EVALUATION OF AGRICULTURAL CONSERVATION PRACTICES ON ECOSYSTEM SERVICES IN SASUMUA WATERSHED, KENYA USING SWAT MODEL

H. M. Mwangi[1], J. M. Gathenya[1], B. M. Mati[1] and J. K. Mwangi[2]
[1]*Biomechanical and Environmental Engineering Department, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya*
[2]*Civil, Construction and Environmental Engineering Department, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya*
E-mail: pathosea2002@yahoo.com

Abstract

Degradation of agricultural watershed reduces the capacity of agro-ecosystems to produce Ecosystem Services such as improving water quality and flood mitigation. Conservation of degraded watersheds can abate water pollution and regulate stream flows by reducing flash floods and increasing base flow as a result of enhanced infiltration. The objective of this study was to evaluate the effect of agricultural conservation practices on hydrology and water quality in Sasumua watershed, Kenya using SWAT model. Filter strips, contour farming, parallel terraces and grassed waterways were represented by adjusting the relevant parameters in the model and the resulting effect on sediment yield and water yield assessed. It was found that the reduction in sediment yield increased with increase in width of the filter strip but the increase was not linear. Contour farming reduced sediment yield by 49%, decreased the surface runoff by 16% and increased base flow by about 7.5%. Simulation of parallel terraces reduced sediment load by 85%, decreased surface runoff by 22% and increased base flow by 10%. Both the contour farming and terraces had only a slight change in total water yield. Grassed waterway simulated for some drainage ditches in the watershed reduced sediment load by about 41% at the outlet downstream of the drainage channels and by 23.5% for the entire Sasumua sub watershed. Terraces were found to be the most effective practices but due to their cost filter strips and contour farming were recommended for agricultural lands and grassed waterways on the seasonal stream channels. Filter strips would eventually evolve into bench terraces.

Key words: SWAT, best management practices, modeling, water balance, sediment load

1 Introduction

Ecosystems provide various services which include and not limited to filtering water and improving its quality, flood mitigation and food production. These services are linked to the livelihoods (Millennium Ecosystem Assessment, MA, 2003). To continue enjoying these ecosystem services, proper and sustainable management of the natural resources is required. Various management options are available for the watershed managers but their effectiveness need to be assessed for proper management decisions to be made. Agricultural conservation practices, also commonly known as Best Management Practices (BMPs), offer management options available for managers in agricultural watersheds. Implementation of agricultural conservation practices can reduce soil erosion; improve water quality of the water bodies by reducing the sediments, nutrients, chemicals and microorganisms that are washed by runoff from the cultivated fields. They would allow more infiltration of the rain water into the ground and thus reduce peak runoff that cause flooding and thus increase base flow in streams.

Some of the conservation practices that have been studied for their effectiveness in abatement of Non Point Source Pollution (NPS) include vegetative filter strips, contour farming, terraces and grassed waterways. A Vegetative Filter Strip (VFS) is a strip or area of herbaceous vegetation that removes contaminants from overland flow (NRCS, 2008). The vegetation could be grass, trees or shrubs or a combination of trees and shrubs and established at the edge of fields along the streams or any other water body (Yuan *et al.*, 2009). Sediments, nutrients and pesticides and bacteria loads in surface runoff are reduced as the runoff passes the filter strip (Neistch *et al.*, 2005; Lovell and Sullivan, 2006). The main effectiveness of the filter strips in prevention of Non-Point Source (NPS) pollution is based on its trapping efficiency which is mainly affected by the width of the filter strip (Yuan *et al.,* 2009; Abu-Zreig, 2001). The trapping efficiency increases with the increase in the width of the filter strip. Some other secondary factors that influence the trapping efficiency include; slope, vegetation particle size, inflow rate and particle size. Trapping efficiency has been found to increase with increase of vegetation cover and to decrease with increase in inflow rates (Abu-Zreig *et al.,* 2004; Fox *et al.,* 2010). It (Trapping efficiency has also been found to decrease with increase in slope (Gilley *et al.*, 2000).

Contour farming is a form of agriculture where farming activities such as ploughing, planting, cultivating and harvesting are done across the slope rather than up and down the slope. Crop row ridges built by tilling and planting on the contour create many small dams. The ridges slow water flow and increase infiltration which reduce soil erosion and subsequent sedimentation which improves the water quality in the water bodies. Contour farming has been studied (Quinton and Catt, 2004; Brunner *et al.*, 2008; Stevens *et al.*, 2009; Shi *et al.*, 2004; Arabi *et al.*, 2008; Gassman *et al.*, 2006) and the results show that they have a positive impact in reducing sediments and other water pollutants from the agricultural lands.

Terraces are structural BMPs that are installed on sloppy land. They reduce soil erosion by reducing long slopes into smaller shorter slopes ones that allow runoff water to infiltrate into the ground and thus reduce surface erosion and its capacity to cause soil erosion. This conservation practice has been studied (Gassman *et al.*, 2006; Arabi *et al.*, 2008; Santhi *et al.*, 2006) and found to be very effective in reducing diffuse pollution.

Grassed waterways are channels or drainage ways either natural or artificial planted with vegetation and carry runoff water to safe disposal without causing soil erosion. The vegetation traps sediments and absorbs chemicals and nutrients washed from the agricultural lands by runoff water. Grassed waterways have been studied and found to reduce surface runoff (Fiener and Auerswald, 2005) and water pollutants (Evrard *et al.*, 2008; Fiener and Auerswald, 2006a; Gassman *et al*, 2006).

Evaluation of effectiveness of BMPs in the field scale is an expensive exercise and watershed managers have relied on models to simulate different management scenarios and evaluate their effectiveness. Soil and Water Assessment Tool (SWAT; Neitsch *et al*., 2005) model has been used widely all over the world to evaluate the effectiveness of the BMPs (Gassman *et al.*, 2007). Bracmort *et al.* (2006), modeled the impact structural BMPs, in different conditions on water quality in Black Creek watershed in Indiana, USA. In this study, grassed waterways, grade stabilization structures, field borders and parallel terraces were represented in SWAT by relevant parameters and their effectiveness evaluated. Sahu and Gu, (2009) used SWAT in 51.3 km^2 Walnut Creek watershed in Iowa, U.S.A. to examine the effectiveness of contour and riparian buffer strips in reducing Nitrate nitrogen outflows from cropped fields to a river. Parajuli *et al.* (2008), used SWAT in Upper Wakarusa watershed (950 km^2) in northeast Kansas, USA to evaluate the effectiveness of vegetative filter strip (VFS) lengths applied at the edge of fields to reduce sediment yield and fecal bacteria concentration. Santhi *et al.* (2006) evaluated the impact of contour farming, grade stabilization structures, manure and nutrient related BMPs, forage harvest management, and other BMPs on water quality in West Fork Watershed in Texas, USA. In Black Brook Watershed in Canada, Yang *et al*. (2009) used SWAT to assess the efficacy of Flow Diversion Terrace (FDT) systems on maintaining surface water quality at the watershed level. Arabi *et al*. (2008) developed and evaluated a method for the representation of BMPs in SWAT. They considered ten conservation practices which include; contour farming, filter strips, field borders, parallel terraces, strip cropping and residue management all of which are applied in upland areas. The method also included conservation practices that can be implemented within small streams namely; grassed waterways, lined waterways and grade stabilization structures. The method was applied to evaluate the impacts of the conservation practices on water quality in a 7.3 km^2 Smith Fry agricultural watershed in Indiana, U.S.A.

The main objective of this study was to evaluate the effectiveness of agricultural conservation practices on water balance and quality in Sasumua Watershed, Kenya using SWAT model. Filter strips, contour farming, terraces and grassed waterways were represented in SWAT and their impact on sediment yield and water balance components evaluated.

2 Methodology

2.1 The Study Area

Sasumua watershed lies between longitudes 36.58°E and 36.68°E and latitudes 0.65°S and 0.78°S (Fig. 1a) and has an altitude of between 2200m and 3850m. The watershed has a reservoir (Sasumua reservoir) which receives water from three sub-catchments (Figure 1b). Sasumua sub-catchment (67.44 km^2) which is seasonal in nature provides water only during the rainy season. Chania sub-catchment (20.23 km^2) and Kiburu sub-catchment (19.30 km^2) both of which are perennial and connected to Sasumua reservoir via tunnel and pipe diversions respectively provide water throughout the year. The total catchment area feeding the reservoir is therefore 107 km^2 about half of which is in the forest reserve. Sasumua sub watershed is mainly agricultural, with only a small portion which is under forest.

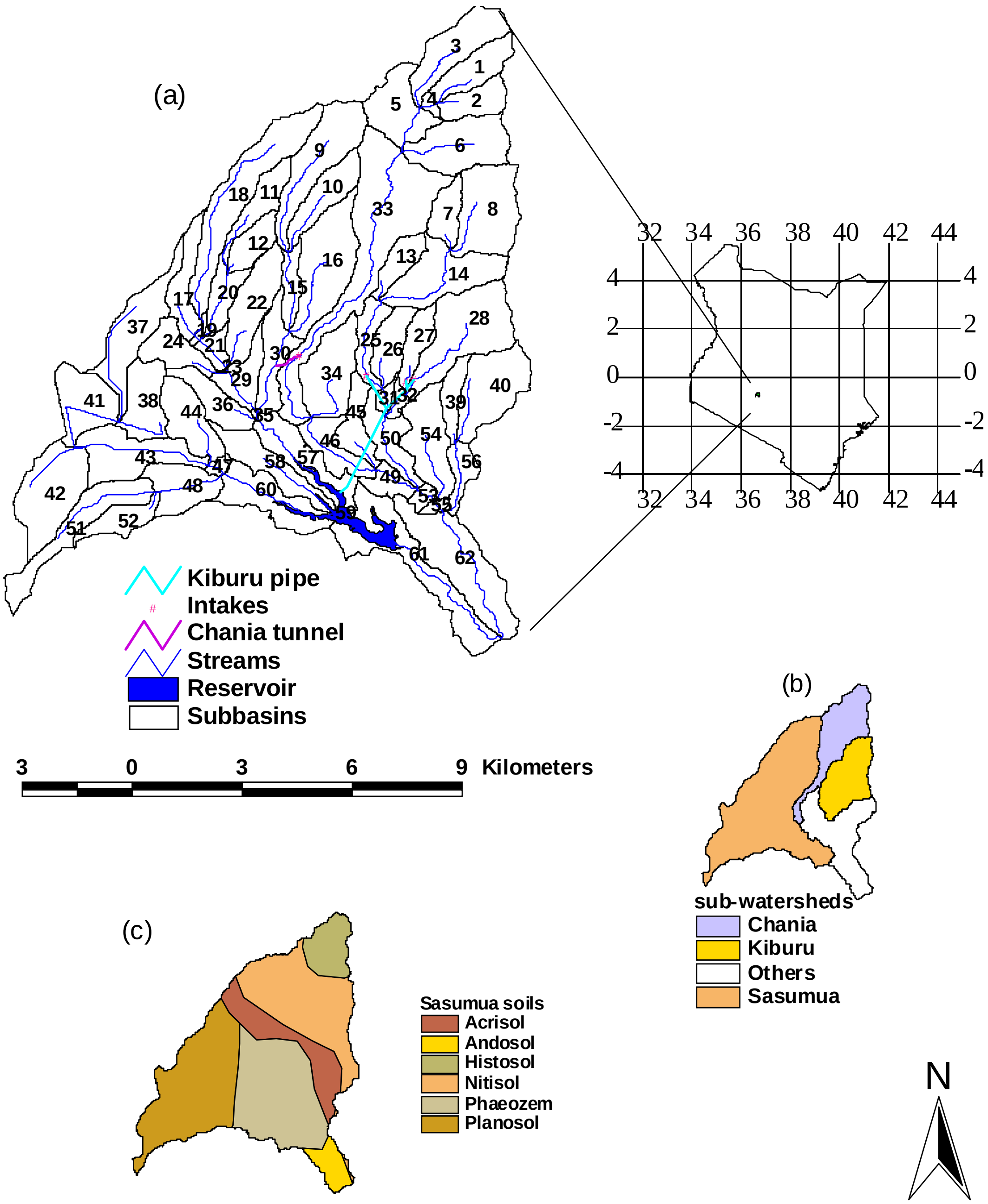

Figure 1: Sasumua watershed (a, sub-basins in SWAT; b, sub-watersheds; c, soils

The reservoir design capacity is 16 million cubic meters and supplies about 64,000 cubic meters, at normal operating conditions, of water daily to Nairobi City which is about 20% of water used in Nairobi. The catchment is composed mainly of small farm sizes which are privately owned. Potatoes and cabbages are the major crops grown in the area and are the main cash crops. The mean annual rainfall in Sasumua ranges from 800- 1600 mm with two main rainfall seasons. Long rains occur from March to June and the short rains from October to December. The soils in Sasumua from the high mountainous Northeastern end are Histosols, Nitisols, Acrisols, Phaeozems, and Planosols on the lower Southwestern plateau area (Figure 1c). Andosols are also present downstream of the dam. The main agricultural part of Sasumua sub watershed is composed mainly of Planosols and Phaeozems.

2.2 SWAT Model

SWAT model which has been calibrated and validated for Sasumua watershed (Mwangi *et al.,* 2011) was used for this study. The model which is a physically based distributed parameter, continuous-time model is described in details in Neitsch *et al*. (2005) and Gassman *et al*. (2007). It operates on a daily time step and is designed to predict the impact of management on water, sediment and agricultural chemical yields in large complex un-gauged watersheds with varying soils, land use and management conditions. The model sub divides the watershed into a number of sub-basins depending on the critical source area specified by the user. The critical source area is required to initiate a channel flow (Arabi, *et al.*, 2008). The sub-basins are further partitioned into Hydrologic Response Units (HRUs). A HRU has homogeneous soil properties, land use and land management.

In SWAT, erosion and sediment yield are calculated using Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975). The difference between MUSLE and Universal Soil Loss Equation (USLE) is that USLE uses rainfall as indicator of erosive energy while MUSLE use the amount of runoff to simulate erosion and sediment yield. The advantages of using MUSLE over USLE are; prediction accuracy of the model is increased, the need of a delivery ratio (sediment yield at any point along the channel divided by the source erosion) is eliminated and estimates of sediment yields for a single storm can be computed (Neitsch *et al.*, 2005). The MUSLE equation (1);

$$Sed = 11.8.(Q_s.q_{peak}.A)^{0.56} \times K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CFRG \qquad (1)$$

Where *Sed* is the sediment yield on a given day (tons/ha), Q_s is the surface runoff (mm/ha), q_{peak} is peak runoff rate (m^3/s), *A* is Area of HRU (ha), K_{USLE} is the USLE soil erodibility factor, C_{USLE} is the USLE cover management factor, P_{USLE} is the USLE support factor, LS_{USLE} is the USLE topographic factor and *CFRG* is course fragmentation factor.

2.3 Evaluation of BMPs

Filter strips- implementation of filter strips would reduce sediments, nutrients, pesticides, and bacteria as the runoff passes through. The filter width parameter (FILTERW) in SWAT was adjusted to simulate this conservation practice. Sasumua dam has a wide buffer strip that extends some distance upstream of Sasumua and Mingotio streams. The buffer area is managed by the Nairobi City Water and Sewerage Company (NCWSC). Sub basins falling in this area were not included in the simulation of the filter strips. Thus, the only sub basins that were included for the simulation of the filter strips were; 12, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 37, 38, 41, 42, 44, 48, 51, and 52 (Figure 1a). The width of the filter strip was increased at interval of 5 meters from 0 to 35 m. Only the parameter FILTERW was adjusted for each simulation. The sediment loading at the outlet of sub basin 61, was then analyzed to investigate the effect of the adjusted width of the filter strip. Sub basin 61 was used as the reference outlet sub basin for the watershed for all the conservation practices. The effectiveness on the filter strips in the reduction of the sediment yield is based on the trapping efficiency. In SWAT, the trapping efficiency for the sediments is modeled as per the equation 2 (Neistch *et al.*, 2005; Arabi *et al.*, 2008);

$$trap_{eff\_sed} = 0.367 \times FILTERW^{0.2967} \qquad (2)$$

Where $trap_{eff\_sed}$ = trap efficiency of the sediments and *FILTERW* is the width of the filter strip (m).

Contour farming- To simulate the effect of contour farming; SCS Curve Number *(CN)* and Universal Soil Loss Equation practice factor *(USLE-P)* were modified. SCS curve number, defines the permeability of the soil and depends on land use, farming practice, hydrologic condition and soil type. It routes the processes of infiltration and generation of surface runoff (Sahu and Gu, 2009; Ullrich and Volk, 2009). The USLE support practice factor, (*USLE-P*), defines the ratio of soil loss with a specific support practice to the corresponding loss with up and down cultivation. This parameter has been found to be very sensitive to the sediment yield (Ullrich and Volk, 2009). To represent this conservation practice, the Curve Number was decreased by three units from the calibration/parameterization values. *USLE_P* was adjusted depending on the slope of the HRU according to Table 1 given in SWAT theoretical documentation by Neistch *et al*. (2005) that gives the recommended *USLE_P* values for contour farming, strip cropping and terracing.

Table 1: USLE-P values for contour farming, strip cropping and terracing
(Adapted from Wischmeier and Smith, 1978).

Land slope (%)	*USLE_P*			
	Contour farming	Strip cropping	Terracing	
			Type 1[a]	Type 2[b]
1 to2	0.60	0.30	0.12	0.05
3 to 5	0.50	0.25	0.1	0.05
6 to 8	0.50	0.25	0.1	0.05
9 to 12	0.60	0.30	0.12	0.05
13 to 16	0.70	0.35	0.14	0.05
17 to 20	0.80	0.40	0.16	0.06
21 to 25	0.90	0.45	0.18	0.06

[a] Type 1: Graded channel sod outlet
[b] type 2: Steep backslope underground outlets

The *USLE_P* values for the target sub-basins (in the agricultural part of the Sasumua sub watershed) were reduced from the calibration (base simulation) value of 0.85.

One of the challenges that have been cited for the adoption of the contour farming is that on very steep slopes water can accumulate in low points, and then break through to form large rills or gullies (Quinton and Catt, 2004). United States Department of Agriculture (NRCS, 2006) recommends implementation of contour farming on slopes less than 10%. In the agricultural part of Sasumua sub watershed where contour farming was simulated the highest slope is about 8%.

2.4 Parallel Terraces

Terraces, if implemented on the sloping part of the watershed would reduce the surface runoff by encouraging more infiltration. Terraces reduce the slope and the slope length and thus reduce the peak runoff rate as well as reducing the erosive power of runoff. To represent this conservation practice, Slope length (SLSUBBSN), USLE support practice factor (*USLE_P*), and SCS curve Number (*CN*) were adjusted (Arabi *et al.*, 2008). Terraces divide the slope length into smaller lengths reducing the sheet and rill erosion. In SWAT, slope length is represented by the parameter *SLSUBBSN*. SLSUBBSN parameter was adjusted using the *horizontal interval* method for terrace design (Arabi *et al.,* 2008). The reduced soil loss was factored in by reducing the USLE practice factor, *USLE_P* in the Modified Universal soil loss equation. *USLE_P* values for terracing type 1 (graded channels sod outlets) in Table 1 were used depending on the average slope of the HRU. The improved infiltration of water in the soil was represented by reducing the *CN* by 7 units as recommended in literature (Neistch *et al.*, 2005; Bracmort *et al.*, 2006; Arabi *et al.,* 2008). Implementation of terraces would affect all these processes together and thus all the parameters were adjusted simultaneously for a single simulation run.

Grassed waterway- implementation of grassed waterway would result in trapping of sediments by grass causing deposition, reduction of flow velocity as a result of increased roughness of the channel and the grass cover in the channel will reduce the channel erosion (Fiener and Auerswalda 2006a; Arabi *et al,* 2007; Arabi *et al,* 2008). In Sasumua, grassed waterways were simulated in several drains that feed Mingotio stream. These drains fall in sub basins 37, 38, 41, 42 and 51 (Figure 1). These drains collect the runoff from the agricultural and the fast growing towns and discharge at Mingotio stream. To represent this conservation practice, Channel Manning's roughness coefficient (*CH_N2),* Channel cover factor (*CH_COV)* and Channel erodibility factor (*CH_EROD)* were adjusted. Channel Manning's roughness coefficient (*CH_N2)* for grassed waterway was selected to be 0.3 $sm^{-1/3}$. This value was selected based on suggested literature values for grassed waterways (Fiener and Auerswald, 2006a; Fiener and Auerswald 2006b; Bracmort *et al.*, 2006; Arabi *et al.*, 2008). Both *CH_COV* and *CH_EROD* were adjusted from 0.2 for the condition to 0.00 (Bracmort *et al.*, 2006; Arabi *et al.*, 2008). A value of 0.00 for both *CH_COV* and *CH_EROD* factors represent a fully covered field with no degradation, respectively.

3 Results and Discussions

3.1 Filter Strips

An increase in the width of the filter strip resulted in a decrease in the sediment loading (Figure 2), with the first few meters having the greatest impact in reducing the sediment loading into the streams.

Figure 2 shows the percentage reduction in sediment loading with increase in filter strip width. The graph shows that the reduction in the sediment loading as a function of the width of the filter strip is not linear but rather logarithmic. There was high reduction in sediment loading in the initial 5 meter-width adjustments than in the last ones. This trend is similar to what has been found in other studies (Abu-Zreig *et al.,* 2004; Yuan *et al,* 2009; Abu-Zreig, 2001).

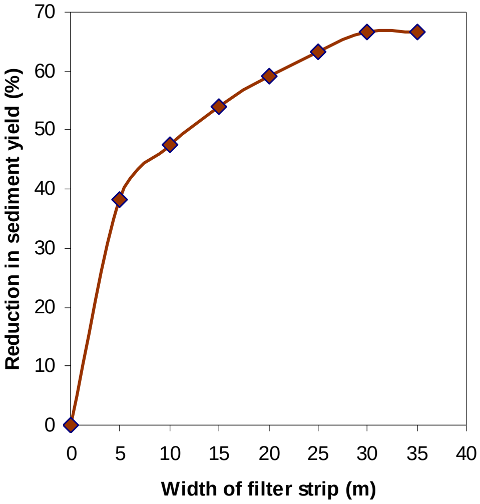

Figure 2: Percentage reduction in sediment yield as a function of the width of the filter strip

This trend can be attributed to equation 3 which incorporates higher efficiencies in the front portion of the strip in trapping the sediments (Arabi *et al.*, 2008). Yuan *et al*. (2009) after reviewing several studies on the effectiveness of the buffer strips concludes that the trapping efficiency of the buffer width would be best fitted in a logarithmic model and that a 5 m buffer can trap up to 80% of the sediments. The variation depending on other factors that affect the trapping efficiency i.e. vegetation type, density and spacing, Manning's roughness coefficient, flow concentration, soil type, sediment particle size and the slope (Yuan *et al.,* 2009; Abu-Zreig, 2001; Fox *et al.*, 2010; White and Arnold, 2009).

The logarithmic relationship between the filter strip width and sediment load reduction is an advantage for Sasumua and Kenya in general where land sizes owned by small scale farmers could be as small as a half acre. These farmers may only afford to sacrifice narrow filter strips for conservation which apparently would still have a substantial reduction in soil loss.

3.2 Contour Farming

The simulation result for contour farming shows that on average the sediment loading to the reservoir would reduce by approximately 49 % from the base simulation. These results compare well with other studies in the area. Hunik *et al.* (2012) who simulated soil conservation practices in the entire upper Tana watershed found out that contour ridges can reduce the sediment loss by 30 - 50 % in the Sasumua subwatershed.

Figures 3 and 4 below show the annual sediment yield in tons/ha from various sub-basins in the Sasumua sub-watershed before and after the implementation of the contour farming.

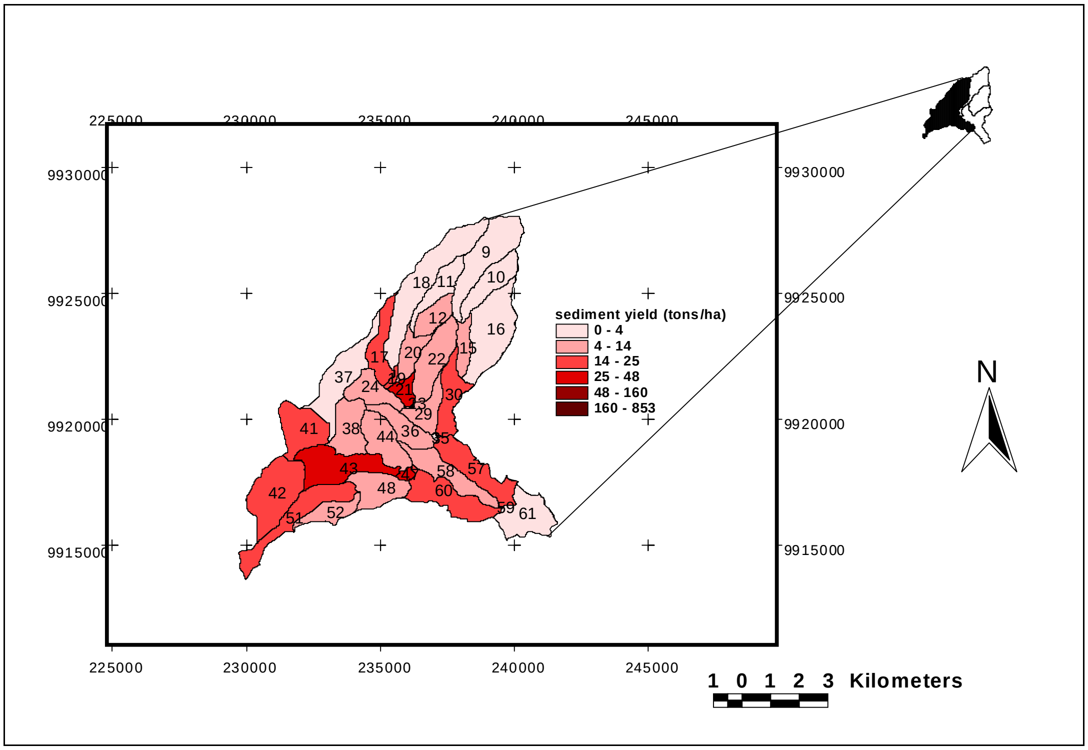

Figure 3: sediment yield (tons/ha/year) for base simulation

The Figure 3 shows that sub basins 9, 10, 11, 16, 18 and 61 which are under forest cover have relatively low sediment yield. Sub-basins 41, 42, 43, 47 and 60 were found to have a relatively higher sediment yield and should be prioritized in the implementation of soil and water conservation measures. This area is characterized by planosols which have very low infiltration rates thus generates high runoff rates which cause high soil erosion rates. Sub basin 43 has a higher slope that further increases soil erosion.

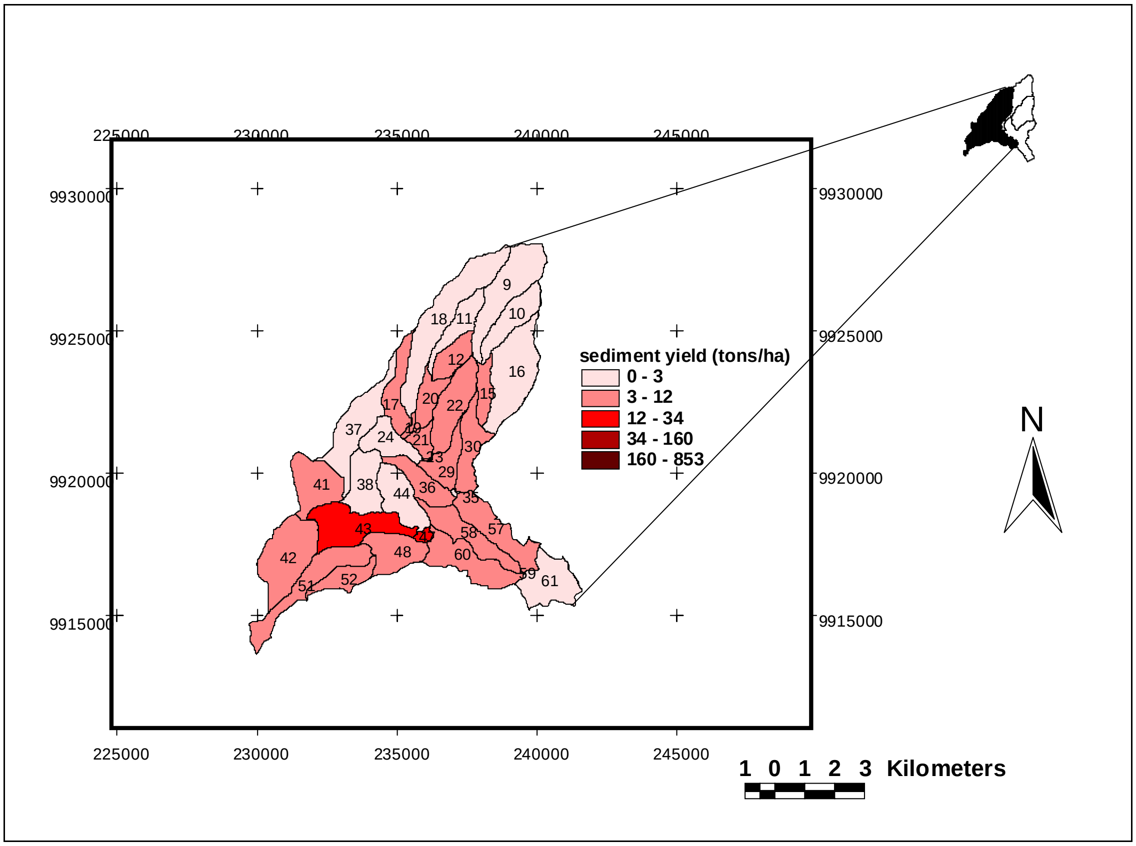

Figure 4: Sediment yield (tons/ha/year) after implementation of contour farming

Contour farming creates surface roughness blocking the surface runoff and encourages infiltration as water ponds in the depressions. This reduces the erosive power of surface runoff and thus reduces soil erosion (Quinton and Catt, 2004; Arabi, *et al.*, 2008).

From the water balance point of view, implementation of contour farming would result into a decrease of surface runoff of about 16% and an increase of base flow of about 7.5% with only a slight decrease in the total water yield as shown in Table 2. In other studies, Quinton and Catt, (2004) found out that event surface runoff from experimental runoff plots was 0.8 mm for cultivation across the slope compared to 1.32 mm when cultivation was done in up and down direction.

Table 2: Water balance with (base simulation) and without contour farming

	Surface runoff (mm)	Lateral flow (mm)	Base flow (mm)	**Water yield (mm)**
Base simulation	193	184	304	680
Simulation with contour farming	162	187	327	675
% change	-16.06	+1.63	+7.57	-0.7

The decrease in the surface runoff is a result of increased infiltration into the ground of water. Contour farming would cause impounding of water into the small depressions and thus more water would infiltrate into the ground. This would in effect enhance the recharge of the shallow aquifer and water will be released to the streams as the base flow. Thus it can be seen that the base flow has increased as a result. The implication of this phenomenon on the ground is that there will be reduced flash floods in the area and more recharge of the shallow aquifer will mean more base flow into the streams even long after the rains. The increased base flow will mean that there will be relatively more water going to the reservoir during the dry periods after the rains.

3.3 Terraces

The results of sediment loading into the streams and the reservoir from Sasumua sub watershed show that terracing would reduce the sediment loading by 84.9% from the base simulation. These results compare well with other studies on the effectiveness of terraces in reducing sediment yield. Gassman *et al*. (2006) found out that terraces would reduce sediment yield by about 63.9% and 91.8% using SWAT and APEX models simulations respectively. Santhi *et al*. (2006) found that contour terraces would reduce sediment yield by between 84 and 86% using SWAT simulations at the farm level.

Terraces would reduce the quantity of the peak surface runoff by impounding the water into small depressions. This would in turn cause more water to infiltrate into the ground. The velocity of the remaining surface runoff would be reduced and thus the erosive power would be much greatly reduced. This explains the significant reduction of the simulated sediment loading to the reservoir.

The water balance after the implementation of the terraces (Table 3) shows that, terraces would reduce the surface runoff by 21.8 % and increase the base flow by 10.2 %. There is only a slight change in the water yield. The enhanced infiltration by terraces would recharge the shallow water table reducing the surface runoff. The water stored in the shallow aquifer will be released to the streams as the base flow. The implication of this is that, the flooding incidences would reduce as the surface runoff is reduced and there would be more regulated stream flows which would run for an extended time because the base flow takes longer time to reach the streams than do the surface runoff.

Table 3: Water balance for the simulation of terraces

	Surface runoff (mm)	Lateral flow (mm)	Base flow (mm)	**Water yield (mm)**
Base simulation	193	184	304	680
Simulation with terracing	151	190	335	674
% change	-21.8	+3.3	+10.2	-0.9

3.4 Grassed Waterway

The results from the simulation of the grassed waterway (Table 4) show that, implementation of grassed waterways would have a sediment reduction of 40.72 % at the outlet of Mingotio stream at the reservoir (sub basin 60) and 23.45% for the whole Sasumua sub watershed (at the outlet of sub basin 61). There was only a small change in stream flow.

Table 4: Simulated sediment yield and stream flow reduction with and without Grassed Waterway (GWW)

	Sediment Yield (tons/year)		Streamflow (m^3/s)	
	Outlet at Mingotio stream (sub-basin 60)	Main Sasumua subwatershed outlet (at sub basin 61)	Outlet at Mingotio stream (sub-basin 60)	Main Sasumua subwatershed outlet (at sub basin 61)
Without GWW	20600	32750	0.603	1.483
With GWW	12210	25070	0.601	1.481
% change	**40.72**	**23.45**		

This shows that grassed waterways can play a significant role in the reduction of sediments in Sasumua. Similar results have been reported by other studies. Fiener and Auerswald, (2006a), for example, found a sediment reduction of about 93% for a 290 m long and 37 m wide grassed waterway. SWAT simulations by Gassman *et al*. (2006) found that grassed waterway can reduce sediment by 45.9%.

The increased roughness of the channels has a great effect in the reduction of the sediment yield. The grass would reduce the velocity of the water in the waterway and in effect reduce the stream power and its sediment transporting capacity hence causing deposition (Simon and Rinaldi, 2006).

Most of the streams in Sasumua are seasonal and only flow during the rainy season. These are the areas that should be targeted for grassed waterways. Though not practiced much in Kenya due to small land sizes owned by farmers, implementation of grassed waterways by farmers in Sasumua is practical since most of them also keep domestic animals. The grassed waterways can be used for conservation during the rainy season and a source of fodder during the dry season.

4 Conclusions

SWAT model was used to simulate the effect of conservation practices on sediment and water yield in Sasumua watershed. Vegetative filter strips, contour farming, parallel terraces and grassed waterways were simulated.

It was found that the filter strips reduced sediment yield with increase in their width and also that the first few increments of 5 m intervals had more reduction in sediment yield. This is attributed to the trapping efficiency of filter strips which is higher in the front part of the filter strip in trapping sediments. At 5 m implementation of filter strips would have a 38% reduction in sediment yield. Simulation of contour farming was found to reduce sediment yield by about 49%. Installation of parallel terraces would result in about 85% reduction in sediment load. Both the contour farming and parallel terraces reduced surface runoff and increased base flow with only minimal decrease in total water yield. If implemented in four sub-basins that have a drainage ditch, grassed waterway would result in a 41% decrease in the sediment load in the outlet of Mingotio stream and a 23% reduction for the entire Sasumua sub-watershed. There was no significant change in the steam flow in the simulation of grassed waterway.

Thus terraces were found to be the most effective BMP in enhancing ecosystem services namely; reducing sediment load in streams and increasing water infiltration. However, terraces are structural conservation measure and are relatively capital intensive and may therefore not be afforded by some farmers. We therefore recommend implementation of filter strips and contour farming on agricultural lands and grassed waterways on stream channels. Filter strips will eventually evolve into bench terraces.

References

Abu-Zreig M. (2001). Factors affecting sediment trapping in vegetated filter strips: simulation study using VFSMOD. *Hydrological Processes,* **15**, pp 1477–1488.

Abu-Zreig, M., Rudra, R. P., Lalonde, M. N., Whiteley, H. R. and Kaushik, N. K. (2004). Experimental investigation of runoff reduction and sediment removal by vegetated filter strips. *Hydrological Processes,* **18:** pp 2029–2037.

Arabi, M., Frankenberger, J., Engel, B. and Arnold, J. (2008). Representation of agricultural management practices with SWAT. *Hydrological Processeses.* Wiley interscience.

Arabi, M., Govindaraju, R. S. and Hantush, M. M. (2007). A probabilistic approach for analysis of uncertainty in the evaluation of watershed management practices. *Journal of Hydrology*, **333:** pp 459–471.

Bracmort, K. S., Arabi, M., Frankenberger, J. R., Engel, B. A. and Arnold, J. G. (2006). Modeling longterm water quality impact of structural BMPs. *Transactinsof ASABE,* **49** (2), pp 367-374.

Brunner, A.C., Park, S. J., Ruecker, G. R. and Vlek, P. L. G. (2008). Erosion modeling approach to simulate the effect of land management options on soil loss by considering Catenary soil development and farmers perception. *Land degradation & development*, **19**, pp 623–635.

Evrard. O., Vandaele. K., Wesemael. B. and Bielders.C. L. (2008). A grassed waterway and earthen dams to control muddy floods from a cultivated catchment of the Belgian loess belt. Geomorphology **100**: pp 419–428.

Fiener, P., Auerswald, K. (2005). Measurement and modeling of concentrated runoff in grassed waterways. *Journal of Hydrology*, **301**, pp 198–215.

Fiener P. and Auerswald K. (2006a). Seasonal variation of grassed waterway effectiveness in reducing runoff and sediment delivery from agricultural watersheds in temperate Europe. *Soil & Tillage Research* (87), pp 48–58.

Fiener P and Auerswald K. (2006b). Influence of scale and land use pattern on the efficacy of grassed waterways to control runoff. *Ecological Engineering,* **27**: pp 208–218.

Fox G.A., Munoz-Carpena R. and Sabbagh G.J. (2010). Influence of Flow Concentration on Parameter Importance and Prediction Uncertainty for Vegetative Filter Strips. *Journal of Hydrology,* (2010), doi:10.1016/j.jhydrol.2010.01.020

Gassman, P. W., Osei, E., Saleh, A. and Rodecap, J. (2006). Alternative practices for sediment and nutrient loss control on livestock farms in northeast Iowa. *Agriculture, Ecosystems and Environment,* **117**:pp 135–144.

Gassman, P. W., Reyes, M. R., Green and Arnold, J. G. (2007). The Soil and Water Assessment Tool: Historical Developments, Applications and Future Research Directions. *Transactions of ASABE*, 50(4):pp 1211-1250.

Gilley, J. E., Enghball, B., Kramer, L. A. and Moorman, T. B. (2000). Narrow grass hedge effects on runoff and soil loss. *Journal of Soil and Water Conservation*, **55** (2): pp 190-196.

Hunink, J.E., Droogers, P. Kauffman, S., Mwaniki, B. M. and Bouma, J. (2012). Quantitative simulation tools to analyze up- and downstream interactions of soil and water conservation measures: Supporting policy making in the Green Water Credits program of Kenya. *Journal of Environmental Management,* **111**: pp 187-194.

Lovell S. T. and Sullivan W. C. (2006). Environmental benefits of conservation buffers in the United States:Evidence, promise, and open questions. *Agriculture, Ecosystems and Environment,* **112**, pp 249–260.

Millennium Ecosystem Assessment (MA). (2003). *Ecosystems and Human Wellbeing: A Framework for Assessment*. Washington, DC: Island Press. http://www.millenniumassessment.org/en/Framework.aspx, accessed, 20th June 2011.

Mwangi, H. M., Gathenya J. M., Mati B. M., Mwangi, J. K. (2011). Simulating the impact of landuse change on watershed services using SWAT. *In* Applied Geoinformatics for Society and Environment (AGSE), Fourth international summerschool and conference. Behr F.J., Ngigi M., Pradeepkumar P. and Zimmermann M. (eds) pp 191-199. ISBN 978-3-943321-00-5 AGSE, Karlsruhe, Germany.

Neitsch S.L., Arnold J.R., Kiniry and Williams J.G. (2005). Soil and Water Assessment Tool (Version 2005) Model Documentation. Temple Tex.: USDA-ARS Grassland, Soil and water research laboratory. Available at: http://www.brc.tamus.edu/swat/doc.html.

Natural Resource Conservation Service NRCS, (2008). Natural Resource Conservation Practice standard: Filter strips.

Natural Resource Conservation Service (NRCS), (2006). Contour farming: *Conservation practice Job sheet: PA330*

Parajuli, P. B., Mankin K. R. and Barnes, P. L. (2008). Applicability of targeting vegetative filter strips to abate fecal bacteria and sediment yield using SWAT. *Agricultural water management,* **95**: pp 1189 – 1200.

Quinton, J. N. and Catt, J. A. (2004). The effects of minimal tillage and contour cultivation on surface runoff, soil loss and crop yield in the long-term Woburn Erosion Reference Experiment on sandy soil at Woburn, England. Soil Use and Management, **20**, pp 343–349.

Sahu, M. and Gu, R.,R. (2009). Modelling the effects of the riparian buffer Zone and contour strips on stream water quality. *Ecological Engineering*, **35**: pp 1167-1177.

Santhi, C., Srinivasan, R., Arnold, J. G., and Williams, J. R. (2006). A modeling approach to evaluate the impacts of water quality management plans implemented in a watershed in Texas. *Environ. Model. Soft*. **21**(8), pp 1141-1157.

Shi, Z.H., Cai, C.F., Ding, S.W., Wang, T.W. and Chow, T.L. (2004). Soil conservation planning at the small watershed level using RUSLE with GIS: A case study in the Three Gorges Area of China. *Catena*, **55**: pp 33–48.

Simon, A. and Rinaldi, M. (2006). Disturbance, stream incision, and channel evolution: The roles of excess transport capacity and boundary materials in controlling channel response. *Geomorphology*, **79**, pp 361–383.

Stevens, C. J., Quinton, J. N., Bailey, A.P., Deasy, C., Silgram, M. and Jackson, D .R. (2009). The effects of minimal tillage, contour cultivation and in-field vegetative barriers on soil erosion and phosphorus loss. *Soil & Tillage Research*, **106:** pp 145–151.

Ullrich, A. and Volk, M. (2009). Application of the Soil and Water Assessment Tool (SWAT) to predict the impact of alternative practices on water quality and quantity. *Agricultural Water Management*, **96**, pp 1207-1217.

White, M. J. and Arnold, J. G. (2009). Development of a simplistic vegetative filter strip model for sediment and nutrient retention at the field scale. *Hydrological Processes*, **23**: pp 1602–1616.

Williams, J. R. (1975). Sediment routing for agricultural watersheds. *Journal of the American Water Resources Association,* Paper *No. 75065* of the Water Resources Bulletin.

Wischmeier, W. H. and Smith, D. D., (1978). Predicting rainfall erosion losses- a guide to conservation planning. U.S. Department of Agriculture, Agriculture Handbook No.537

Yuan, Y., Bingner, R. L. and Locke, M. A. (2009). A review of effectiveness of vegetative buffers on sediment trapping in agricultural areas. *Ecohydrology,* **2**: pp 321-336.