CUP can help decrease model uncertainty by eliminating some probable bases of modeling and calibration errors. Finally , it is highly advisable to distinct quantitatively the result of different uncertainties on model yields, but it very hard to do. The joint effect, however, should always be calculated on model outputs [11].

SWAT-CUP

SWAT-CUP is a package intended to incorporate different sensitivity programs for SWAT (Soil & Water Assessment Tool) using the same interface. Dufferent computer programs have been technologically advanced by hydrologists for parameters uncertainty analysis in river basin model, such as, (GLUE) [12], (SUFI-2), [11], parameter solution (ParaSo)and Markov chain Monte Carlo (MCMC). The generalized likelihood uncertainty estimation (GLUE). [12] was make known to partially to agree for the possible non-uniqueness of parameter sets for the period of the valuation of model parameters in over parameterized models. The procedure is simple and requires few assumptions when used in practical applications. The ParaSol method aggregates objective functions (OF's) into a global optimization criterion (GOC), minimizes these OF's or GOC using the shuffle complex evolution (SCE-UA) algorithm and performs uncertainty analysis with a choice two statistical concepts. The MCMC (Markov Chain Monte Carlo) generates samples from a random walk, which adapts to the posterior distribution. In this particular study, it was preferred to use sequential uncertainty fittings (SUFI2). It is automated model calibration needs that the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are taken out from the model output files. The main function of an Interface is to provide a link between the input/output of a calibration program and model. Schematic of the linkage between SWAT and five optimization programs is illustrated in Figure-III.1.

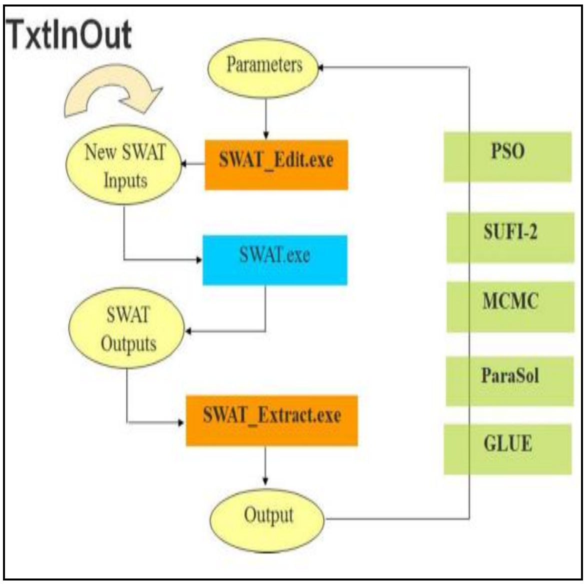

Figure III.1 Schematic linkage of the five optimization

Calibration and validation of model

Model calibration can be performed either by trial and error or by automated techniques. Automated calibration can be performed by means of specifying an objective or a set of objective functions. Uncertainty in models will lead to uncertainty in model parameters and model estimates. Automated parameter estimation techniques for model calibration are accurate and rapid.

Validation of hydrologic models is a process of matching the simulated results with observed values without altering the calibrated parameters. Correction was simulated by matching the output of the SWAT model with the observed data at the unchanged situations. For calibration and validation, the Sequential Uncertainty Fitting (SUFI-2) calibration method within the SWAT Calibration and Uncertainty Procedures (SWATCUP) was used. Figure III.2 bellow shows the procedure of calibration using the Sequential Uncertainty Fitting (SUFI-2).

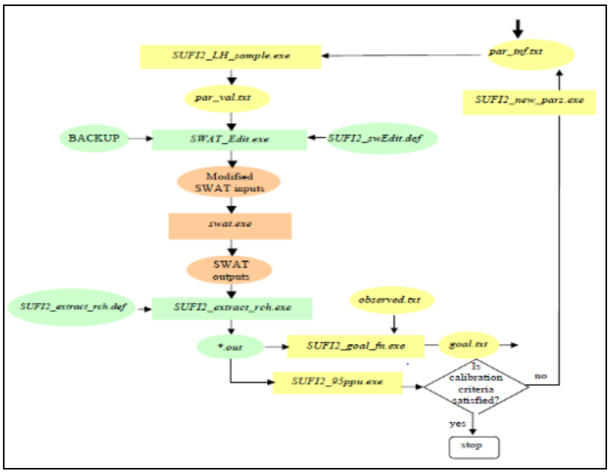

Figure III.2 Systematically creating of SWAT-SUFI2 input files

In this study, this model was also calibrated for sediment for the period of 1999 to 2001 and validated for 2002 to 2004 for monthly time step. The graphical and statistical approaches were used to evaluate the
Arc SWAT model routine a number of times until the satisfactory result were obtained for sediment independently Two statistical model performance measures used in calibration and validation procedure of sediment.

Evaluation of model performance

Two methods for goodness-of-fit measures of model predictions were used for the duration of the calibration and validation periods, these two numerical model performance measures are coefficient of determination (R2 coefficient) and Nash-Suttcliffe simulation efficiency (ENS).The range of values for *R*2 is between1.0 (best) to 0.0 (bad). A value of 0.0 for *R*2 means that none of the variance in the measured data is replicated by the model predictions. On the other hand, a value of 1.0 indicates that all of the variance in the measured data is replicated by the model predictions.
The Nash-Sutcliffe simulation efficiency (ENS) values range from 1.0 (best) to negative infinity. A value of 0.0 for ENS means that the model predictions are just as accurate as using the measured data average to predict the measured data. ENS values less than 0.0 indicate the measured data average is a better predictor of the measured data than the model predictions while a value greater than 0.0 indicates the model is a better predictor of the measured data than the measured data average.

Sensitive Parameters

The most sensitive parameters for erosion simulations were (HRU_SLP), (SLSUBBSN), Initial residue cover (RSDIN), (CH_COV2), (USLE_K), SCS runoff curve number f(CN2), are sediment parameters are used to calculate the amount of sediment from a catchment (from upland)
and from the channel (in stream sediment). To see which parameter is highly sensitive to sediment from the list of parameters in Global sensitivity analysis was applied and from Seventeen parameters that directly affect the sediment yield and sediment transport in the watershed were analyzed and the most eight sensitive parameters are tabulated in Table III.1 below.

Table III: 1.Result of most sensitive parameters

NO	Parameter	Fitted Value	Min value	Max value
1	SPEXP	1.082	1.081077	1.086
2	SPCON	0.004	0.004084	0.004
3	RSDIN	881	881	882
4	HRU_SLP	0.003	0	0.011
5	CH_COv2	0.614	0.612381	0.615
6	CN2	69.38	66.95037	69.56
7	SLSUBBSN	17.04	17.0369	17.04
8	USLE_K	0.037	0.029215	0.043

Since there was lack of reliable sediment data the following equation has been used for all river basin in Ethiopia. To simalate the sediment concentration at a for certain duration and location, a two-parameter regression approach was adopted to calculate sediment yield within the catchment.

$$\text{Log (SSC)} = \text{Log } a + b\,(\text{Log } Q) \quad (6)$$

$$Qs = aQ^{b} \quad (7)$$

Table III:2. Sediment yield data of selected river gauging stations (reprocessed after Redeco 2002)

Station Name	Regression Model (6)			Catchment area	Mean flow Conditions		
	a	b	R2	Km2	Q(l/s)	SSC(m/g)	SSY(t/yr/km2)
Abbay river Basin							
Yeda	369.66	0.19	0.12	125	33136	2589	902
Jedeb	16.83	0.45	0.30	305	80852	2753	959
Mega	17.84	0.40	0.43	375	99409	1745	608
Awash River Basin							
Berga	54.20	0.15	0.09	248	11633	216	13
Akaki	1.99	0.60	0.24	884	17691	718	19
Holeta	64.27	0.16	0.06	119	5679	250	16
Genale Dawa river Basin							
Woyib (agrafa)	58.21	0.04	0.03	7719	270011	90	4
Rift valley							
Aleta wedo	220.80	-0.09	0.01	206	21162	95	13
Bedessa	59.98	0.14	0.02	81	8321	208	28
Gelana	14.86	0.32	0.08	141	14485	322	44

Q river flow rate; SSC suspended sediment concentration; SSY specific sediment yield

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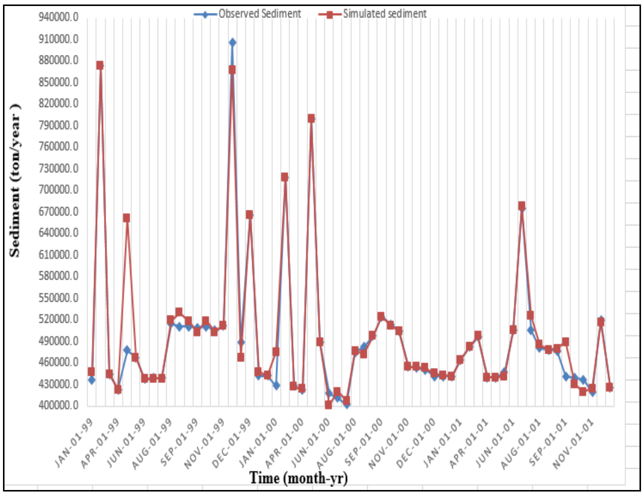
Calibration of sediment

It is performance of simulation was checked by relating model estimations of output with observed or real gauged of sediment data by calibrating for the year 1999-2001 as shown in table below.

Table III:3. Calibration of observed and simulated sediment.

Average observed and simulated for sediment ton/month				Model efficiency	
Station	year	Observed	Simulated	R^2	NS
Weib@ Agarfa	1999-2001	370545.6	35323.08	0.94	0.81
Weib@ Sofumer	1999-2001	171691.2	17182.01	0.87	0.85

A)Weib@Agarfa



B) Weib @ So Umer

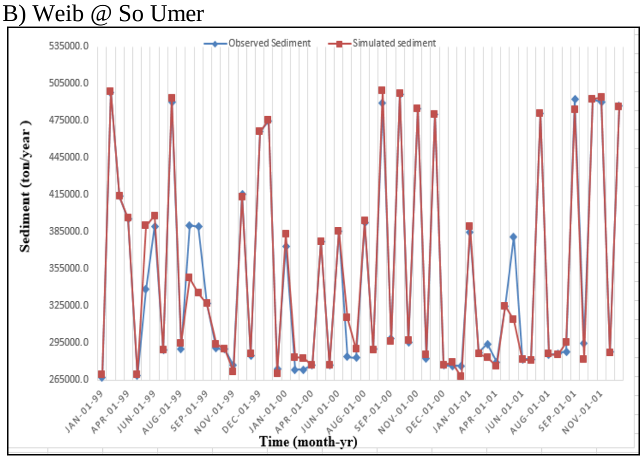
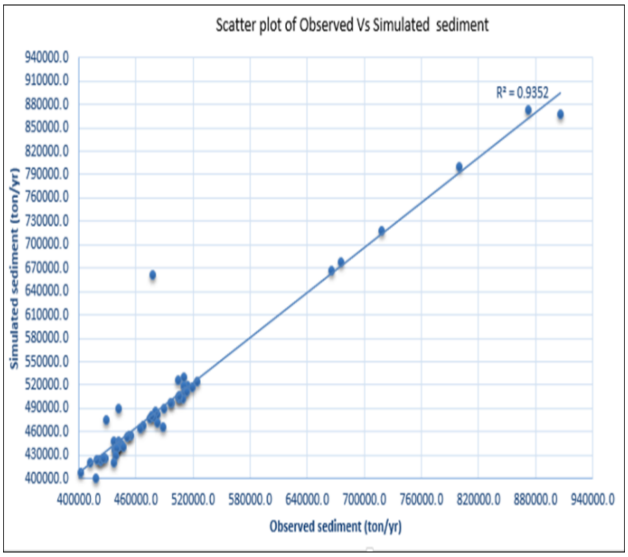


Figure III.3 gauged and output of sediment for calibration

A)Weib@Agarfa



B) **Weib @ So Umer**

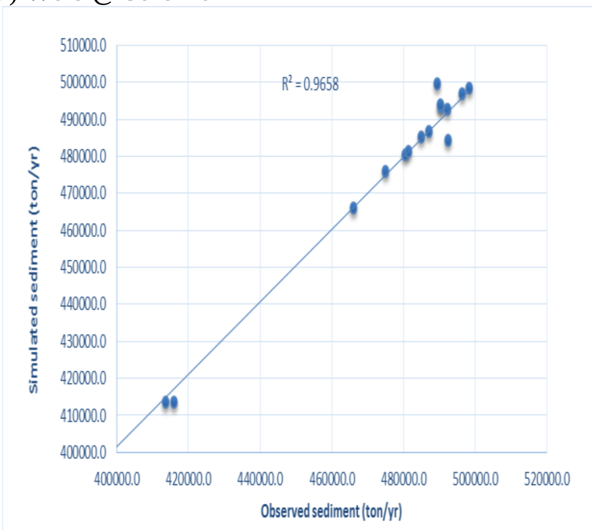


Figure III.4 Fit line gauged and output of sediment for calibration

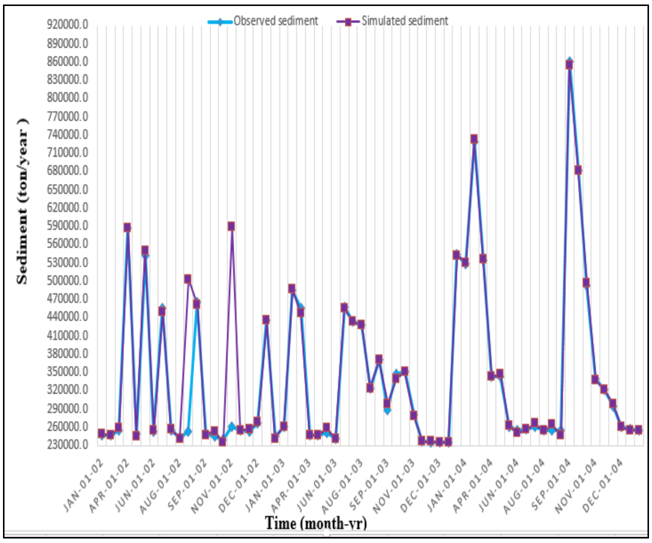
Model Sediment Validation

The performance of validation is done for checking the simulated data is taken for input for different purposes at differing duration trough keeping sensitive parameters unchanged during calibration period from 2002 to 2004.

Table III:4. Observed and simulated for sediment validation

Average observed and simulated for sediment ton/year				Model efficiency	
Station	year	Observed	Simulated	R2	NS
Weib @ Agarfa	2002-2004	370545.6	35323.08	0.89	0.86
Weib@ Sofumer	2002-2004	171691.2	17182.01	0.97	0.85

A) Weib@ Sofumer



B) Weib @ Agarfa

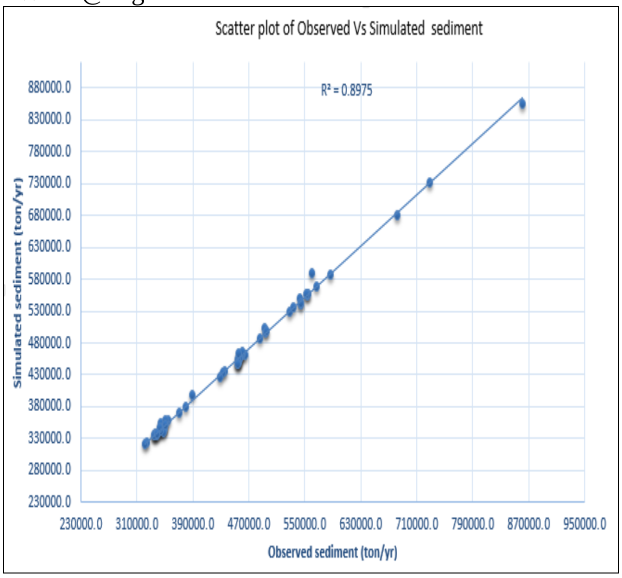
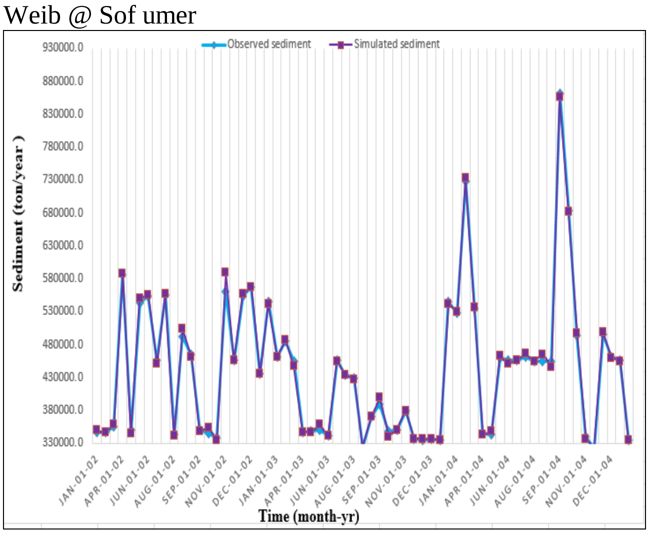


Figure III.5 Gauged and output of sediment for validation Weib @ So Umer

A) Weib @ Sof umer



B) Weib @ Agarfa

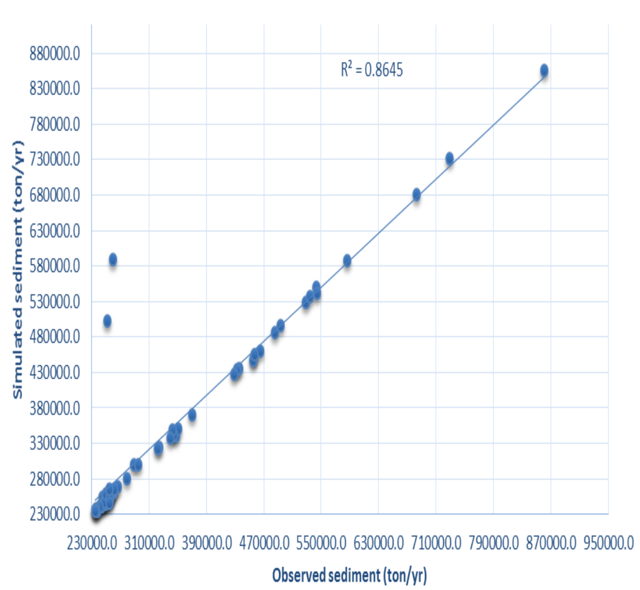


Figure III.6. Fit line gauged and output of sediment for validation period

After simulation of the model the total observed and sediment yield in the Weib catchment at Agarfa and Sof Umer Gauging stations during calibration and validation period, the results show good relationship. Therefore, we can say it is good to use SWAT estimation of catchment sediment yield in the study area. The result indicated that the model simulation is almost similar to the observed sediment yield. The total annual sediment yield from catchment during calibration and validation period was estimated using the model is 4, 4062,162 and ton/year. The total catchment area of this study is 7407.42km2. Therefore, the annual specific sediment yield from the catchment can be calculated as the total sediment yield divided by the area of the catchment which is equal to 5948.4 ton/km2/year. To illustrate the sediment distribution within the catchment based on the land use land cover change is shown with classification of sub basin in table table III.6

Table III:1. Sediment load simulated for year of 1986, 1995 and 2010

	Simulated Annual Average sediment load (ton/ha)				Change b/n LULC 1986 and LULC 1995	Change b/n LULC 1986 and LULC 2010	change (%) b/n LULC 1986 and LULC 1995	Change (%) b/n LULC 1986 and LULC 2010
Sub- basin	Area(Km2)	LULC 1986	LULC 1995	LULC 2010				
1	1626	10.05	21.56	30.23	11.51	20.18	53.39	66.75
2	994.27	18.34	41.9	52.1	23.56	33.76	56.23	64.80
3	476.29	27.42	52.6	71.18	25.18	43.76	47.87	61.48
4	1059	20.19	54.68	69.84	34.49	49.65	63.08	71.09
5	901.62	25.4	30.85	51.3	5.45	25.9	17.67	50.49
8	135	28.02	57.68	62.05	29.66	34.03	51.42	54.84
					Average		48.27	61.58

Spatial distribution of sediment in Weib watershed

The spatial variability of sedimentation rate were recognized for area of interest can be classified for soil erosion anaysis. Wearing way of soil prone areas identification in the area for soil conservation and mitigation measures after the result of simulation as shown below.

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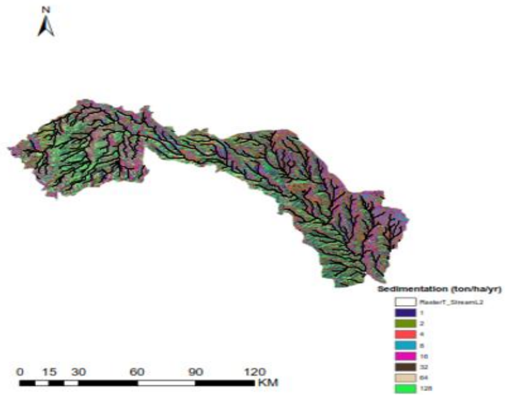

Figure III.7: Spatial distribution of sediment yield of Weib catchment

After the simulation of sediment which helped to identify the spatial sediment distribution on the Weib catchment. Table IIII.5 shows the spatial distribution of sediment in the Weib catchment. The most sensitive sub-catchments for erosion which have the maximum annual sediment generation in the sub-catchments are sub-basin 3, 4, 8, 5 and 2, sub basins have annual sediment above 556 ton/ha moreover, the sub catchments with the minimum annual sediment generation in the study area are sub-basins 1 and 6 have annual sediment generation less than 167.61 ton/ha. Therefore, sub catchment sub-basin 3, 4, 8, 5 and 2, are more erodible areas. Among these sub basins as shown in table III.2 , sub basin 1,2, 3,4, and 8 falls under high critical condition respectively in their sediment yield. As presented in the previous chapter land use of this sub basin which fall under high erosion class is characterized by intensive cultivation. This shows that the cultivation practices in the area accelerate runoff which leads to high sediment susceptibility. From the result of simulated conditions of a fixed with only the measured land cover changes inserted, simulated sediment yield increased by 66.75%, 64.80%, 61.48%, 71.08%, and 54.47% for year 1986 and 2010 respectively [13].

Scenarios development for mitigation measure

To understand sedimentation and soil erosion of simulation through different scenarios is necessary. Scenario comparison is can be done through appraising possible future events through different results. So these events compared it should be considered several options of upcoming developments.

The basic benefit analysis of scenario help to make decision making on water resource development to improve watershed management process of the study area.

From simulation of SWAT land use adopted in this study consisted of about 14.1 % Grass, 20.3 % Forest, 22.6 % Agriculture (Cultivated land), 24.4% Urban land (Settlement) and 0.5% of water body. The valuable scenario development was made by changing the agricultural land to forest cover by10%,20%,30%, 40%,50% and e.i. AGRL(40%), FRST(10%), GRS(12%), and AGRL(50%), AGRC(5%), FRST(15%), PAST(10%), RANG(5%), FRSE(15%) which reduces low amount of sediment which is 16% and 12% respectively and difficult for application[13].

The SWAT model simulation shows that the scenarios are:-

So = Original land

Scenario -1_ 10% Agricultural land change to forest mixed land.

Scenario-2 _ 20% Agricultural land change to forest mixed land.

Scenario-3_ 30% Agricultural land change to forest mixed land.

Scenario-4_ 40% Agricultural land change to forest mixed land.

Scenario-5_50% Agricultural land change to forest mixed land.

Scenario-6_ practice of filter strip to agricultural land, forest area and grass land between a slopes of 0 to 20 %.

Scenario-7_ applying terracing to agricultural land, forest area and grass land between a slopes of 0 to 20 %.

The results of scenarios was tabulated in table III.7

Table III:2. Summary of scenario development

Scenarios	Average Sediment yield (ton/yr)	Sediment change (%)
Base Scenario	722556.8	0
Scenario-1	316510.1	-56.2
Scenario-2	497641.4	-31.1
Scenario-3	481195.9	-33.4
Scenario-4	502770.2	-30.4
Scenario-5	465511.3	-35.6
Scenario-6	431686.7	-40.3
Scenario-7	575256.3	-20.4

The scenario developed in table III.7 above shows the percentage of reduction of sediment volume increases when the percentage of agricultural land to forest mixed increases. 50% Agricultural land change to forest mixed land results 40% reduction of sediment volume [14].

The life of community around this study area is depended on agriculture especially irrigation using the natural river and using traditional dams. Therefore applying scenario five which is changing 50% Agricultural land change to forest mixed land as best management strategy is not simply applicable management type because it reduces highly the functional agricultural land. To make balance of the functionality of the agricultural land and reduction of sediment yield, scenario three (30% Agricultural land changed to forest mixed land) preferable best management method. Moreover, applying filter strip and terracing in low slope areas is also taken as operational management method because we can easily apply it without additional complicated technology.

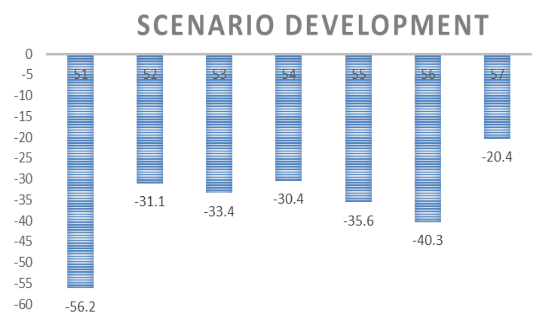

Figure III.8: Comparison of change of sediment load.

The scenario developed in table III.7 above showed the percentage of reduction of sediment volume increases when the percentage of agricultural land to forest mixed increases. 50% Agricultural land change to forest mixed land results 40% reduction of sediment volume. The life of community around this study area is depended on agriculture especially irrigation using the natural river and using traditional dams. Therefore applying scenario five which is changing 50% Agricultural land change to forest mixed land as best management strategy is not simply applicable management type because it reduces highly the functional agricultural land. To make balance of the functionality of the agricultural land and reduction of sediment yield, scenario three (30% Agricultural land changed to forest mixed land) preferable best management method. Moreover, applying filter strip and terracing in low slope areas is also taken as operational management method because we can easily apply it without additional complicated technology.

IV. CONCLUSION

The focus of this study is to assess the spatial-temporal change of soil erosion and river sedimentation using SWAT simulation Model

Two gauge calibration and validation method was used to evaluate the representativeness of the sediment data of the whole catchment.

The model performance evolution the model performance evaluation during monthly sediment yield calibration and validation period indicated that R^2=0.94, NS=0.87and R^2=0.81, NS=0.85 respectively.

From the LUCC analysis, it can be concluded that Weib catchment had experienced a significant change in land use and land cover over the past three decades.

The most sensitive parameters for erosion simulations were Average slope steepness (HRU_SLP), Average slope length (SLSUBBSN), Initial residue cover (RSDIN), Channel cover factor (CH_COV2), USLE equation soil erodibility (K) factor (USLE_K), SCS runoff curve number f (CN2), Linear parameter for calculating the maximum amount of sediment that can be re-entrained during channel sediment routing (SPCON) and Exponent parameter for calculating sediment re entrained in channel sediment

From the result of simulated conditions of a fixed with only the measured land cover changes inserted, simulated sediment yield increased by 66.75%, 64.80%, 61.48%, 71.08%, and 54.47% of year 1986 and 2010 respectively

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