MODELING THE EFFECTS OF LAND USE CHANGE AND MANAGEMENT PRACTICES ON RUNOFF AND SEDIMENT YIELDS IN FINCHA WATERSHED, BLUE NILE

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Abstract: In the Nile Basin, water from the Ethiopian highlands, particularly from the Blue Nile, has in the past benefited downstream people in Sudan and Egypt in different ways – agriculture, livestock, industry and power generation. Blue Nile contributes up to 62% of the total flow (measured at Aswan) and similar proportion of sediment to the Nile flow system. However, such benefits are now threatened due to the fact that the upper Blue Nile is heavily affected by watershed management problems, caused by overpopulation, poor cultivation and land use practices, deforestation and overgrazing, resulting in significant loss of soil fertility, rapid degradation of natural systems, significant sediment depositions in the lakes and reservoirs and sedimentation of irrigation infrastructures such as canals. Poor water and land management upstream reduces both potential runoff yields and the quality of water reaching downstream. The result is a vicious cycle of poverty and food insecurity for millions in the upstream; and poor water quality, heavy siltation, flooding, and poor temporal water distribution in the downstream threatening livelihood and economies in the downstream. It is widely recognized that improved watershed management in the Blue Nile will significantly increase water availability for various stakeholders within the basin. Preventing anthropogenic sediments reaching the Nile water system and enhancing runoff generated from upstream watersheds requires a better understanding of the characteristics, sources and processes generating the sediments so that effective land use and management practices can be implemented. The objective of this study was, therefore, to predict the effects of land use and management practices on runoff and sediment yields in Fincha watershed of Upper Blue Nile, Ethiopia, using SWAT (Soil and Water Assessment Tool) model. Calibration results showed that the model adequately predicted runoff volumes and sediment yields with coefficient of determinations (R^2) ranging from 0.82 to 0.86 and Nash Sutcliffe efficiency (E_{NS}) ranging from 0.73 to 0.85. Simulation of various land use scenarios showed that average monthly runoff volumes increased by 12.68, 2.24 and 4.74%, respectively, when 20% of forest, 20% of grazing, and 20% of shrub land is converted to agricultural land. The respective increase in average monthly sediment yields were 16.20, 2.07 and 3.80%. Moreover, average monthly runoff volumes and sediment yields were increased by 17.86 and 19.46%, respectively, when 20% of each of forest, grazing, and shrub lands are converted to agricultural land simultaneously. Simulation of management practices also indicated that while runoff volumes remained almost constant, average monthly sediment yields decreased by 20.82 – 24.41 t/ha under various land use scenarios as the result of soil conservation interventions. This study demonstrated that SWAT model is a useful tool for modeling the impacts of land use and management practices on the hydrological processes and thus can serve as a basis for developing sound watershed management interventions in the study area.

Keywords: Ethiopia, Fincha watershed, land use, runoff, sediment yield

INTRODUCTION

Quantifying the impacts of land use change and management practices on the hydrological response of a watershed has been an area of interest for hydrologists in recent years as this information could serve as a basis for developing sound watershed management interventions. The effects of land use change and management practices on the hydrological response of a watershed are most likely where the change alters the surface characteristics of a watershed. It is one of the most important factors that have shaped the landscapes in many parts of the world [1-4] and influencing the hydrological processes of a watershed. The degree and type of land cover influences the rate of infiltration, runoff, and consequently the volumes of surface runoff and total sediment loads transported from a watershed. It often leads to significant land resources degradation such as loss of soil by erosion, nutrient leaching and organic matter depletion. For example, land use change can result in change of flood frequency [5, 6], flood severity [7], fluctuation in base flow [8], and change in annual mean discharge [9]. Moreover, land use change has a direct impact on land management practices, economic health and social processes of concern at regional, national and global levels [10].

A study conducted by Assefa [11] and Oromia Agriculture and Development Bureau, OADB, [12] showed that after the construction of hydropower reservoir dam in Fincha watershed, the area experienced a substantial land use change. Moreover, the establishment of state farm downstream of the Fincha reservoir for producing food and commercial crops at the expense of forests and marginal areas further led to degradation of the area. The gradual expansion of agricultural land from gently sloping land onto the steeper slopes of neighboring mountains on the one hand, and into the flat swampy plains of the plateau on the other accelerated soil erosion [13]. Consequently, large areas of forest, grazing, and shrub lands have been converted to farm lands leading to sever soil erosion and sedimentation of rivers, streams, reservoir, and siltation of low land areas [14]. At present, the majority of the watershed is under intensive cultivation of annual crops with poor farming system that encourage erosion. These include cultivation of cereal crops such as *teff* (Ergrotis tef) and wheat (*Triticum sativum*) which require the preparation of a fine-tilth seedbed. Moreover, the socio-political situation, especially insecurity of land tenure system has greatly discouraged farmers from investing in soil conservation practices [14].

Thus, soil erosion and its consequent effects are the most important environmental problem in Fincha watershed and will continue to be the most severe threat to the area unless conservation-oriented land management practices are employed. The patterns of land use change and present status of soil erosion found in Fincha watershed will generate substantial soil erosion and in the long run aggravate the poverty of farmers living in the area pollution of water resources in the Nile river system. Therefore, there is an urgent need for developing integrated watershed management plan to retard and reverse this degradation process based on hydrological simulation studies using suitable modeling approach. In order to develop efficient strategies for the sustainable development of the watershed, it is essential to quantify the extent to which land use and management practices influence the hydrological processes of the watershed such as surface runoff and sediment yields.

Considering the hydrological behavior of the watershed and applicability of the existing models for the solutions of aforementioned problems, this study was undertaken using SWAT model to estimate surface runoff and sediment yields in Fincha watershed. The objective of this study is, therefore, to predict the effects of land use change and management practices on runoff and sediment yields using the SWAT model in Fincha watershed, Ethiopia.

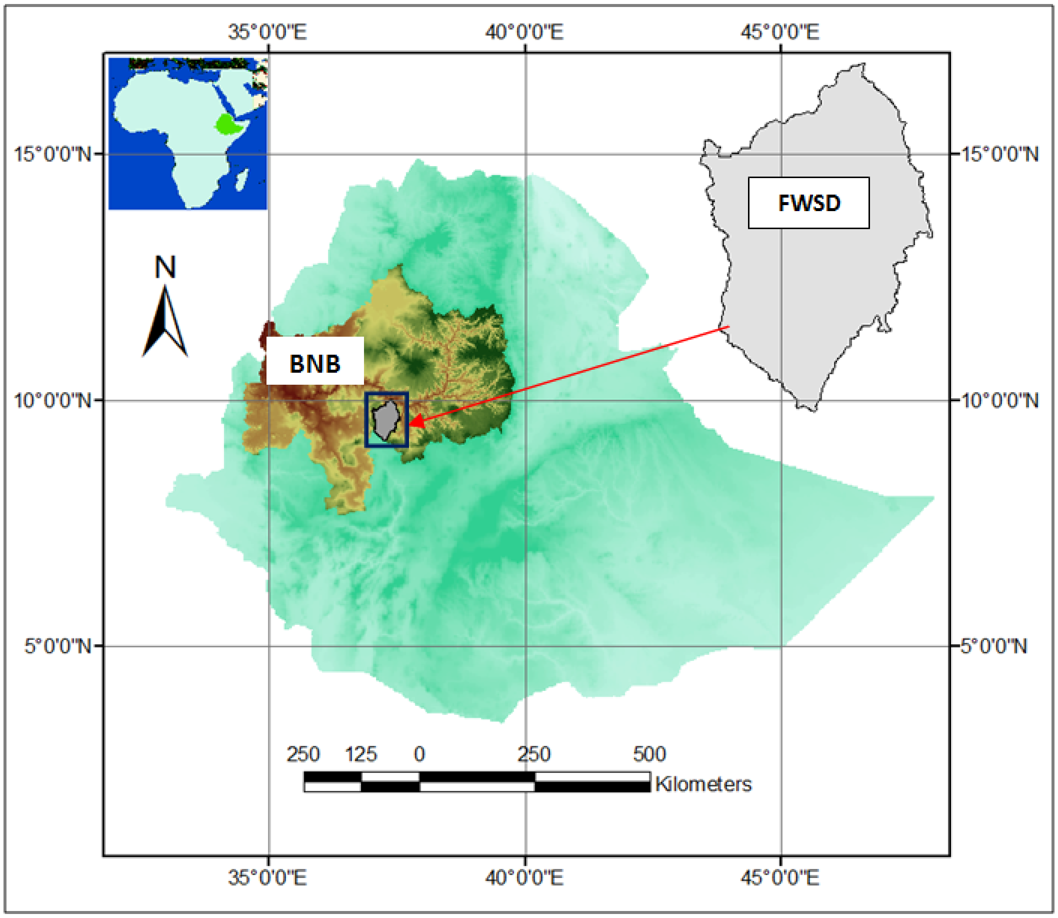
MATERIALS AND METHODS

Study area

Fincha watershed is located in Horro Guduru Wollegga Zone, Oromiya Regional State, Ethiopia, between 9°9′53″ N to 10°1′00″ N latitudes and 37°00′25″ E to 37°33′17″ E longitudes (Fig. 1). The watershed has an area of 3251km^2 and covers partly six districts namely: Jimma Geneti, Horro, Abbay Chomen, Ababo Guduru, Guduru, and Jimmaa Rare.

The major land form of the watershed includes flat, gently sloping to undulating plains, hills, and mountains. The western part of the watershed is characterized by mountainous, highly rugged and rolled topography with steep slopes and the lower part is characterized by valley floor with flat to gentle slopes. Elevation of the watershed varies from 1043 to 3196 masl.

The climate of the watershed is ‘tropical highland monsoon’ with an average annual rainfall of 1,604mm. Most of the rain falls during the months of June to September with peaks occurring during July to August and virtually dry from November through April. As the watershed is located in the high rainfall area, it receives frequent torrential showers and frequent flash floods. The mean monthly temperature of the area varies from 15.50°C to 18.62°C (Fig. 2).



BNB: Blue Nile basin **FWSD:** Fincha watershed

Figure 1: Location of the study watershed

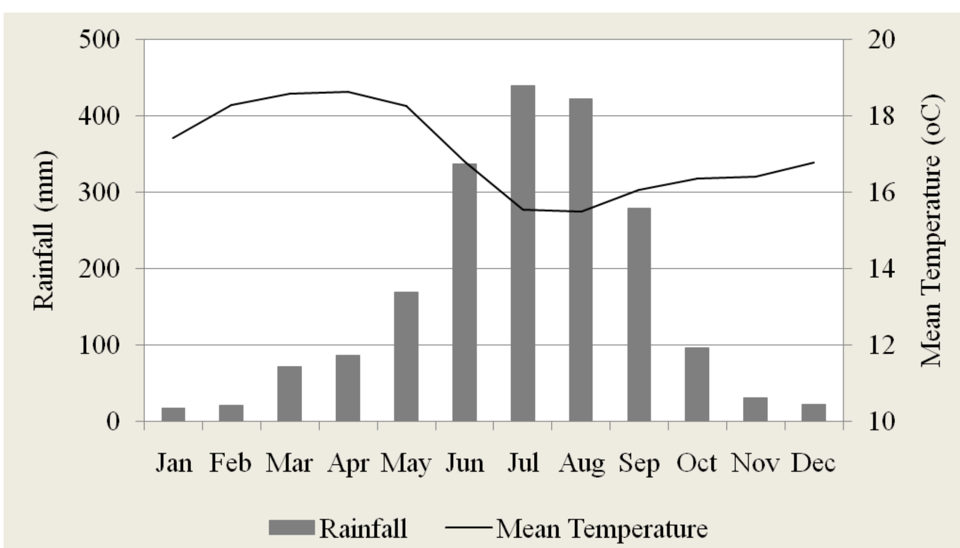


Figure 2: Mean monthly rainfall and temperature of the study watershed

The watershed has a wide range of soil types mainly dominated by clay-loam, clay, and loam soil [14]. The largest portion of the watershed is characterized by clay soil commonly associated with swamps and temporary wetlands on the plain grounds with good to moderate fertility.

Since agriculture is the dominant economic sector in the area, the major portion of the watershed is under intensive cultivation of annual crops. *Teff*, maize, barley, and wheat are the major crops grown in the watershed. Mixed farming (integrated crop–livestock production) is the main agricultural system in the study area.

Description of SWAT model

Soil and Water Assessment Tool (SWAT) is a physically-based, conceptual, and continuous-time river basin simulation model originated from agricultural models with spatially distributed parameters operating on a daily time step [15]. The model is used to quantify the impact of land management practices on water, sediment, and agricultural chemical yields (nutrient loss) in large complex watersheds with varying soils, land use, and management conditions over long period of time [16-18].

SWAT incorporates the effects of weather, surface runoff, evapotranspiration, irrigation, sediment transport, groundwater flow, crop growth, nutrient loading, pesticide loading, and water routing, as well as the long term effects of varying agricultural management practices [19, 20]. In the SWAT model, the watershed is partitioned into subbasins that are further subdivided into one or several homogeneous hydrological response units (HRUs) with relatively unique combinations of land cover, soil, and topographic conditions. The hydrology component of the model calculates a soil water balance at each time step based on daily amounts of precipitation, runoff, evapotranspiration, percolation, and baseflow. The simulated variables (water, sediment, nutrients, and other pollutants) are routed through the stream network to the watershed outlet.

Surface runoff

In the SWAT model, surface runoff is estimated separately for each subbasin of the total watershed area and routed to obtain the total runoff for the watershed. Surface runoff volume is estimated from daily rainfall using modified SCS-CN method [21] given as follows:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \quad (1)$$

where Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), I_a is the initial abstractions which includes surface storage, interceptions and infiltration prior to runoff (mm), S is the retention parameter (mm). The retention parameter varies spatially due to change in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined as follows:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad (2)$$

where CN is curve number. The initial abstractions, I_a, is commonly approximated as 0.2S. Therefore, the SCS curve number equation becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \quad (3)$$

Runoff occurs only when $R_{day} > I_a$.

Sediment yield

In the SWAT model, simulation of sediment yields are computed at the HRU level with the Modified Universal Soil Loss Equation (MUSLE) [22] and are summarized in each subbasin using the following equation:

$$Sed = 11.8(Q_{surf} \times q_{peak} \times area_{hru})^{0.56} K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CFRG \quad (4)$$

where Sed is sediment yield on a given day (metric tons), Q_{surf} is surface runoff (mm/ha), q_{peak} is peak runoff rate (m^3/s), $area_{hru}$ is area of HRU (ha), K_{USLE} is USLE soil erodibility factor, C_{USLE} is USLE cover and management factor, P_{USLE} is USLE support practice factor, LS_{USLE} is USLE topographic factor, and *CFRG* is coarse fragment factor.

METHODOLOGY

Preparation of model inputs

The basic spatial input data sets used by the model include the Digital Elevation Model (DEM), land use/cover data, soil data, and weather data.

Digital elevation model (DEM) is one of the main inputs of the SWAT Model. Topography was defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution. A 30m grid digital elevation model was downloaded from ASTER GDEM. The DEM was used to delineate the boundary of the watershed and analyze the drainage patterns of the land surface terrain. Terrain parameters such as slope gradient, slope length and the stream network characteristics such as channel slope, length, and width were derived from the DEM.

The land use map of the study area for the year 2005 was produced from Landsat ETM + image through supervised classification based on minimum distance algorithm. A modified version of the Anderson scheme of land use and land cover classification method [23] was used to classify the land use and land cover of the study watershed.

The soil textural and physicochemical properties required by the SWAT model includes soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for each soil types. These data were obtained from different sources including Ministry of Water Resources Development (MoWRD) of Ethiopia, Soil and Terrain Database for northeastern Africa [24], Major Soils of the world [25], and Digital Soil Map of the World [26].

The weather variables required by the SWAT model for driving the hydrologic balance are daily rainfall and daily minimum and maximum temperatures. These time series data, covering a period of twenty two years (1985 - 2006), were obtained from the National Meteorological Service Agency (NMSA) of Ethiopia**.**

The observed runoff and sediment yield data at the outlet of the watershed were obtained from the Hydrology Department of the Ministry of Water Resources (MoWR) of Ethiopia. These data are required for the calibration and validation of the SWAT model.

Model set-up

Digital elevation model (DEM) was imported into the SWAT model. A masking polygon (in grid format) was loaded into the model in order to extract area of interest, delineate the boundary of the watershed, and digitize stream networks of the study area. In this study, the minimum threshold area used to discretize the watershed into subbasins was 5000ha. The land use/cover and soil map of the study area (in grid format) were also imported into the model and overlaid. In this study, multiple HRU with 10 percent land use, 20 percent soil, and 10 percent slope thresholds were used. These threshold levels were set to eliminate minor land uses, soils and slope classes in each subbasin so that a maximum of 10 HRUs with unique land use/soil/slope combinations would be created in each subbasin as recommended in the SWAT user manual.

Daily rainfall and daily minimum and maximum temperature data were also prepared in appropriate format (.dbf) and imported into the model.

Model calibration and validation

Model calibration was performed using both manual and auto-calibration processes using time series data from January 1985 to December 2006 on monthly basis. The first two years of the modeling period were used for 'model warm-up'. Data pertaining to year 1987 to 2000 were used for calibration and the remaining data sets were reserved for validation. The hydrological and erosion components of the model were calibrated sequentially until the average simulated and measured values were in close agreement.

During calibration process, runoff curve numbers (CN) were adjusted to estimate surface runoff because CN is a soil moisture balance parameter that allows the model to modify moisture condition of the soil. As SWAT uses the Modified Universal Soil Loss Equation (MUSLE) [22], the model was calibrated for sediment yield estimation by adjusting the USLE crop cover and management factor, C. The C-factor was adjusted to represent the surface cover better in grazing and agricultural lands.

During validation process, the model was operated with input parameters set during the calibration process and the results were compared against an independent set of observed data.

Evaluation of model performance

In this study, the goodness-of-fit between the simulated and measured runoff and sediment yields were evaluated using the coefficient of determination (R^2) and Nash-Sutcliffe coefficient of efficiency (E_{NS}) [27] which is defined as follows:

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n} (O_i - S_i)^2}{\sum_{i=1}^{n} (O_i - O_{av})^2} \tag{5}$$

where E_{NS} is the efficiency of the model, O_i and S_i are the measured and simulated values, respectively, and O_{av} is the average measured values. The closer the model efficiency is to 1, the more accurate the model is.

Evaluation of land use change scenarios

To evaluate the effects of land use changes on the hydrological responses of the study watershed, mainly on surface runoff and sediment yields, five land use scenarios were formulated and the model was run to simulate runoff and sediment yields under these scenarios.

The land use scenarios were formulated based on the population growth rate, historical land use changes and the land use transition probabilities of the study area between 1985 and 2005 as predicted by Markov model [28]. Therefore, conversion of 20% of forest land, 20% of grazing land, and 20% of shrub land to agricultural land would represent the actual land use/cover condition of the study area. Hence, the formulated land use scenarios are:

Scenario A: Base scenario (land use of 2005).

Scenario B: Conversion of 7,106.2ha (20%) of forest land to agricultural land.

Scenario C: Conversion of 7,653.4ha (20%) of grazing land to agricultural land.

Scenario D: Conversion of 3,782.2ha (20%) of brush land to agricultural land.

Scenario E: Conversion of 20% of forest land, 20% of grazing land and 20% of shrub land to agricultural land.

The first Scenario A uses land use map of the study area in the year 2005 (Fig. 3), that is 173,692ha (53.43%) agricultural land, 35,531ha (10.93%) forest land, 38,267ha (11.77%) grazing land, 18,911ha (5.82%) shrub land, and the remaining 18.05% under swamp and water body. In Scenario B, 20% of forest land was converted to agricultural land by keeping the other land uses unchanged, therefore, agricultural land increased to 180,798.2ha (55.62%) and forest land dropped to 28,424.8ha (8.74%). In Scenario C, 20% of grazing land was converted to agricultural land resulting in an agricultural land area of 181,345.4ha (55.79%) and grazing land area of 30,613.6ha (9.42%). In Scenario D, 20% of shrub land was converted to agricultural land. Hence agricultural land increased to 177,474.2ha (54.59%) and shrub land reduced to 15,128.8ha (4.65%). In Scenario E, 20% of each of forest, grazing, and shrub lands were simultaneously converted to agricultural land. As a result, the area under agricultural land increased to 192,233.8ha (59.14%) and that of forest, grazing, and shrub lands decreased to 28,424.8ha, 30613.6ha, and 15,128.8ha, respectively.

In order to evaluate the variability of hydrologic responses (runoff and sediment yields) due to management practices, the calibrated model was run to simulate surface runoff and sediment yields under each land use scenarios (with and without soil conservation interventions).

For developing the various land use scenarios, a neighborhood operation of the spatial analyst tool in GIS was used. It involves a center cell and a set of surrounding cells. In this study, a 3-by-3 rectangular area was used. The center cell was converted to the majority (category that occupies the largest percentage of the cell's area). Moreover, the key processes and related model parameters such as the runoff curve number (CN) and MUSLE crop cover and management factor (P) were modified in the appropriate SWAT input files. The MUSLE P factor of 0.6 and 1.0, respectively, were used during calibration to reflect the condition of the watershed with and without soil conservation intervention.

RESULTS AND DISCUSSION

The SWAT model has been calibrated and validated to evaluate the impact of land use/cover change and management practices on the hydrological process of Fincha watershed. The major land use classes of the study watershed for the base scenario are presented in Table 1. The land use/cover map of the study area during this period is also shown in Fig. 3.

Table 1: Major Land use Classes of Fincha Watershed in 2005

Land use class	Area (ha)	% Total
Agricultural land	173,692	53.43
Forest land	35,531	10.93
Grazing land	38,267	11.77
Water body	39,790	12.24
Swamp area	18,885	5.81
Shrub land	18,911	5.82
Total	325,076	100

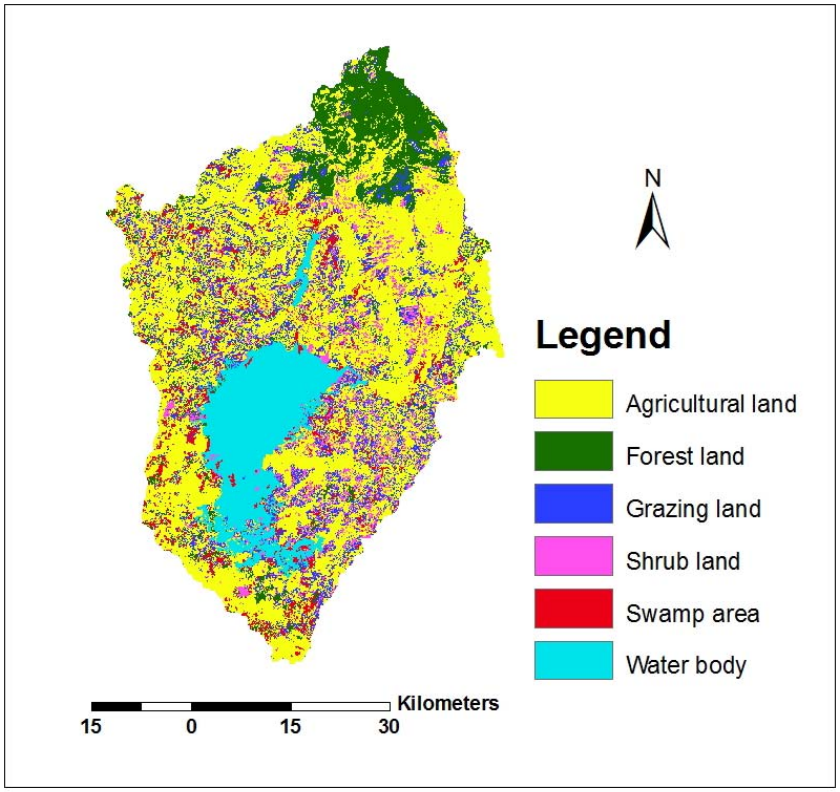


Figure 3: Land use Map of the Study Watershed under the Base Scenario

Table 2: Simulated Statistical Results for Various Land use Scenarios

	Runoff		Sediment yield	
Description	R^2	E_{NS}	R^2	E_{NS}
Scenario A	0.84	0.74	0.84	0.81
Scenario B	0.84	0.75	0.84	0.81
Scenario C	0.83	0.74	0.86	0.84
Scenario D	0.83	0.75	0.86	0.84
Scenario E	0.83	0.75	0.86	0.85

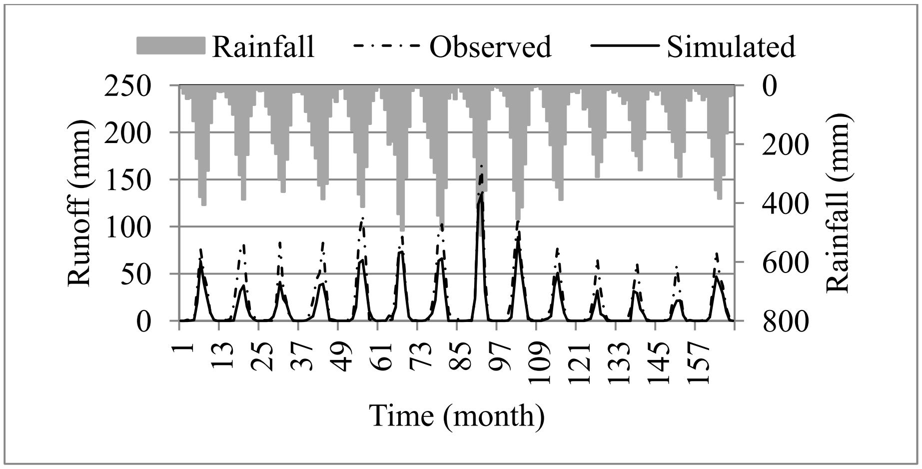


Figure 4: Simulated and Observed Average Monthly Runoff Volumes under Land use Scenario E

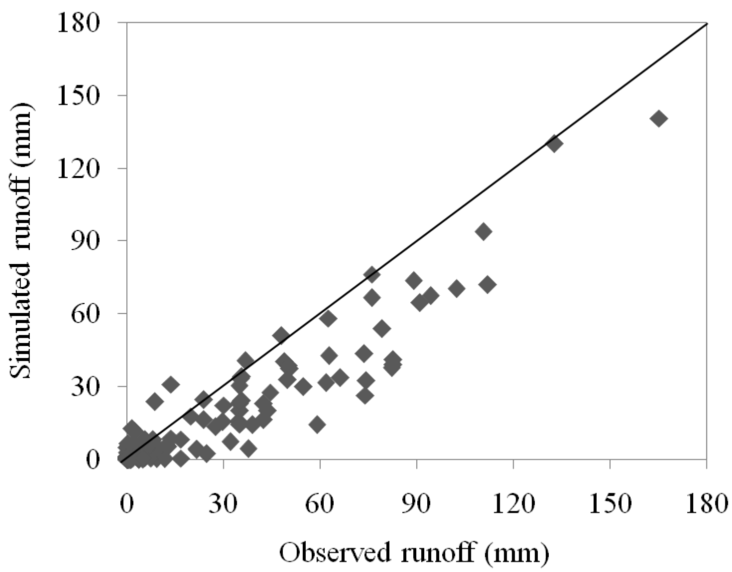


Figure 5: Scatter Plot of Simulated vs Observed Average Monthly Runoff Volumes under Land use Scenario E

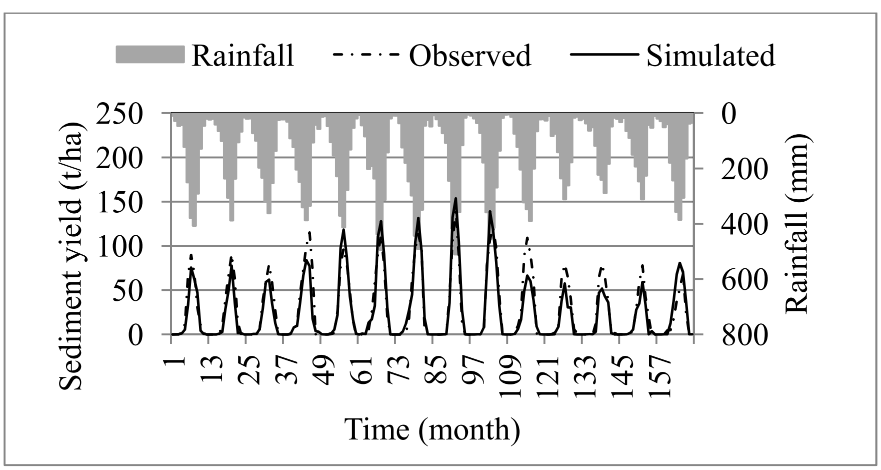


Figure 6: Simulated and Observed Average Monthly Sediment Yields under Land use Scenario E

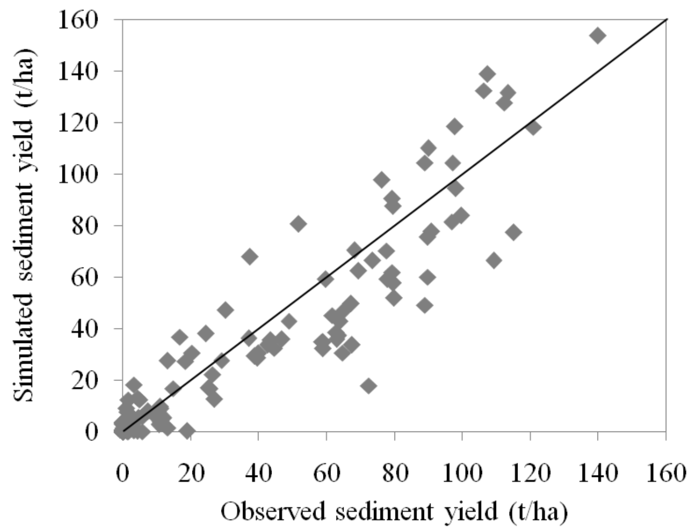


Figure 7: Scatter Plot of Simulated vs Observed Average Monthly Sediment Yields under Land use Scenario E

Table 3: Simulated Monthly Runoff and Sediment Yields with and without Interventions under Various Land use Scenarios

Land use scenarios	Runoff (mm)		Sediment yield (t/ha)	
	Without interventions	With interventions	Without interventions	With interventions
Scenario A	151.42	151.51	51.80	30.98
Scenario B	170.62	170.58	60.19	36.48
Scenario C	154.81	154.88	52.87	31.90
Scenario D	158.60	158.65	53.77	32.42
Scenario E	178.47	178.42	61.88	37.47

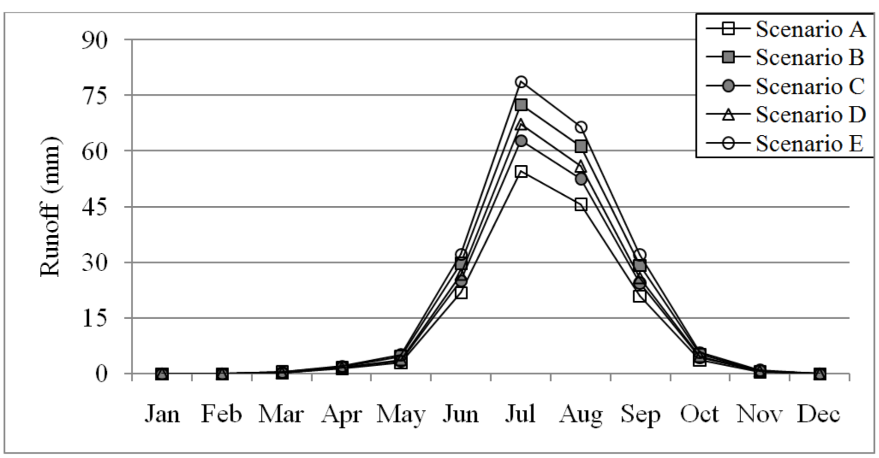


Figure 8: Simulated Average Monthly Runoff Volumes under Various Land use Scenarios

Model calibration

SWAT model was applied to predict the impacts of land use and management practices on runoff and sediment yields from Fincha watershed. Model calibration results showed that there is good agreement between the predicted and measured average monthly runoff volumes (with R^2 values ranging from 0.82 to 0.84 and E_{NS} values ranging from 0.73 to 0.75) (Table 2). The adequacy of the model is further indicated by its clear response to extreme rainfall events resulting in high runoff volumes. The simulated and observed average monthly runoff volumes for the land use scenario E is shown in Fig. 4. As it can be shown on the scatter plot (Fig. 5), the simulated average monthly runoff volumes were underestimated by the model.

Sediment yields were also adequately predicted by the model and in general showed good agreement between the measured and simulated values (with R^2 values ranging from 0.84 to 0.86 and E_{NS} values ranging from 0.81 to 0.85) (Table 2). Fig. 6 shows the simulated and observed average monthly sediment yields for land use scenario E. Although sediment yields were adequately captured, the model tends to underestimate the sediment yields during some years and overestimate during some other years (Fig. 7). The discrepancies between the simulated and observed average monthly sediment yield values may be attributed to the high deposition of sediments in the reservoir and channels and to the channel erosion during high flows. Nevertheless, the overall adequacy of the model in simulating runoff and sediment yields indicates its usefulness in predicting the effects of land use and management practices in the study watershed.

Model validation

During the validation period, there was close agreement between the observed and simulated average monthly runoff volumes (with R^2 values ranging from 0.77 to 0.78 and E_{NS} values ranging from 0.76 t0 0.78). It was also shown that simulated average monthly sediment yields agreed closely well with measured average monthly sediment yields (with R^2 values ranging from 0.84 to 0.86 and E_{NS} values ranging from 0.52 to 0.71).

Effects of land use change on runoff and sediment yields

In order to evaluate the effects of land use changes on the hydrological responses of the watershed, the calibrated model was run to simulate runoff and sediment yields under various land use scenarios.

Simulation of land use scenarios showed that average monthly runoff volumes increased by 19.20, 3.39 and 7.18mm, respectively, when 20% of forest, 20% of grazing, and 20% of shrub lands are converted to agricultural land. Furthermore, the average monthly runoff volumes increased by 27.05mm when 20% of each of forest, grazing, and shrub lands are simultaneously converted to agricultural land (Table 3). The simulated average monthly runoff volumes under various land use scenarios are shown in Fig. 8.

Simulation results also indicated that average monthly sediment yields increased by 8.39, 1.07 and 1.97 t/ha, respectively, when 20% of forest, 20% of grazing, and 20% of shrub lands are converted to agricultural land. Moreover, the average monthly sediment yields increased by 10.08 t/ha when 20% of each of forest, grazing, and shrub lands are simultaneously converted to agricultural land (Table 3). Fig. 9 shows the simulated average monthly sediment yields under various land use scenarios

Simulation of various land use scenarios clearly indicated that, as the result of the expansion in the area of agricultural land, both runoff and sediment yields increased. As hydrologic responses of a watershed are influenced by the type and degree of land use/cover conditions, the relative impact of land use change can be observed in the amount of runoff and sediment yields generated. For example under scenario B, the increase in the area of agricultural land due to deforestation increased average monthly runoff volumes and sediment yields from 151.42 to 170.62mm and from 51.80 to 60.19 t/ha, respectively, (Table 3). This is because the soils in the agricultural lands are bare and easily susceptible to erosion when repeatedly tilled and left without a protective cover. They are less protected against raindrop impact shortly after sowing, when the plants do not cover the soil completely and thus runoff and transportation of soil particles increased. Such condition will cause significant soil erosion and sedimentation. This shows that hydrologic responses are an indicator of watershed conditions, and any change in land use/cover can affect the overall health and condition of the watershed.

Effects of land management practices on runoff and sediment yields

In order to have a clear picture of the impacts of management practices on the hydrological responses of the watershed, the calibrated model was run to simulate runoff and sediment yields using two land management scenarios (with and without soil conservation interventions) under various land use scenarios.

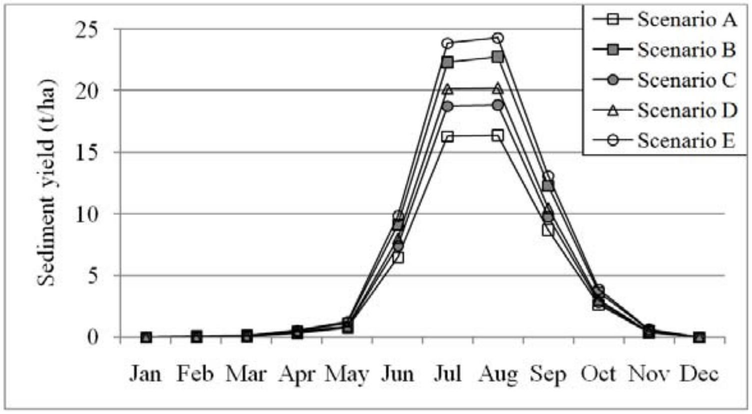


Figure 9: Simulated Average Monthly Sediment Yields under Various Land use Scenarios

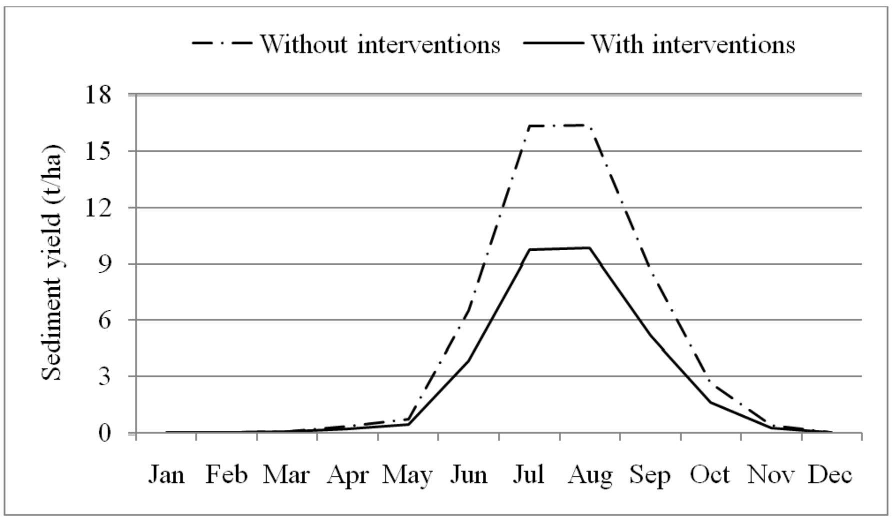


Figure 10: Simulated Average Monthly Sediment Yields with and without Soil Conservation Intervention under Land use Scenario B

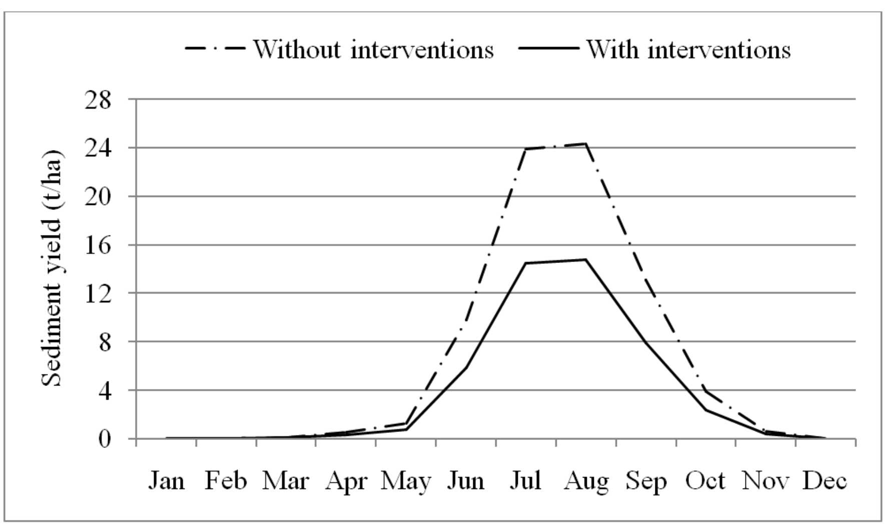


Figure 11: Simulated Average Monthly Sediment Yields with and without Soil Conservation Intervention under Land use Scenario E

Simulation results showed that under the existing land use conditions, average monthly sediment yields decreased by 20.82 t/ha as the result of soil conservation interventions. The result also showed that due to soil conservation interventions average monthly sediment yields decreased by 23.71, 20.97 and 21.35 t/ha, respectively, when 20% of forest, 20% of grazing, and 20% of shrub lands are converted to agricultural land. Likewise, when 20% of each of forest, grazing, and shrub lands are simultaneously converted to agricultural land average monthly sediment yields decreased by 24.41 t/ha as the result of soil conservation interventions (Table 3). However, average monthly runoff volumes remained almost unchanged with and without interventions under various land use scenarios. The simulated average monthly sediment yields with and without soil conservation interventions under land use scenario B and E are shown in Figs. 10 and 11, respectively.

The difference in the simulated values of sediment yields during the simulation of management practices clearly indicated that the rate of soil erosion and the amount of soil particles transported from agricultural lands decreased with soil conservation interventions. For example under scenario B, as the result of soil conservation interventions average monthly sediment yields decreased from 60.19 to 36.48 t/ha (Table 3). It follows that appropriate land management practices such as strips of crops, strips of woodland, and hedgerows are highly effective at reducing overland flow by increasing subsurface storage and infiltration rates, thereby causing a significant reduction in surface runoff and sediment yields. Protection of the soil surface from the erosive forces of rainfall significantly reduces soil particle detachment by raindrop impact and sediments transported by concentrated overland flow along with a reduction of mechanical soil movement.

CONCLUSIONS

The Soil and Water Assessment Tool (SWAT) model was calibrated to predict the effects of land use change and management practices on runoff and sediment yields from the Fincha watershed, Ethiopia with an area of 3,251km^2. Calibration results showed that SWAT model adequately predicted monthly runoff and sediment yields with R^2 and E_{NS} values ranging from 0.82 to 0.86 and from 0.73 to 0.85, respectively.

Simulation of various land use scenarios clearly indicated that average monthly runoff volumes increased by 12.68, 2.24 and 4.74%, respectively, when 20% of forest, 20% of grazing and 20% of shrub lands are converted to agricultural land. The respective increase in average monthly sediment yields are 16.20, 2.07 and 3.80%. Moreover, average monthly runoff volumes and sediment yields increased by 17.86 and 19.46%, respectively, when 20% of each of forest, grazing, and shrub lands are simultaneously converted to agricultural land.

Simulation of land management practices also showed that while monthly runoff volumes remained almost unchanged, average monthly sediment yields decreased by 40.19, 39.39, 39.66 and 39.71%, respectively, as a result of soil conservation interventions under the base scenario, when 20% of forest, 20% of grazing, and 20% of shrub lands are converted to agricultural land. Furthermore, the average monthly sediment yield decreased by 39.45% due to interventions when 20% of each of forest, grazing, and shrub lands are simultaneously converted to agricultural land.

The simulated effects of conversion of forest, grazing, and shrub lands to agricultural land clearly indicated an alarming situation under all the land use scenarios in general and under scenario E in particular. Therefore, we recommend that policies addressing this issue should be formulated both at the local and national level. Besides, an intensive information and educational campaign about the consequences of expansion of crop land on the expenses of forest, grazing, and shrub lands and ways of rehabilitating the watershed should be undertaken.

As land development is a continuous process, for the optimum use of the land and water resources of the area, it is suggested that soil and water conservation such as construction of various terraces, water ways, rehabilitation of degraded areas, and land management practices such as crop residuals, contour tillage, strip cropping on the contour etc should be considered.

Finally, alternative livelihood opportunities for farmers living surrounding Fincha reservoir, and those living on the steep and mountainous areas within the watershed should be considered in policy implementation.

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REFERENCES

[1] Black AE, Strand E, Wright RG, Scott JM, Morgan P, & Watson C (1998) Land use history at multiple scales: implications for conservation planning. Landscape and Urban Planning, 43, 49–63.

[2] Correia PT (2000) Future development in Portuguese rural areas: how to manage agricultural support for landscape conservation? Landscape and Urban Planning 50 (2000), Pp 95–106.

[3] Bicik I, Jelecek L and Stepanek V (2001) Land-use changes and their social driving forces in Czechia in the 19th and 20th centuries. Land Use Policy 18 (2001), Pp 65–73.

[4] Bürgi M and Russell EWB (2001) Integrative methods to study landscape changes. Land Use Policy 18 (2001), Pp 9–16.

[5] Brath A, Montanari A, Moretti G (2006) Assessing the effect on flood frequency of land use change via hydrological simulation (with uncertainty). J Hydrol 324 (1-4): 141–153.

[6] Crooks S and Davies H (2001) Assessment of land use change in the Thames catchment and its effect on the flood regime of the river. Physics and Chemistry of the Earth, Part B 26 (7–8): 583–591.

[7] De Roo A, Odijk M, Schmuck G, Koster E and Lucieer A (2001) Assessing the effects of land use changes on floods in the Meuse and Oder catchment. Physics and Chemistry of the Earth, Part B 26 (7): 593–599.

[8] Wang X, Melesse AM and Yang W (2006) Influences of potential evapotranspiration estimation methods on SWAT's hydrologic simulation in a northwestern Minnesota watershed. Trans ASABE 49(6): 1755-1771.

[9] Costa MH, Botta A, Cardille JA (2003) Effects of large-scale changes in land cover on the discharge of the Tocantins River, Southeastern Amazonia. J Hydrol 283: 206–217.

[10] Ojima DS, Galvin KA and Turner BL (1994) The global impact of land-use change. Biosci 44: 300–304.

[11] Assefa K (1994) Valuing Environmental Quality Changes in Horro Guduru. Field Survey Report. Neqemte, Ethiopia: The Finnish Forest Research Institute.

[12] OADB (Oromiya Agriculture and Development Bureau) (1996) Land Resource and Socio-economic Survey Report of Cooman Watershed, Ethiopia. Addis Abeba, Ethiopia: Oromiya Agriculture Development Bureau.

[13] Hurni H (1990) Degradation and conservation of soil resources in the Ethiopian highlands. Mt Res Dev 8 (2-3): 123–130

[14] Bezuayehu T (2006) People and dams: environmental and socio-economic impacts of Fincha'a hydropower dam, western Ethiopia. Tropical Resource Management paper 75. Wageningen University, Wageningen, The Netherlands.

[15] Arnold JG, Williams JR, and Maidment DR (1995) Continuous-time water and sediment-routing model for large basins. J Hydraul Eng 121: 171–183.

[16] Arnold JG and Fohrer N (2005) SWAT2000: Development and Applications. Hydrolo Proc 19: 563–859.

[17] Behera S and Panda RK (2006) Evaluations of management alternatives for an agricultural watershed in a sub-humid subtropical region using a physical process model. Agric Ecosyst Environ 113(1-4): 62–72.

[18] Gassman PW, Reyes MR, Green CH and Arnold JG (2007) The Soil and Water Assessment Tool: historical development, applications, and the future research directions. Trans ASABE 50(4): 1211–1250

[19] Neitsch SL, Arnold JG, Kiniry JR, Srinivasan R and Williams JR (2002) Soil and Water Assessment Tool (SWAT) User's Manual, Version 2000.

[20] Neitsch SL, Arnold JG, Kiniry JR and Williams JR (2005) Soil and Water Assessment Tool (SWAT), Theoretical Documentation, Version 205.

[21] USDA-SCS (1972) National Engineering Hand Book, Hydrology section 4, Chapter 4-10 [M]. Washington DC: US Dep. Agriculture, Soil Conservation Service.

[22] Williams JR (1975) Sediment Routing for Agricultural Watersheds. Water resources bulletin 11 (5): 965-974.

[23] Anderson JR, Hardy EE, Roach JT and Witmer RE (1976) A Land Use and Land Cover Classification System for Use with Remote Sensing Sensor Data. USGS, Geological Survey Professional Paper 964, Pp 28 Washington DC.

[24] FAO (1998) The Soil and Terrain Database for northeastern Africa. FAO, Rome.

[25] FAO (2002) Major Soils of the world. Land and Water Digital Media Series. FAO, Rome.

[26] FAO (2005) Digital Soil Map of the World and Derived Soil Properties of the World. FAO, Rome.

[27] Nash JE and Sutcliffe JV (1970) River flow forecasting through conceptual models, part I: A discussion of principles. J Hydrol 10 (3): 282–290

[28] Abdi BA and Ekasit K (2012) Land use change analysis using remote sensing and Markov Modeling in Fincha watershed, Ethiopia. Kasetsart Journal: Natural Science, 46 (1): 135 – 149.

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