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Assessment of sediment yield and conservation practices in Akaki watershed, Upper Awash Basin, Ethiopia

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ABSTRACT

Changes in land use / land cover, coupled with poor management systems, can result in a high rate of soil erosion and increased sediment transport by changing the extent and structure of runoff and sediment yield. The purpose of this study was to assess sediment yield and conservation practices in the Akaki watershed using the Soil and Water Assessment Tool (SWAT) model. The watershed has been severely degraded due to increasing urbanization, deforestation, careless use of land and water resources that have led to soil erosion. MUSLES were used to estimate sediment yield in watersheds. SWAT has been used to delineate the watershed and to analyze the slope of the watershed, soils and land uses. In addition, ground control points, interviews and field observations were conducted to collect data on the effects of soil erosion and the status of existing conservation measures. The average annual soil loss in the study area is estimated at 2.12 tonnes / ha / year due to the high erosivity of rainfall in the region. In addition, the results showed a direct relationship between precipitation and sediment yield. Spatial variability of sediment yield was performed using simulated sediment yield results for LULC generated. Also based on the spatial outcome for critical sub-watersheds, the design and development of best management practices were proposed under different scenarios. The scenarios showed that the average annual reduction in sediment yield at the sub-basins of hot spots after the application of filter belts, terraces and stone bunds was 75.6%, 68.8% and 69.6% respectively, 4% of sediment reduction. Therefore, the placement of filter strips for the Akaki catchment should be developed and encouraged for effective sediment reduction.

Keywords: Akaki watershed, LULC, MUSLE, sediment yield, SWAT, ERDAS Imagine, Upper Awash Basin

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1. INTRODUCTION

The mountainous areas of Ethiopia, with a population of between 1,000 and 4,533m a.m.s.l, are home to the majority of the country's population [1]. We also know that half of the country is protected by this altitude range. More than 90% of the uplands were formerly forested. Today, the percentage of forest cover decreases considerably because of the invasion of humans. This is due to large-scale deforestation that has led to severe soil erosion and increased soil degradation throughout the country in general and in the uplands in particular. Soil erosion and sediment production include the processes of detachment, transport and deposition of sediments by the impact of rain and running water [2]. Soil erosion is one of the most serious environmental problems in the world, as it affects agricultural land and the natural environment [3]. The [4] study on global soil loss showed that the rate of soil loss in the United States is 16 t / ha / year, in Europe it is between 10 and 20 t / ha / year. Year, while in Asia, Africa and South America between 20 and 40 tons / ha / year. Average annual soil erosion in Ethiopia ranges from 16 to 50 tonnes / ha / year, depending mainly on rainfall intensity, vegetation covers and slope [5]. Multi-variable and multi-site approaches to calibrate and validate SWAT have been used through trial and error processes. Not only were the model's internal hydrologic processes evaluated, but several sub-watersheds were also used for this calibration [6]. Several global studies have been conducted using the SWAT model, for example [7-9] ... etc., and some studies have been conducted according to this model in Ethiopia [10, 11]. Models are used to predict the reliable quantity and rate of sediment transport from the earth's surface to streams, rivers and bodies of water to identify areas of erosion within an area. Watershed and to propose best management practices to reduce the impact of erosion. Removal of vegetation may increase base flows if soil infiltration capabilities remain intact [12]. On the other hand, if clearing is followed by land-use practices that compact soils and expose them to erosion, this may result in a decrease in percolation in groundwater. In this paper, the model of the Soil Water Assessment Tool [13] was applied to simulate the small-scale performance of the Akaki Basin in the Upper Awash Basin. The Akaki watershed is the main part of the Upper Awash Basin, which includes the city of Addis Ababa and some cities around the city. The city has grown since its founding and the rapid conversion of land from rural uses to urban uses more than anywhere else in the country. Over the past 100 years, for example, there has been an intensive conversion of rural land to urban development, such as buildings, transportation networks, shopping centers, various types of industries, parks and recreation areas [14]. The objective of this study was therefore to evaluate the sediment yield, to determine the spatial variability of sediment yield, to identify the sub-basin of hotspots, to evaluate different conservation scenarios to reduce the yield of sediments. Sediments and recommend high-impact watershed management interventions.

2. DESCRIPTION OF THE STUDY AREA

Figure 1 (Akaki watershed) is located in central Ethiopia, along the western boundary of the main Ethiopian rift valley. The watershed is located northwest of the Awash River between latitude 8°46' - 9°14' N and longitude 38°34' - 39°04'. The Akaki watershed covers approximately 1314.43 km^2. The topography is hilly and forms a plateau in the northern, western and southwestern parts of the city, while the southern and southeastern parts of the city have soft morphology and flat areas [15].

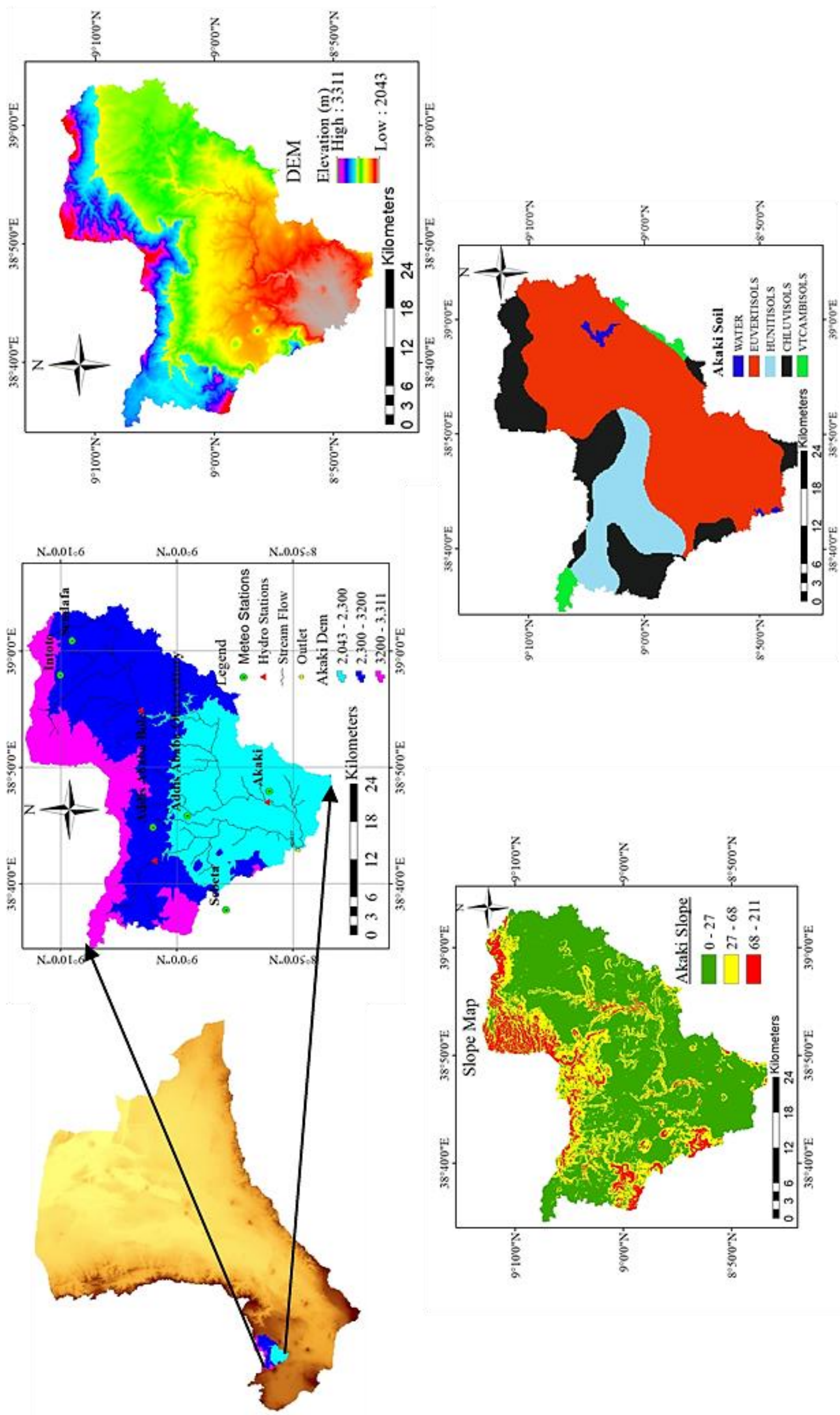


Figure 1. The study area and Awash basin.

The range of mean annual rainfall for the stations in the period 1985-2016 is 1183.56 mm. The mean monthly rainfall between June to September is above 100 mm, with monthly maximum rainfall record 298.88 mm in August, while November to January show the lowest mean monthly rainfall record 9.6 mm. The maximum temperature of Addis Ababa ranges between 21 ºC (in wet season) to 26 ºC (in dry season), while the minimum falls between 8 ºC to 12.5 ºC in the year. The major soils types in this watershed are Chromic Luvisols, Verti Cambisols, Water, Eutric Vertisols, and Humic Nitisols having coverage of 21.06%, 1.99%, 0.72%, 60.42% and 15.81% respectively.

2. MATERIALS AND METHODS / RESULT AND DISCUSSION

Land use/land cover data

Land use is one of the most important factors affecting runoff, evapotranspiration and surface erosion in a watershed. In addition, the land use / cover map is a very important element for SWAT to determine the impacts on runoff and sediment volume in the watershed. Satellite imagery for 2018 was obtained from Landsat Thematic Mapper (TM) sensors at a spatial resolution of 30m × 30m and downloaded from the USGS Earth Explore. The LULC map of the area has been reclassified based on the available topographic map (1:50,000) and the satellite image of the year 2018.

The reclassification of the land use map has been prepared to represent land use according to specific types of land cover such as crop type, stand, grassland, bare soil, water and forest. A lookup table identifying the SWAT land use code for the above land use classes was also prepared to establish a relationship between grid values and SWAT LULC classes.

Ground truth /Field survey

Field truth or field investigation was conducted to observe and collect field condition information at a test site and to determine the relationship between the remote sensing data and the object to be observed. 1384 GCP were collected in the field (Figure 2). That was used for the analysis, interpretation, comparison and expression of land cover using GPS. These GCPs were used to produce a signature for supervised classification and assessment of the accuracy of the watershed satellite images. A stratified and random sampling method was used for GCP collection [16]. Within these strata, representative areas have been selected, guaranteeing 500 points for cropland, 550 for stand, 215 for forests, 89 for grasslands, 20 for bare soil and 10 points for water.

After GCP collection, image pre-processing, image overlay and image sub- setting were performed in ERDAS IMAGINE. The images used in this research were obtained at different time scales. They have a veil and a dust of different proportions. These camouflage real changes or can show different classes of land cover. To solve such problems, atmospheric correction methods are used [17].

Radiometric image enhancement is an important step in pretreatment. Image enhancement aims to make objects more visible by improving the quality of images to differentiate between different objects or different categories of vegetation cover. Mist and noise reduction techniques have therefore been applied to the images for a better understanding of LULC classes [18].

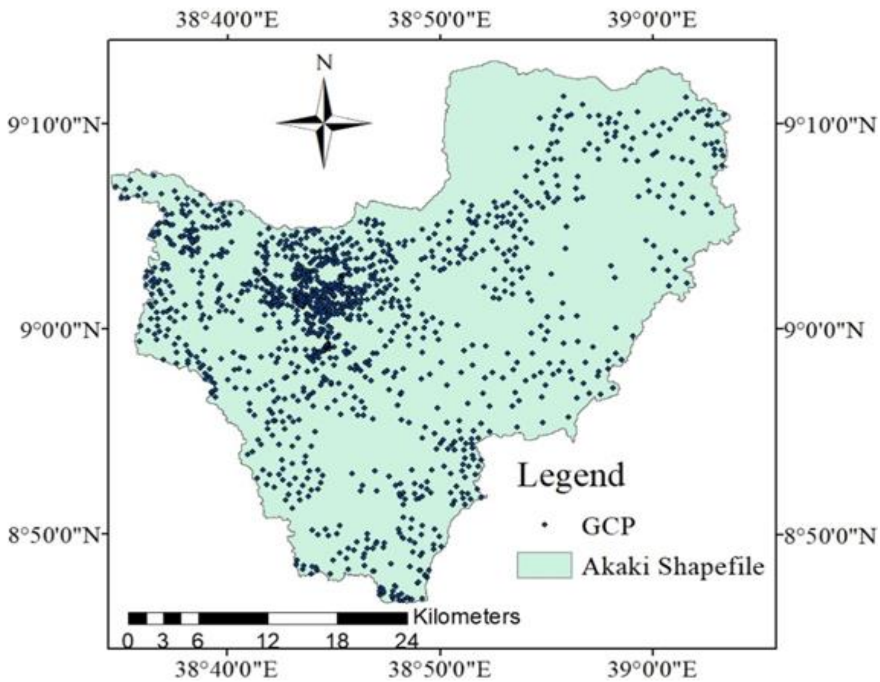


Figure 2. Spatial distribution of GCPs in Akaki watershed

Accuracy Assessment

Accuracy assessment is an important step in the process of analyzing remote sensing data. It determines the value of the resulting data to a particular user, i.e. the information value. In essence, therefore, classification accuracy is typically taken to mean the degree to which the derived image classification agrees with reality or conforms to the 'truth' [19, 20]. A classification error is, thus, some discrepancy between the situation depicted on the thematic map and reality. The main technique for accuracy assessment is using change maps for evaluating each class and calculating the expected accuracy [21]. The confusion matrix is currently at the core of the accuracy assessment literature [22, 23].

Catchment delineation

For this study Arc SWAT integrated with Arc GIS was used to delineate the watershed area and process the slope, soil and land use map. The reason for selecting SWAT model was, among others, its computational efficiency, its ability to simulate long-term impacts, its applicability to large-scale watershed. SWAT requires daily values of precipitation, maximum and minimum temperatures, solar radiation, relative humidity and wind speed. In addition, soil and land use maps are needed to run the model.

Estimation of sediment yield

The sediment yield of the study area, Akaki watershed, was calculated by MUSLE (Modified Universal Soil Loss Equation). The MUSLE sediment yield module uses factors that characterize physical conditions on the surface of a catchment as input information. The equation is written as:

$$sed = 11.8(Q_{surf}.q_{peak}.area_{hru})^{0.56}.K_{USLE}.C_{USLE}.P_{USLE}LS_{USLE}.CFRG \quad \text{........ (1)}$$

In which, sed is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff from the watershed (mm /ha), q_{peak} is the peak runoff rate (m^3/s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the soil erodibility factor (0.013 metric ton m^2 hr/(m^3-metric ton cm)), C_{USLE} is the cover and management factor, P_{USLE} is the support practice factor, LS_{USLE} is the topographic factor and CFRG is the coarse fragment factor.

SWAT-CUP

The objectives of SWAT-CUP (SWAT Calibration and Uncertainty Procedures) is to: integrate various calibration/uncertainty analysis procedures for SWAT in one user interface, make the calibrating procedure easy to use for students and professional users, make the learning of the programs easier for the beginners, provide a faster way to do the time consuming calibration operations and standardize calibration steps and add extra functionalities to calibration operations such as creating graphs of calibrated results, data comparison, etc.

Upon choosing a procedure, the program guides the user step by step through the input files necessary for running each program. Each SWAT-CUP project contains one calibration method and allows running the procedure many times until convergence is reached. It allows saving calibration iterations in the iteration history.

Land use/land cover analysis

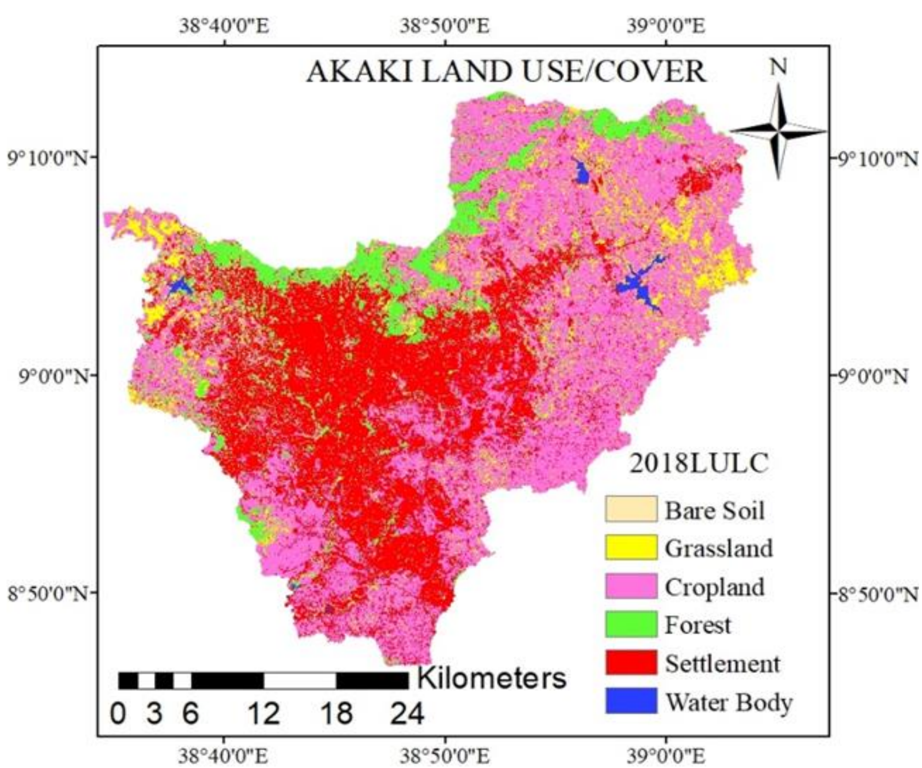


Figure 3. Land use land cover map

A spatial analysis was performed to describe the LULC change for 2018. The land cover map shown in Figure 3 shows a dominant cover of cropland with a coverage of 45.92%, followed by settlement, forest and grassland with 33.77%, 8.75% and 8.36% respectively. The bare soil and the water cover a small percentage, namely 2.65% and 0.55% respectively [24]. Showed that the coverage of the future area cultivated in 2020 for the Akaki watershed was 49.23%, which is in line with the results of this study which was 45.22% during 2018.

Accuracy assessment of land cover classification

Accuracy assessment is an important step in the process of analyzing remote sensing data. It determines the value of the resulting data to a particular user, i.e. the information value. The accuracy assessment is used to determine the degree of 'correctness' of a map or classified image. The confusion matrix/error matrix has numbers as the quantity of sample. Any particular quantity arranged in rows and columns i.e. square matrix, where columns represent the referencing data while row represents the classification data. The overall accuracy for the LULC image are defined as the total correct pixels (major diagonal's sum) divided by the total number of pixels in the provided matrix which is 93.96%. In addition, the overall kappa coefficient for the image was 0.922 i.e. 92.2% better agreement than by chance alone respectively.

Table 1. Error matrix accuracy for the classified image.

Classifications	Reference Data							Percent	
	BS	GL	CL	F	S	WB	Total	CE(%)	UA(%)
BS	3	0	0	0	1	0	4	25	75
GL	0	19	2	2	0	0	23	17.39	82.61
CL	1	1	43	0	0	0	45	4.44	95.56
F	0	0	0	30	2	0	32	6.25	93.75
S	0	0	0	0	37	0	37	0	100
WB	0	0	0	0	0	8	8	0	100
Total	4	20	45	32	40	8	149	OA=93.96%	
OE	25	5	4.44	6.25	7.5	0	0		
PA	75	95	95.56	93.75	92.5	100	100	Kappa=0.922	

Bare Soil (BS), Grassland (GL) Cropland (CL), Forest (F), Settlement(S), Water Bodies (WB), Omission error (OE), Commission error (CE), Producer accuracy (PA) and User accuracy (UA) and Overall accuracy (OA).

$$OA = \frac{((3+19+43+30+37+8)}{(4+23+45+32+37+8))} * 100 = 93.9$$

$$Kappa = \frac{(149 * (3 + 19 + 43 + 30 + 37 + 8)) - ((4 * 4) + (20 * 23) + (45 * 45) + (32 * 32) + (40 * 37) + (8 * 8))}{((149^2) - ((4 * 4) + (20 * 23) + (45 * 45) + (32 * 32) + (40 * 37) + (8 * 8)))}$$

$$Kappa = \frac{15791}{17132} = 0.922 = 92.2\%$$

Kappa values are characterized as <0 as indicative of no agreements and 0 to 0.2 as slight, 0.2 to 0.41 as fair, 0.41to 0.60 as moderate, 0.60 to 0.80 as substantial and 0.81–1.0 as almost perfect agreement [25]. Therefore, the overall classification accuracy of the image yielded a Kappa statistic of 92.2% for the 2018 image. This implies that the image classification accuracy was almost perfect agreement.

Sediment yield modeling

The global effect of each used parameter was classified using total sensitivity function in SWAT-CUP. The capability of a hydrological model to adequately simulate streamflow and sediment concentration typically counts on the precise calibration of parameters [26].

In fact, model calibration and validation are indispensable for simulation process, which are used to estimate model expectation results. During sensitivity analysis of sediment seven sediment parameters were checked for sensitivity and sensitive parameters were identified.

Table 2. Sensitive sediment flow parameters.

Prameter Name	Description	Parameter Range	Calibrated Value	t-stat	p-value	Rank
Spcon	Linear factor for channel sediment routing	0.0001–0.01	0.002	-6.579	0	1
Ch_cov	Channel cover factor	0 – 1	0.415	-2.078	0.037	2
USLE_P	USLE support practice factor	0 – 1	0.2	1.75	0.08	3
Ch_erod	Channel erodibility factor	0 – 1	0.15	-1.538	0.124	4
CANMX	Maximum canopy storage	0 – 10	1.973	-1.208	0.227	5
Spexp	Exponent factor for channel sediment routing	1 – 2	1.75	0.903	0.366	6
USLE_C	USLE equation soil erodibility (K) factor	0 – 1	0.003	-0.862	0.388	7

Calibration and validation of sediment yield

After the sediment sensitive parameters were identified during sensitivity analysis, calibration process took place. Simulating the sediment yield was performed for nine years' period (1990–1998) for calibration including one-year warm period and six years' period (1999-2004) for validation. Sediment yield calibration and parameters adjustment performed iteratively until simulated and observed sediment yield fitted. The performances of the calibrated and validated simulations were also checked by NSE, R^2 and RSR.

Table 3. Performance evaluation of calibrated and validated sediment yield

Performance criteria	Calibration	Validation
NSE	0.83	0.85
R^2	0.84	0.86
RSR	0.39	0.40

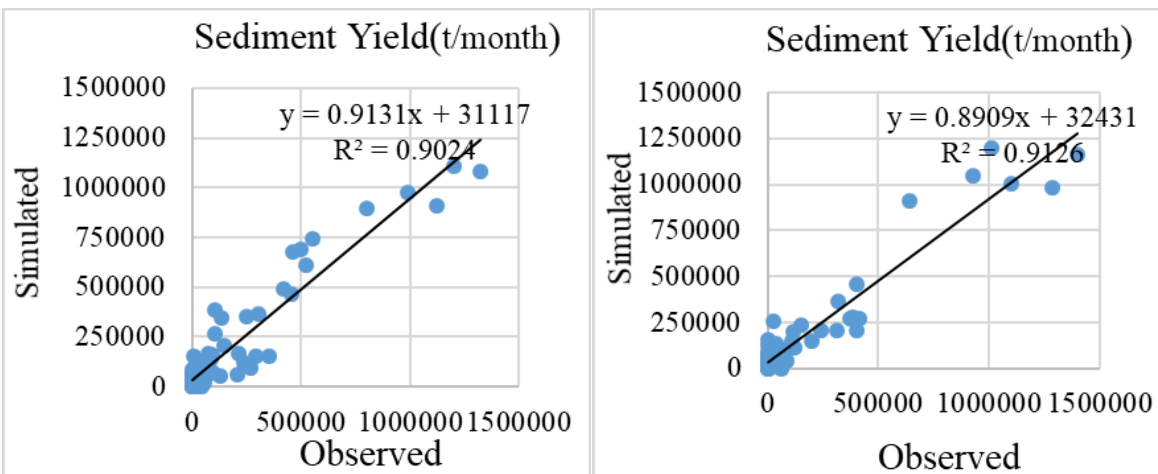
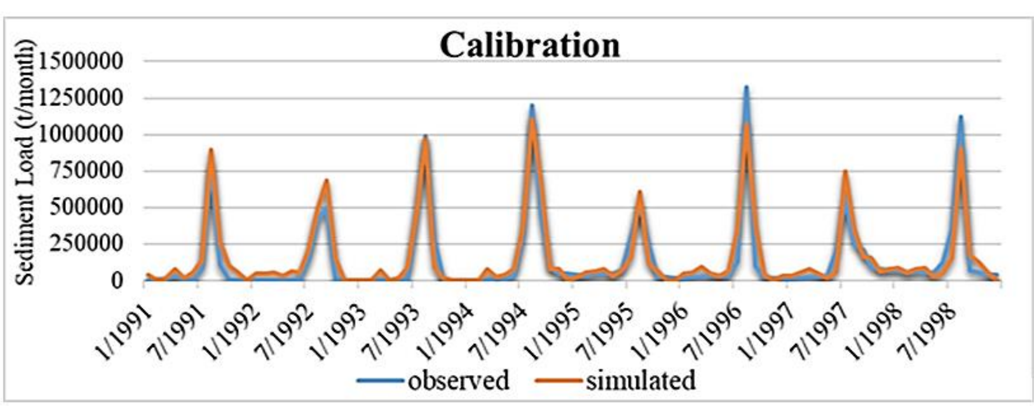
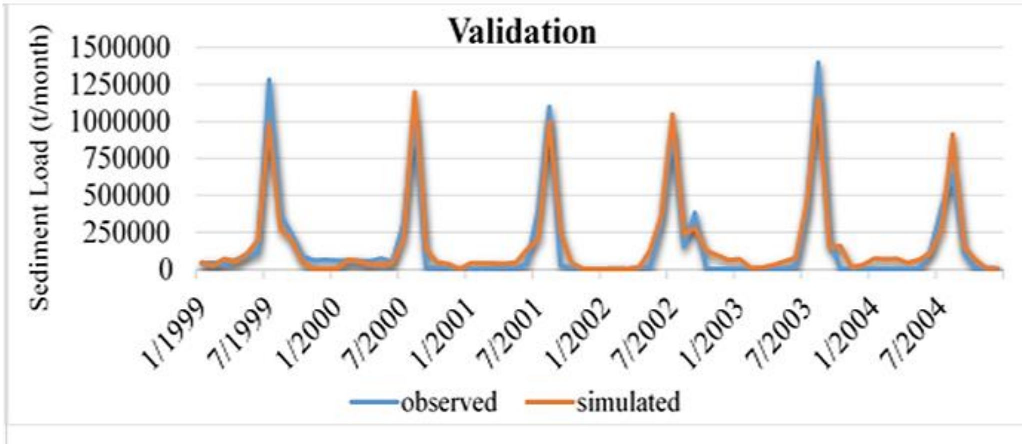


Figure 4. Coefficient of determination (R^2) a) calibration 1991-1998 and b) validation 1999–2004.

Uncertainty measures of SUFI- 2 showed that P-factor of 0.77 and R-factor of 0.33 for calibration and P-factor of 0.75 and R-factor of 0.41 for validation at the Akaki gauging station. The monthly calibrated and validated results of Sediment yield are presented below in Figures 5.



(A)



(B)

Figure 5(A,B). Monthly calibrated and validated sediment yield

The calibrated and validated sediment yield results showed a very good agreement to the observed data (Figure 5). Therefore, these results of estimated sediment yield indicate that SWAT model is good predictor of sediment yield of Akaki watershed. In which the observed mean annual sediment was used as a comparison for simulated sediment yield results. Hence, as in Table 3 the observed mean sediment shows a very good agreement and correlation with the simulated flows.

Spatial Variability of Sediment Yield in the Watershed

The average annual yield of sediment transport out of reach during the time step in metric tons for all watershed was 2.12 ton/ha/yr. Spatial variability of sediment yield from Akaki watershed was identified from the simulated annual sediment outputs for each of the sub-basins.

Variability of sedimentation rate was also identified from the potential areas. The average annual yield of sediment transport out of reach during the time step in metric tons for each sub-basin was used to generate the sediment source map and the result shows the ranges was between 0.11 to 21.75 ton/ha/yr for the sub-basins.

According to the sediment results of the sub-basins in Akaki watershed (Figure 6), sub-basins 26, 40, 43, 44, 56, 59 and 79 are Very high, sub-basins 17, 35, 36, 48, 58,72 and 80 were high, sub-basins 9, 15, 16, 21, …,75 to 78 and 81 were moderate potential source area for sediment and the other sub-basins such as 1-8, …, 75-78, and 82 were low potential source area for sediment having less than 3 t/ha/yr.

As shown in Figure 6 above, it is observed that 14 affected sub basins dominantly covered with intensively and moderately by crop land, grass land and bare soil which are the main sources for annual sediment yield and in sub-basin 26 it is highly affected sub-basin because it is covered by crop land as well as the topography of that sub-basin is very steep slope compare to the neighbor sub-basins. And also the dominant soil types of these sub-basins are Euvertisols and Humic nitisols.

The identification of highly erosive sub-watersheds will help local governments, policy makers and other stakeholders for proper management and watershed development.

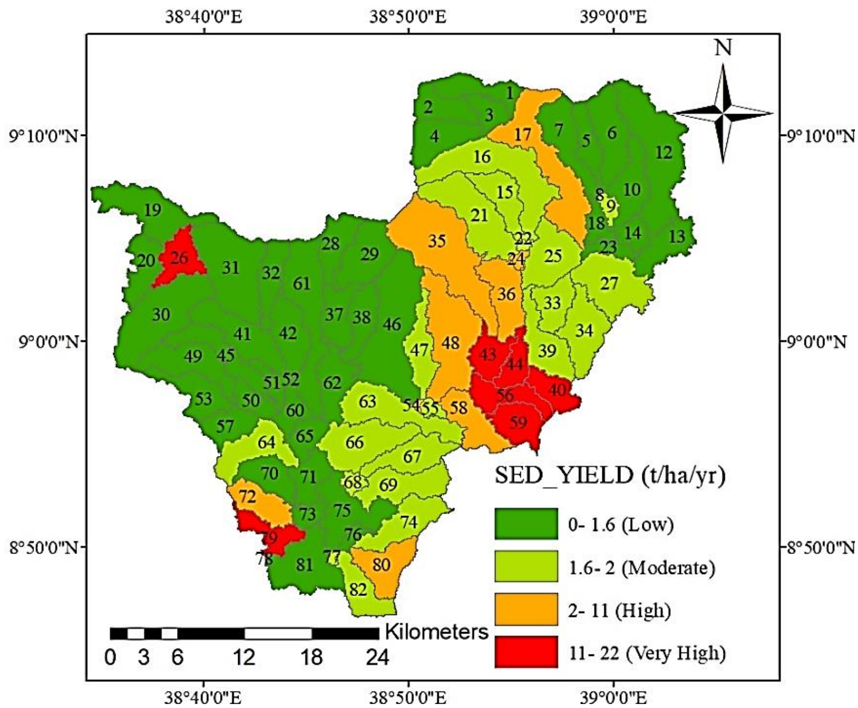


Figure 6. Spatial variability of sediment yield (t/ha/yr) in Akaki watershed

Best Sediment management scenario development and analysis

A study of soil formation rates in different agro ecological zone of Ethiopia indicates that the range of the tolerable soil loss level for the various agro ecological zones of Ethiopia were 2 to 18 t/ha/yr [27]. According to spatial variability of sediment source and sediment rate/erosion level identified in section 3.2.2. The BMP scenarios were developed. Identified and selected scenarios were also applied to SWAT model for simulating and identifying the effects of these best management practices on sediment yield of the watershed.

During this study three different scenarios were developed and compared according to their effectiveness of soil conservation or sediment reduction. Those scenarios were scenario I (Terracing), scenario II (Filter strip) and scenario III (stone/soil bunds). Baseline scenario was used as a reference for comparisons of the effectiveness of the developed sediment reduction scenarios.

In Baseline scenario (S_0) the watershed existing conditions were considered. In this scenario, fourteen critical sediment source sub basins were identified for simulation of three selected sediment reduction scenarios. Each scenario was then run for the same simulation period (1991-2016) for 2018 LULC to provide a consistent basis for comparison of the scenario results. Out of fourteen critical sub basins, seven were very high (11-22 ton/ha/yr.) and seven were high (2-11 ton/ha/yr.) sediment yielding sub basins. Average sediment yield of fourteen identified critical sediment source sub basins was 13.28 ton/ha/yr.

In scenario I terracing practice used as part of a resource management system constructed to reduce erosion and sediment yield in the watershed by reducing slope length and steepness of sub basins. Simulation of terracing on the selected critical sediment source sub basins by adjusting the curve number (TERR_CN), USLE crop practice (TERR_P) and slope length

(TERR_SL) significantly reduced average annual sediment yield rate by 68.75% (13.28 ton/ha/yr to 4.15 ton/ha/yr). At the entire watershed level, the average annual sediment yield was reduced from 212 ton/km^2/yr to 165 ton/km^2/yr which accounts 22.2% sediment yield reduction. After application of terraces all critical sub-basins turned from the category of very high and high to category of low sediment yielding (Figure 8).

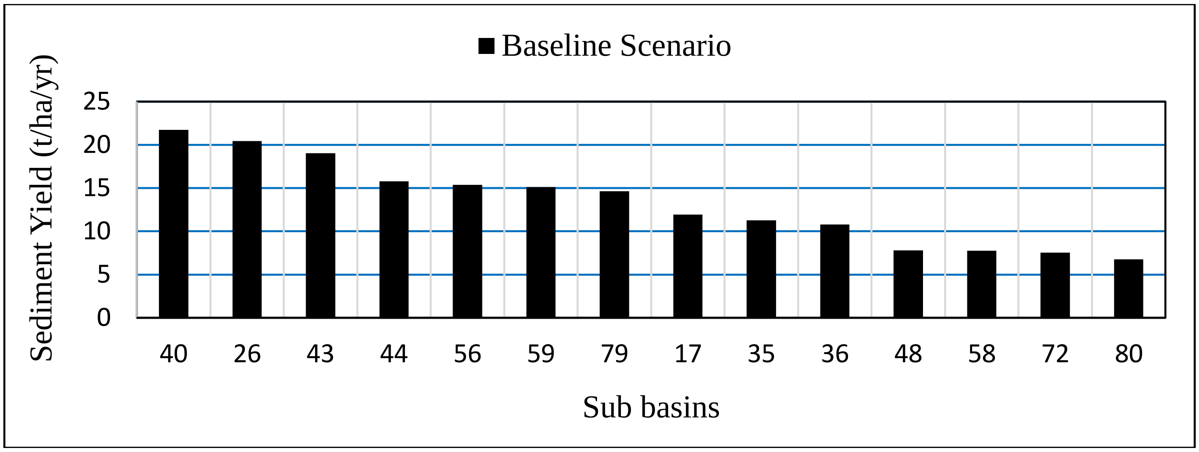


Figure 7. Baseline scenario (existing) sediment yield rate (ton/ha/yr)

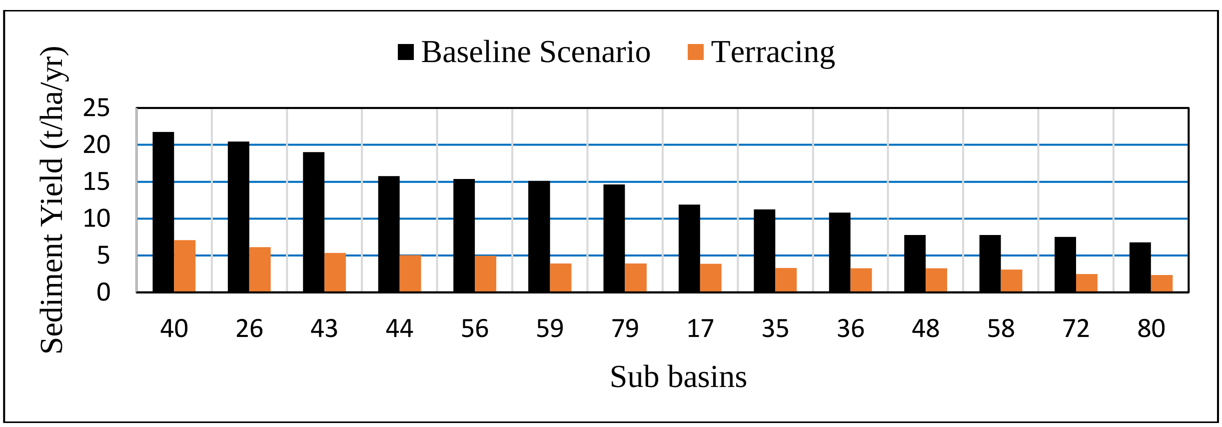


Figure 8. Average annual sediment yield reduction due to application of terracing

In scenario II filter strips were placed on all agricultural HRUs which are a combination of cultivated land, all soil types and slope classes. The effect of the filter strip is to filter the runoff and trap the sediment in a given plot. Appropriate model parameter for representation of the effect of filter strips is width of filter strip (FILTERW). FILTERW value of 1m spacing was checked to simulate the impact of filter strips on sediment trapping and this shows substantial reduced average annual sediment yield rate by 75.6% (13.28 ton/ha/yr to 3.24 ton/ha/yr). At the entire watershed level, the average annual sediment yield was reduced from 212 ton/ha/yr to 106 ton/ha/yr which accounts 50% sediment yield reduction. The filter width value was assigned based on local research experience in the Ethiopian highlands.

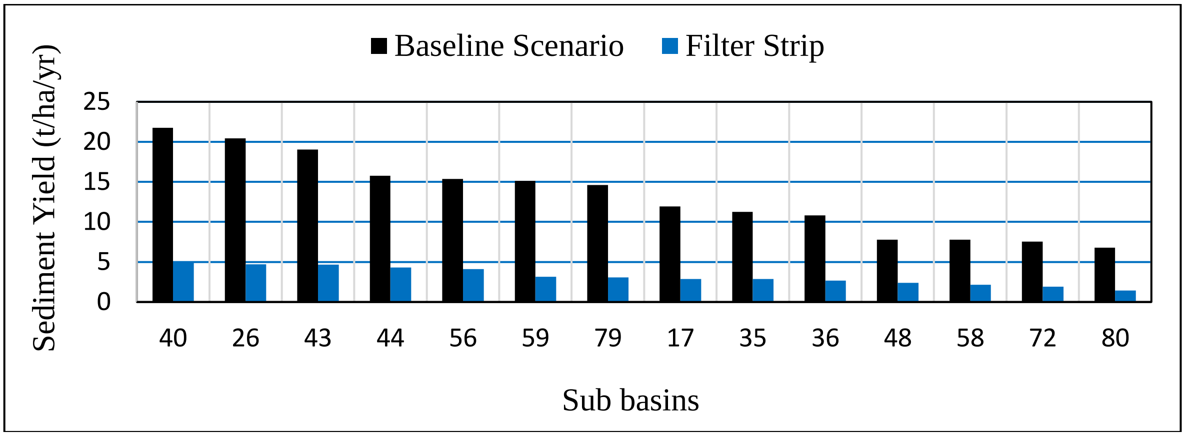


Figure 9. Mean annual sediment yield reduction due to application of filter strip

Stone bunds were designed as scenario SIII, by changing the parameter values of SLSUBBSN and USLE-P files on SWAT parameters database table this shows considerable reduced average annual sediment yield rate by 69.4% (13.28 ton/ha/yr to 3.24 ton/ha/yr). At the entire watershed level, the average annual sediment yield was reduced from 212 ton/km^2/yr to 133 ton/km^2/yr which accounts 37.3% sediment yield reduction. SLSUBBSN and USLE_P values were modified on (hru) and (mgt) input tables respectively. The practice of using stone bunds has a function to reduce overland flow, sheet erosion and reduces slope length.

Table 4. Summary of developed scenarios result for fourteen affected sub basins

Sediment source Sub-basin	Baseline scenario	Average Sediment Yield (ton/ha/yr) reduction		
		Filter Strip	Terracing	Stone Bund
40	21.75	4.98	7.09	6.18
26	20.44	4.70	6.12	5.90
43	19.02	4.67	5.33	5.85
44	15.77	4.32	5.03	5.39
56	15.37	4.10	4.95	5.17
59	15.13	3.16	3.94	3.95
79	14.62	3.07	3.92	3.77

17	11.92	2.88	3.90	3.57
35	11.26	2.88	3.31	3.55
36	10.80	2.65	3.26	3.32
48	7.79	2.39	3.25	3.02
58	7.77	2.15	3.11	2.70
72	7.54	1.92	2.50	2.40
80	6.76	1.44	2.35	2.20
Average	13.28	3.24	4.15	4.07

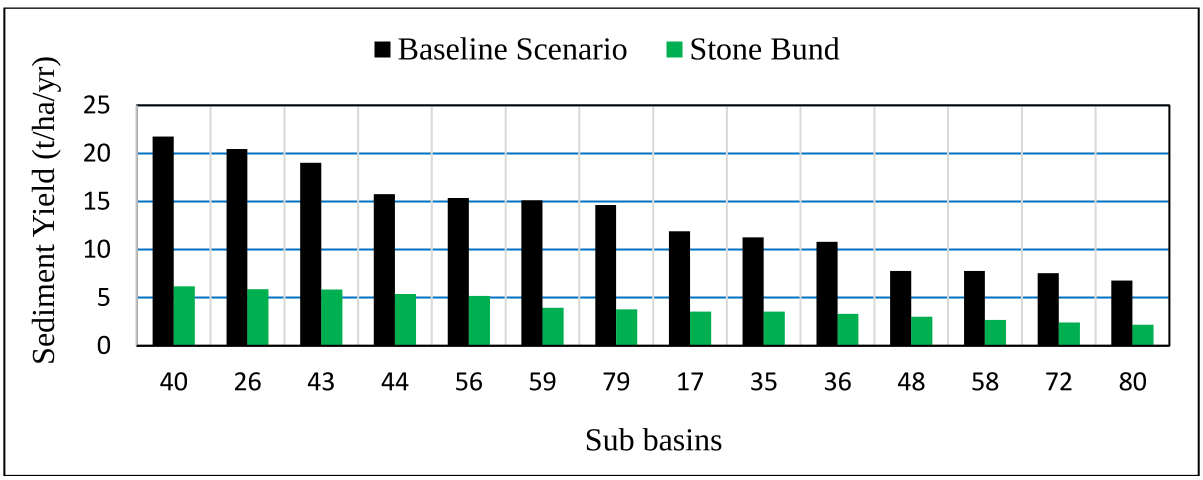


Figure 10. Mean annual sediment yield reduction due to application of stone/soil bund

Comparison of scenarios results

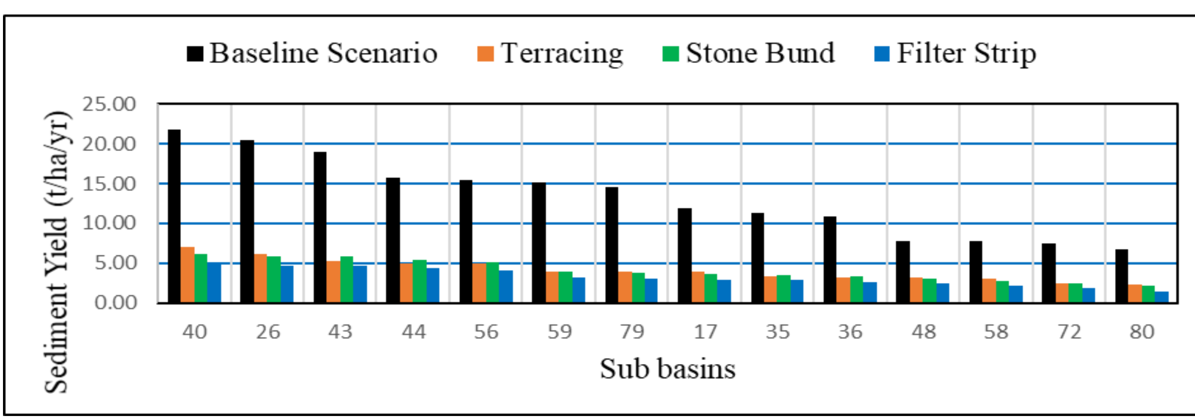


Figure 11. Scenarios comparison with their sediment yield reduction on selected sub basins

Three scenarios were developed in the above section 3.2.3. and it is possible to compare those scenarios result to select best one for the affected sub-basins. As shown in Figure 11, the spatial variability of sediment yield reduction after application of filter strip, terracing and stone bund were relatively consistent in all sub-basins. As presented in Table 5; from those BMPs; Filter Strip was the best effective method of sediment reduction in Akaki watershed.

Table 4. Summary of scenarios comparison with baseline scenario.

Scenario	Mean annual sediment yield reduction at hotspot sub-basins level		Mean annual sediment yield reduction at entire watershed level	
	Sediment reduction (ton/ha/yr.)	Sediment % age of reduction	Sediment reduction (ton/ha/yr.)	Sediment % age of reduction
Baseline scenario	13.28	-	212	-
Filter Strip	3.24	75.6	106	50
Terracing	4.15	68.8	165	22.2
Stone Bund	4.07	69.4	133	37.3

3. CONCLUSIONS

In this study the classification of land use/land cover on Akaki watershed for 2018 year were detected using Landsat satellite images from USGS earth explorer. The classification of LULC image were performed on ERDAS Imagine 2015 integrated with other GIS data as a result sediment simulations were done using SWAT model.

Based on SWAT model watershed delineation, at outlet of Akaki watershed or at the entrance of Aba Samuel Reservoir having a watershed area of 1314.43 km^2. Overlaying land use, soil and slope were performed to generate HRUs. The sediment flow sensitivity analysis result showed that the sediment loss from the watershed is sensitive to both HRU properties and channel properties (linear factor for channel sediment routing (SPCON), USLE support practice factor (USLE_ P) and exponential factor for channel sediment routing (SPEXP).

The average annual yield of sediment transport out of reach during the time step in metric tons for all watershed was 2.12 ton/ha/yr.

The developed sediment yield reduction scenarios result showed that average annual sediment yield reduction at entire watershed level after application of filter strips, terracing and stone bund were 50%, 22.2% and 37.3% respectively. Also at treated sub-basins level 75.6%, 68.8% and 69.4% of average annual sediment yield reduction observed after application of filter strips, terracing and stone bund respectively. Thus, the result indicating that filter strip was relatively more sediment reduction practice than other conservation measures on the majority of the affected sub-basins in the study watershed.

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