Evaluation of impacts of Soil and water Conservation on Watershed hydrology of Kulfo River Using Hydrological SWAT Models, SNNPR

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Abstract—Land degradation due to soil erosion and nutrient depletion is one of the main problems constraining the development of the agricultural sector in Ethiopia. For this problem Ethiopian governments have attempted to implement different soil and water conservation activities. The main objectives of this work was to assess the impact of implemented SWC Practices in the watershed, to reduce land degradation and to realize the results so far achieved, using Soil and Water Assessment Tool (SWAT) model. The purpose of this research was to develop a field scale under different SWCp sub model for the Soil and Water Assessment Tool (SWAT). SWAT model was applied to the catchment area Calibrated and Validated using 15 years stream flow data from 1993 to 2007. Nash-Sutcliffe model fit for monthly stream flow was 0.73 for calibration and 0.75 for validation period. The three SWC measures assessed at sub basin levels were Grassed waterway, Filter strip and Terracing. In this work, I present the results of a study, which evaluates the impact of the Grassed waterway, Filter strip and Terracing on water balance components and erosion at basin scale by using the soil and water assessment tool model (SWAT). The model also simulated this suitable SWC Practices on Surface runoff and sediment yield in the catchment. There was a significant reduction in the production of surface runoff and sediments between scenarios. The model predicts that SWCp produce annually a reduction of 15.5 and 50.3% in surface run-off and Sediment Yield, respectively, and an increase in aquifer recharge of 17.2%. Catchment management has resulted in a higher infiltration rate and a reduction of direct runoff which has had a positive influence on the catchment water balance. The overall result suggests that thus all the conservation practices investigated were found to have a positive impact in enhancing the ecosystem services. Therefore, in order to manage soil and water resources in Kulfo Catchment, sustainable investment on appropriate land management practices has to be implemented cooperatively. **Index Terms**—Minimum 7 keywords are mandatory, Keywords should closely reflect the topic and should optimally characterize the paper. Use about four key words or phrases in alphabetical order, separated by commas.

Keywords: SWAT model, SWC measure, Grassed waterway, Filter strip and Terracing, land management practices, Land degradation, soil erosion

1 INTRODUCTION

Land degradation is a serious global environmental problem. Throughout the world today, reduction of natural resources is among the major problems facing human beings. The International soil Reference and Information Center (1995) estimated that nine million hectares of the world lands are tremendously degraded and their original biotic functions are severely degraded.However, 1.2 billion hectares of the world land were moderately degraded. Worldwide inappropriate agricultural practices account for 28% of the degraded soils (Addisu, 2011). Ethiopia can be a good example where such depletion of the soil resources is enormous. Dominated by small-scale agricultural producers, Ethiopia is one of the most severely eroded countries in the world. The land degradation, soil erosion, and deforestation; the Ethiopian governments have attempted to implement different soil and water conservation activities. The positive effects of soil and water conservation (SWC) may occur through time and adoption of SWC agricultural technologies depends on the ability of the technologies to improve agricultural land productivity and income, and risk decisions facing individual households both in short and long term. Those activities are physical structure (terraces, soil Bund, waterways, check dams, etc.) to reduce over land flow, thereby preventing removal of soil, soil fertility improvement practices (compost application), agro-forestry and reforestation of deforested hilly areas, maintaining soil pH, no till farming practices and the positive results yielded. To overcome the problem of soil and water conservation practice, the current Government of Ethiopia has taken different measures such as policy interventions, conducted studies, and implemented massive soil and water conservation (SWC) and capacity building programs, especially after the 1987/88 of rainy seasons (Shiferaw et al., 1999). Theevaluation of conservation measures at the watershed scale is highly desirable. The application of measured conservation practice efficiencies from research fields or plot studies is common, but these methods cannot account for local conditions. Simulation models such as the Soil and Water Assessment Tool (SWAT) (Arnold, 1998) have been accepted as surrogate measures to quantify the impacts of conservation programmes. The SWAT model is widely used to evaluate conservation practices at the watershed scale (Gassman P.W., 2007); there are many examples in the published literature.

The most serious problems in Kulfo watershed addressed in this study are the high rate of soil erosion from the Mountains and agricultural part of the watershed and concerning land resources, is the removal of fertile top soil by water and change landscape of catchment. Thus the intention of this study was to simulate the effect on hydrology of Kulfo watershed. This will be done by using Hydrological Soil and Water Assessment Tool (SWAT) model.

2 OBJECTIVES OF THE STUDY

This study aims to assess the impact of the SWC measures implemented to reduce land degradation in the Kulfo watershed, southern Ethiopia, and to realize the results so far achieved. This could lead to further improvement of policies implemented in the future.

The specific objectives are:

- ✓ To assess the effect of implied conservation practices on water and sediment yields and characterize soil and water conservation practices adopted in the area. □
- ✓ To analyze the effects of conservation practices on surface runoff and related soil erosion considering different conservation practice. □
- ✓ To simulate the effect of feasible land management options on soil erosion to propose at the catchment scale. □
- ✓ To make recommendations that would improve the current soil, water agricultural management practices.

3 MATERIALS AND METHODOLOGIES

3.1 Study area

The study area, Kulfo River watershed, is located in the Abaya-Chamo sub-basin of the southern Ethiopian Rift Valley and drains to Lake Chamo. The watershed is situated between 5°58′ N – 6°18′N latitude and 37°18′E – 37°38′E longitude; latitude and has a land area of 395 km2 where 85 % of the watershed is gauged before it joins Lake Chamo. Smallholder agriculture is the dominant land use in the watershed. Kulfo River is a tributary of the Lake Chamo system, draining the western Garbsen shoulder and meeting Lake Abaya-Lake Chamo just in the transition zone.

The alluvial fan deposited by the Kulfo River shows a relict braided drainage pattern, indicating that the Kulfo River alternately flowed into Lake Abaya and Lake Chamo, while today Kulfo River is canalized and flows into Lake Chamo (See Figure 1).

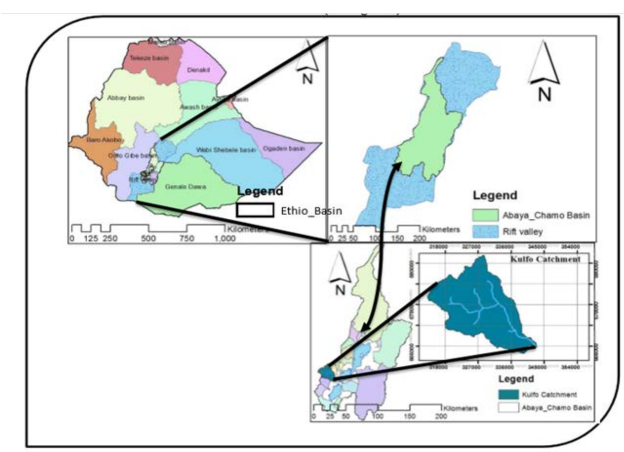

Figure 1:- Location of Kulfo Watershed

3.2 Method of the study

The methods used for Assessment of soil and water conservation practice impacts watershed hydrology of Kulfo River. general steps followed in this study works are outlined below.

1. Input data collected for the study such as: The digitized map of the study area and DEM data collected from MOWEE, meteorological data from NMA, physical characteristics of the Practice.
2. Setting-up, calibration and validation of SWAT model with climate and stream flow data representing the current climate condition.

The methodology of this study is summarized in a form of a flow chart as shown in Figure below. The flow chart depicts the steps followed in carrying out the modeling of the catchment level changes.

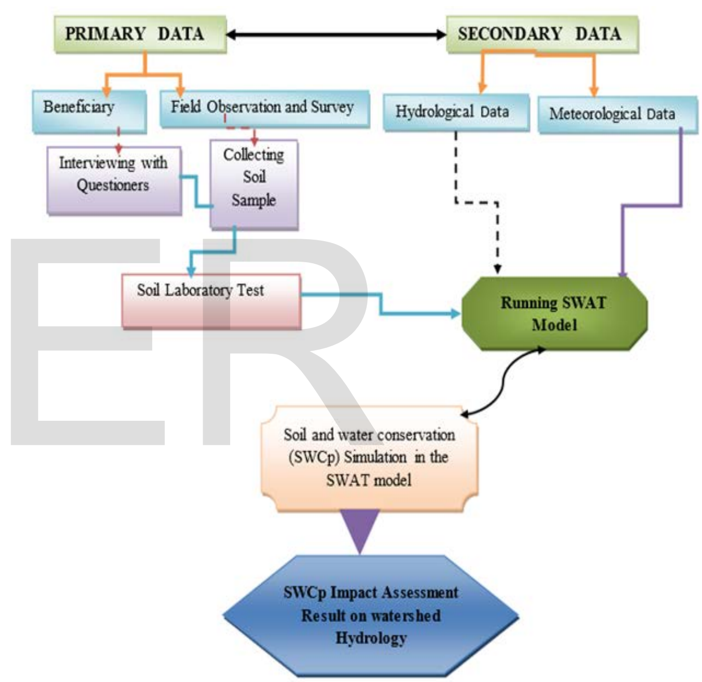

Figure 2:- The flowchart of general methodology used in this work

Data Analysis

Physical investigation on the watershed to see the corresponding problems that faced on the catchment area and Characterizing soil and water conservation practices. Calculating the flow of the river, in gauging stations.

The spatially distributed data (GIS input) needed for the Arc SWAT interface include the Digital Elevation Model (DEM), soil data, and land use data. Data on weather and flow is used for the prediction of water balance and calibration purposes respectively.

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Hydrological Model

SWAT Model was used to assess the effects of water harvesting technology on downstream water availability. The model simulates the hydrology of a watershed done in two separate divisions. The land phase of the hydrological cycle and routing phase of the hydrologic cycle for this study land phase Hydrological components of SWAT was used.

SWAT model simulates hydrology of the area with watershed level. In this study the model simulate the area on two watersheds Bilate and Shala because the Woreda fall on the two catchments. Hydrological components simulated in land phase of the hydrological cycle canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow.

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_o + (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad 1$$

Calibration is modification of model parameters based on checking results against observations to ensure the same response over time. This involves comparing the model results, generated with the use of historic meteorological data, to recorded stream flows. The performance of SWAT was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values.

Evaluation of Conservation Practice Using the Baseline Conservation Condition. This study assesses the use and effectiveness of conservation practices in the Kulfo River Basin for the period 1993 to 2007 to determine the baseline conservation condition for the region. The baseline conservation condition provides a benchmark for estimating the effects of existing conservation practices as well as projecting the likely effects of alternative conservation treatment. Conservation practices that were evaluated include structural practices.

Structural conservation practices, once implemented, are usually kept in place for several years. Designed primarily for erosion control, they also mitigate edge-of-field nutrient and pesticide loss. Structural practices evaluated include—

• In-field practices for water erosion control, divided into two groups: □

- practices that control overland flow (terraces, Filter strips, contour farming, strip cropping, contour strip-cropping), and □
- practices that control concentrated flow (grassed waterways, grade stabilization structures, diversions, and other structures for water control);

In this study three structural conservation practice were simulated by hydrological SWAT model. Terraces, Grassed Waterway and vegetative filter strips were simulated as SWC practice, which are hydrologically similar. SWAT model is widely used to evaluate conservation practices at the watershed scale (Gassman P.W., 2007); there are many examples in thepublished literature. (Bracmort et al., 2006) Used the SWAT model to evaluate the long term effectiveness of structural Best Management Practices (BMPs) on sediment and phosphorus. (Vache et al., 2002) Used the SWAT model to evaluate the effect of riparian buffers, engineered wetlands, grassed waterways, filter strips and field borders on nutrient and sediment losses from corn fields. (Chu et al., 2005) Used SWAT to simulate the effect of nonstructural BMPs including conservation tillage, no-till, contour farming and strip cropping. (Arabi et al., 2008) Evaluated crop rotation, cover crops, contour cropping, strip cropping, residue management, terracing, and field borders using SWAT.

The methodology used for the simulation of conservation practices in this study is based mainly on the methodology developed for simulation of conservation practices in SWAT by (Arabi et al., 2008). In this the agronomic and vegetative conservation practices considered the **Grassed Waterway and vegetative filter strips and terracing**

4 Result and Discussions

This section presents results of the study and discusses the result by giving an appropriate emphasis on the projected research objective.

The standard land phase hydrologic parameters used in SWAT were considered for annual water balance. For this study, Average annual water balance in the watershed for both calibration and validation period was done. The simulation result that largest portion of the average annual precipitation (83%) falling in the watershed is lost through Transmission losses. This value indicates that there is high sensitivity of Transmission losses to any change than any other hydrologic parameter governing the sub watersheds" water balance.

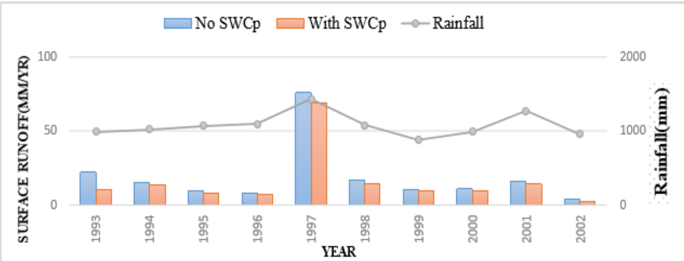
The impact of Soil and Water Conservation Practice on water balance and erosion was evaluated in the Kulfo Watershed. Kulfo watershed currently is limited to produce some of environmental services it is expected to produce mainly because of human activities.

The work evaluated the performance of SWAT model using Standard calibration and validation statistics. A good agreement between measured and simulated monthly streamflow was demonstrated by correlation coefficient (R2 = 0.82), Nash-Sutcliffe model efficiency (ENS = 0.73) and mean deviation (D = 17.2) for calibration period and R2 = 0.75, ENS = 0.93 and D= 25.4 % for validation periods.

The figure below shows the variation of the runoff results from the simulation of the SWCp, the result was an average decrease of runoff by about 17% over a period of 10 years (19932002) when compared with Base scenario (No SWCp) with some implemented conservation practice (With SWCp).

Results of simulation under different conservation practices in the catchment area are given in output showed that SWCp in area generated 23.6t/hec/yr. sediment yield. That the simulation results revealed that soil conservation practices used in simulation could significantly reduce the annual sediment yield in the river. The SWCp implemented in the watershed reduce the sediment yield by 50% from the base value ofsediment yield with no conservation practices.

Figure 4.1:- Impact of SWC practice on Surface run-off.



The model also simulates average values of groundwater flow contribution (GWQ mm) to total water yield (TWY) for each sub-basin that SWC practice appeared (implemented). The results of simulation with SWC practice show an increase of groundwater contribution in the sub basins. There is an increase Annual in GWQ from 5.07% (49.84 to 52.327mm) this is due to the water storage capacity of the large number of grassed waterway realized in this part of the basin that increases the percolation into the soil. A general reduction in total stream flow is simulated around the basin due to this Conservation Practice.

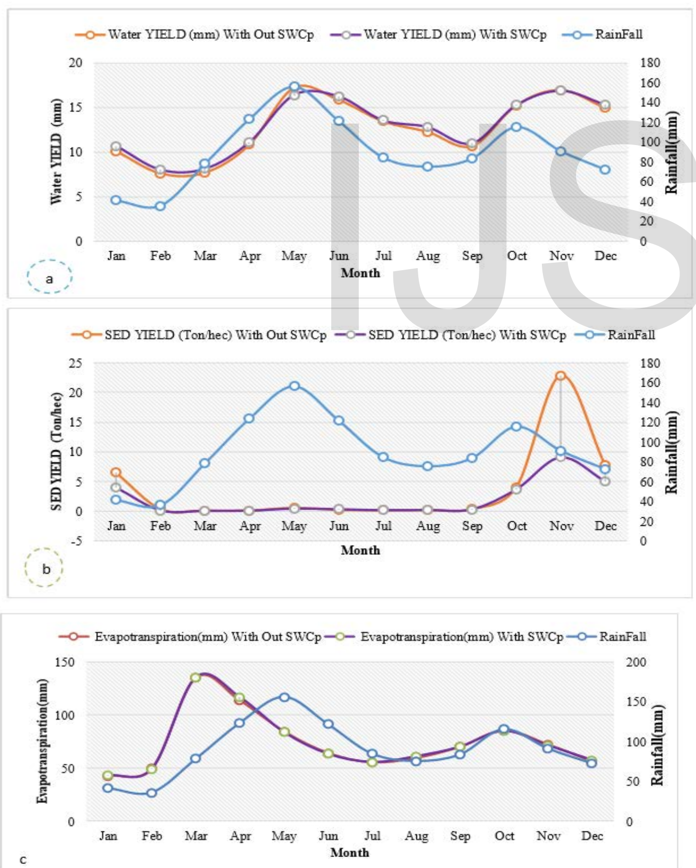


Figure 5.7:- Water balance components of Kulfo Watershed: Sediment Yield (a); Total water yield (b); (c) and Evapotranspiration.

The effect of the Conservation Practice on the water balance of the Watershed is well verified by the water yield component of the Water balance. The Water Yield comprises the surface Runoff and the lateral flow, also known as interflow.

The other interesting result on the impact of Conservation Practice was related to the sediment yield and Evapotranspiration component of the Water balance. Figure 5.7b, c presents the reduction of sediment yield to the stream flow increment of Evapotranspiration.

5 Conclusions and Recommendations

This study assessed the impact of various SWC measures implemented in the Kulfo watershed, Southern Ethiopia. The study indicated that there has been success in maintaining and improving land resources, viz. soil, and water due to the implementation of SWC measures.

The impact of Soil and Water Conservation Practice on water balance and erosion was evaluated in the Kulfo Watershed. Kulfo watershed currently is limited to produce some of environmental services it is expected to produce mainly because of human activities.

The work evaluated the performance of SWAT model using Standard calibration and validation statistics. A good agreement between measured and simulated monthly streamflow was demonstrated by correlation coefficient (R2 = 0.82), Nash-Sutcliffe model efficiency (ENS = 0.73) and mean deviation (D = 17.2) for calibration period and R2 = 0.75, ENS = 0.93 and D= 25.4 % for validation periods.

Following calibration and validation of Hydrological SWAT model useful to identify the most appropriate location for the SWCWs and their impact on water balance and sediment yield at basin scale. Three scenario analyses were tested to reduce sediment loads from critical sub basins. In fact, the results of this study show that a greater reduction of stream flow occurred in the basin

However, a general problem in watershed modelling yet to be addressed is the limited availability of data, especially in terms of measured water quality for calibrating and validating these models. The lack of long time series of sediment with daily time step and high spatial resolution has limited the capacity of work to evaluate the simulations. Although the results are affected by uncertainty, they can be useful to improve the river basin management in datapoor regions. As this study show, there is a need to understand the catchment sediment balance better with field measurements

Therefor the results of the simulation study suggest that SWCp can be effective in reducing sediment yield from the catchment area of the Kulfo River and may be considered for implementation

The current practice in the watershed reduction in the Surface runoff and sediment yield feasible in the catchment was 15% and 50% respectively in the case of Grassed waterway, Filter strip and Terracing.

In general conclusion the finding of this study key function of conservation are: erosion control, safe runoff disposal, and water retention and fertility improvement.

Key strategies suggested to the attainment of sustainable soil and water management activities include: Community participation and empowerment, appropriate technology, issuing of polices, regulations and bylaws and considering of complimentary strategies.

Therefore the results of the simulation study suggest that Grassed waterway, Filter strip and Terracing can be effective in reducing surface runoff and sediment yield from the catchment area of the Kulfo River and may be considered for implementation.

Recommendations

Stream flow data for the gauging stations in the watershed was not available since it is not collected. Hydrological projects and studies like hydrological modelling rely on these data. Availability of that data would improve the calibration and validation of the model. The ministry of Water Irrigation and Electricity of Ethiopia should put mechanisms of collecting the data.

Grassed waterway were found to be the most effective conservation practice in reducing sediment yield and increasing infiltration. It is recommended that bench terraces should be constructed in the watershed. I further recommend construction of Terraces and Filter strip in the drainage channels that feed water to Kulfo stream.

Poor land management activities currently being practiced such as over-cultivation and overgrazing have increased sediment loading to the streams thus impairing water quality and also reducing infiltration of water into the ground. This has resulted in flash flood during the rainy seasons and low dry weather flows. This study has however found that the two environmental services would be improved if soil and water conservation measures are implemented in the watershed.

I recommend that these areas should be prioritized in the implementation of soil and water conservation measures. Implementation of soil conservation measures in these areas would reduce soil erosion and reduce the sedimentation into the streams.

References

[1] Addisu. (2011). Benefit and challenge of adoption soil conservation techniques in goromt watershed central Ethiopia. Addis Ababa.

[2] Addisu, D. (2011). Benefit and challenge of adoption soil conservation techniques in goromt watershed central Ethiopia, Addis Ababa University, Ethiopia.

[3] Arabi, M. J. (2008). Representation of agricultural management practices with SWAT. Hydrol. Process.Wiley interscience.

[4] Arnold, J. S. (1998). Large area hydrologic model development and assessment Part 1 Model.

[5] Bracmort, K. S. (2006). Modeling long-term water quality impact of structural BMPs. Transactions of the ASABE 49(2), 367–374.

[6] Chu T, S. A. (2005). Watershed level BMP evaluation with SWAT model. In Proceedings of the American Society of Agricultural Engineers Annual International Meeting, July 17–20, 2005, Tampa, Florida, USA, ASABE Publication.

[7] Gassman P.W., M. R. (2007). The soil and water assessment tool: Historical development, applications and future research directions.Transactions of the ASABE 50(4), 1211– 1250.

[8] Shiferaw. B and Holden. ST. (1999). Soil erosion and smallholders' conservation decisions in the highlands of Ethiopia. Worled Development 27, 739-752.

[9] Vache, K. B. (2002). Water quality modeling of alternative agricultural scenarios in the US Corn Belt. Journal of the American Water Resources Association 38(3), 773–787.