Application of AnnAGNPS model for runoff and soil loss simulation at Anjeni watershed, Northwest Ethiopia

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Abstract

A study was conducted in 2009/2010 to evaluate the predictive capability of Annualized Agricultural Nonpoint Source (AnnAGNPS) model with respect to both event wise and annual values of runoff and soil loss on a 96 ha agricultural watershed in northwest Ethiopia. Input data used for the model including climate, runoff, soil loss, land use, and soils were generated from the Soil Conservation Research Program (SCRP) data base and previous research works. The model was calibrated and validated against observed data. Event wise runoff was over predicted by 3.1% (R^2 = 0.863) and under predicted by 21.4% (R^2 = 0.730) during calibration and validation, respectively. Sediment yield on an event basis was over predicted by 134.7% (R^2 = 0.528) and by 14.8 % (R^2 = 0.756) during calibration and validation, respectively. Annual predicted values resulted in errors of 1.99% and 11.53% for runoff and soil loss, respectively. Generally, results showed that the model performed satisfactorily in simulating both annual and event wise runoff and soil loss for the study watershed.

Key words: AnnGNPS, calibration, validation, watershed.

Introduction

The response of landscape and soil erosion processes to both natural and anthropogenic influences are a function of many independent variables that can be analyzed by monitoring the behaviour of individual landscape parameters such as vegetation, soil, and water, or holistically through watershed-scale field studies. The complexity and expensive nature of monitoring programs, however, necessitates the development and use of hydrologic models such as AnnAGNPS (Cronshey and Theurer, 1998). AnnAGNPS has been developed for evaluating the hydrologic and erosion responses of a watershed to land use practices (Yuan *et al*., 2001). An effective simulation tool can increase awareness and understanding of land use practices by land users and watershed planners and promote adoption of alternative land use practices (Yuan *et al*., 2008).

Physically-based models have the potential to simulate the runoff and erosion processes and behaviour of sediment movement accurately, with little or no calibration of the parameters used (Cronshey and Theurer, 1998). Using such models is significantly less expensive than large-scale monitoring of these processes in the field (Yuan *et al*., 2001). AnnAGNPS is one such model developed for use with little local calibration on un-gauged watersheds. This study was conducted to simulate runoff and sediment yield for Anjeni watershed (a typically agricultural watershed in Northwest Ethiopia) using the AnnAGNPS model with the objective to adapt the model for application in the Northwest Ethiopian highland environment.

Materials and methods

The study area

The study was conducted in 2009/2010 in Anjeni watershed to simulate runoff and sediment yield. Anjeni watershed is situated in Northwest Ethiopia in the Gojjam highlands (Figure 1) within an altitude range of 2407 m to 2507m above sea level between $37^0$31'30" to $37^0$32'20" E longitude and $10^0$40'10" to $10^0$41'50" N latitude. It is an agricultural watershed having a hydrologic surface area of about 96 ha. The average annual rainfall is about 1692 mm (SCRP, 2000). Mean daily temperature is 16 °C. The topography of the watershed is dominated by undulating slopes ranging in steepness from 8% to more than 30% (SCRP, 2000). Almost rectangular in shape, the watershed is north to south oriented, dissected by the Minchit perennial stream through the middle, which forms part of the Blue Nile basin. The mean annual river discharge is about 730 mm with the drainage ratio of rainfall being around 43% (Herweg and Stillhardt, 1999). The mean annual erosion rate is 54.1 tons ha^{-1} yr^{-1} (SCRP, 2000). The soils of the watershed can be described as well to excessively drained that are clay in texture and acidic in reaction (Gete Zeleke, 2000). Agriculture in the study area is characterized by a subsistence rainfed production highly oriented toward grain production and is dependent on the use of ox power for land preparation. Free grazing on communal lands is also a major component of the farming system. Tef, barley, wheat, oil crops, and pulses are the major crops grown in the study area. The study area has a unimodal rainfall regime as a result of which the condition allows only one cropping season.

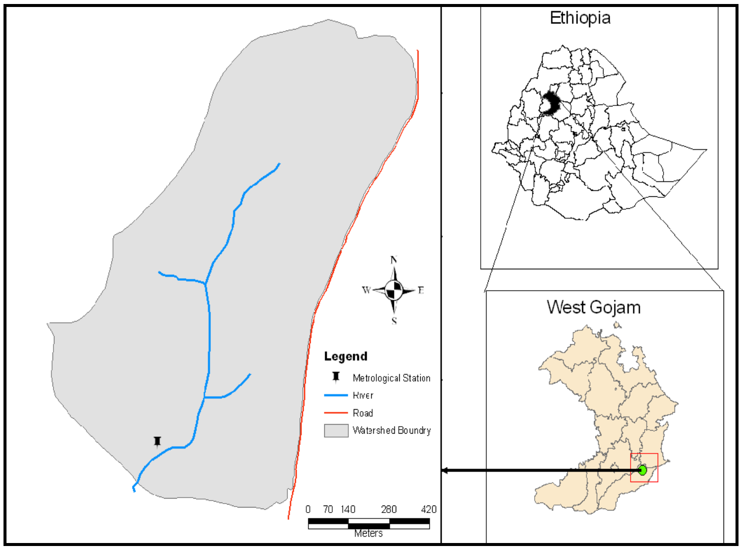

Figure 1. Location map of the study area.

Model structure

AnnAGNPS is a distributed parameter, process-based, continuous-simulation, watershed-scale model to be used as a tool to evaluate non-point source pollution from agricultural watersheds ranging in size up to 300,000 ha (Cronshey and Theurer, 1998). AnnAGNPS can simulate quantities of surface runoff and sediment yield leaving user specified computational areas within a watershed called cells and their transport through the entire watershed. Runoff estimates in AnnAGNPS are based on the SCS curve number (CN) method (USDA, SCS, 1972). Daily sheet and rill erosion is calculated in AnnAGNPS using the RUSLE equation (Renard *et al.*, 1997). Since RUSLE does not account for deposition and is only used to predict sheet and rill erosion, the Hydro-geomorphic Universal Soil Loss Equation (HUSLE) (Theurer and Clarke, 1991) was used to calculate sediment delivery to the stream system from the contributing cells. The Bagnold equation (Bagnold, 1966) is used within AnnAGNPS to determine sediment transport capacity of the stream, and sediment transport in reaches is based on Einstein deposition equation (Einstein and Chein, 1954).

Input requirements

Climate

The climate input file was created using recorded historical data from SCRP data base for the watershed. Specific data inputs required for the climate data file are maximum and minimum daily temperatures, daily precipitation, average daily dew point, cloud cover, and wind speed.

Topography

The watershed was subdivided into 100 m X 100 m grid cells as per the recommendation by Young *et al*. (1989) using GIS application from a DEM of the watershed from which flow direction and slope data were derived. Additional field checking was carried out to verify values generated by GIS and gather data on channel characteristics.

Soils

The major soil type and associated soil characteristics required by the model were determined and assigned for each AnnAGNPS cell. Required inputs include particle size fraction, bulk density, saturated hydraulic conductivity, field capacity, and wilting point.

Land use and management practices

The dominant land use in each AnnAGNPS cell was assigned to the entire AnnAGNPS cell and all associated parameter values (such as curve number) of the land use were assigned to the AnnAGNPS cell. From interviews with farmers insight was gained about management practices for each crop. A typical management cycle for annual crops in the study watershed involves a ploughing operation of one to six times to a depth of 15-20 cm and several weeding operations, depending upon the crop types. The predominant crops considered were tef, barley, niger seed, linseed, horse bean, and maize.

Selection of runoff curve number (CN) values

Initial CN values were defined for each land use and hydrologic soil type combination based on the TR-55 manual (SCS, 1986). The model itself updates the CN values according to the changes in soil moisture and cover description.

Model simulation

The simulation process using AnnAGNPS involved model sensitivity analysis, calibration and validation processes. Performance of the model was evaluated based on qualitative and quantitative assessment. The qualitative procedures consisted of visually comparing the observed and simulated values. The data sets used for model calibration and validation are presented in Tables 1 and 2.

Table 1. Observed and predicted runoff volume and sediment yield data used for AnnAGNPS calibration in Anjeni watershed.

	Observed values		Predicted values	
Event	Runoff volume (m^3)	Sediment yield (tons)	Runoff volume (m^3)	Sediment yield (tons)
6/3/1994	7258.67	187.71	9376.77	412.47
6/9/1994	3187.36	27.74	1962.77	57.45
6/24/1994	4414.96	26.32	5830.98	115.41
6/25/1994	5238.70	32.79	6154.42	108.15
6/27/1994	7369.52	75.88	6564.37	133.96
7/4/1994	7372.10	53.14	8367.90	121.30
7/27/1994	17339.29	47.42	19934.49	265.04
7/28/1994	15424.52	68.43	11594.03	122.51
8/1/1994	12049.62	41.32	12931.51	150.97
8/4/1994	13292.12	127.28	13172.50	127.83
Total	92946.86	688.03	95889.74	1615.09
Mean	9294.69	68.80	9588.97	161.51

Table 2. Observed and predicted runoff volume and sediment yield data used for AnnAGNPS validation in Anjeni watershed.

	Observed values		Predicted values	
Event	Runoff volume (m^3)	Sediment yield (tons)	Runoff volume (m^3)	Sediment yield (tons)
7/19/1994	5855.07	13.38	2837.61	27.24
8/9/1994	10776.73	54.08	8428.92	72.05
8/231994	6310.90	40.62	6718.36	35.64
8/271994	4493.24	19.88	3898.32	22.05
8/31/1994	4485.19	24.23	3195.72	17.77
Total	31921.13	152.19	25078.93	174.75
Mean	6384.23	30.44	5015.79	34.95

Results and discussion

Sensitivity analysis

Sensitivity analysis was carried out to identify the most important input parameters to the model to be subjected to calibration. It was found that SCS curve number had direct effect on runoff and sediment yield whereas LS-factor, soil K-factor, crop cover factor, crop management factor, and surface roughness factor affected only sediment yield.

Calibration

Historical daily runoff and sediment yield data from the SCRP data base were used in this simulation study. The first step in model calibration was carried out by comparing predicted and observed runoff. Only CN values were adjusted for calibration of runoff, since the sensitivity analysis showed that runoff was not affected by the other parameters. Since the first selected CN values resulted in too high runoff simulation, the CN values for each land use were lowered by the same proportion until best runoff estimates were obtained. Eventually, the model resulted in an overestimated mean daily runoff by 3.17%

with R^2 value of 0.86 (Figure 2). The over prediction , even though it is small, is mainly attributed to the fact that spatial variability still exists within a landscape that is assumed to be uniform in the modelling process. Similar results were obtained by Nigussie Haregeweyn (2000) at Agucho watershed and Eshetu Eltamo (2003) at Gununo watershed by applying the old AGNPS model.

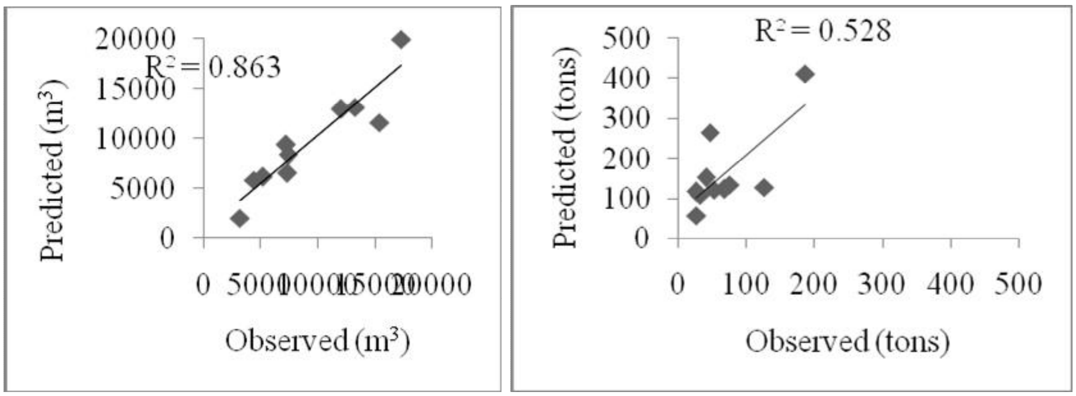

Figure 2. Calibration of AnnAGNPS model for runoff volume (left) and sediment delivery (right) at the watershed outlet of Anjeni watershed.

The second step to calibrate AnnAGNPS was done by comparing the predicted against measured sediment yield values. The parameters affecting sediment yield were adjusted within their tolerable ranges in order to bring down the very high predicted values that resulted from first model run. After such alterations, average sediment yield was over predicted by 134.74% with R^2 value of 0.528 (Figure 2). Similar trend was obtained by Shrestha *et al.* (2006) by applying AnnAGNPS in Siwalik, Nepal. These authors indicated that average event wise sediment yield was over predicted by 153% with R^2 value of 0.62. Polyakov *et al.* (2007) also applied the model in the Island of Kauai, Hawaii, and reported that AnnAGNPS overpredicted sediment yield. The use of RUSLE and associated parameters are meant to be used for making long-term estimates. This is, therefore, expected to have caused the observed errors between the measured and predicted event wise values.

Validation

During validation runoff was under predicted by 21.43% with R^2 value of 0.730 (Figure 3). The fact that it is impossible to fully account for spatial variability in the modelling process is responsible for such an error between observed and predicted values. Similar result was reported by Yuan *et al.* (2001) in which AnnAGNPS underestimated observed runoff in the Mississipi Delta.

Average sediment yield during validation was still over predicted by 14.83% with R^2 value of 0.756 (Figure 3). The decrease in the error between predicted and observed values and the increase in the R^2 value at the validation stage shows that sediment yield was predicted with a better accuracy during validation.

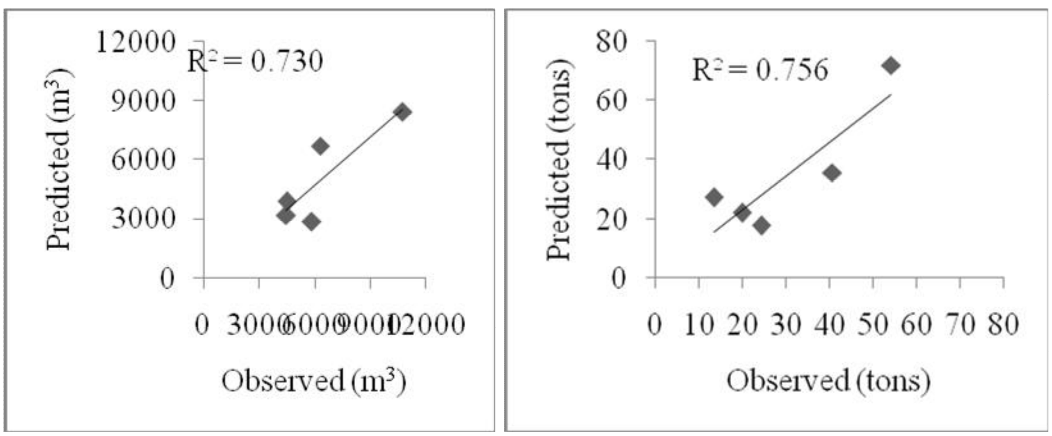

Figure 3. Validation of AnnAGNPS for runoff volume (left) and sediment yield (right) at the watershed outlet of Anjeni watershed.

Annual runoff and soil loss simulation

Being a continuous-simulation model, AnnAGNPS is capable of producing estimates of average annual runoff and erosion values. The simulation results in the study watershed showed that mean observed annual runoff (358.92 mm) and erosion rate (54.1 tons ha^{-1} yr^{-1}) values at field plot level were under predicted by 1.99% (351.79 mm) and 11.53% (47.86 tons ha^{-1} yr^{-1}), respectively. The observed values at field plot level involved only a small number of field plots that are too small in number to represent the entire watershed as the watershed is composed of diverse landforms. Therefore, the observed erosion rate values obtained from field plot data are expected to involve considerable errors, explaining the differences observed between measured and predicted annual values.

Conclusions

The AnnAGNPS hydrologic model was applied to predict surface runoff and sediment yield at Anjeni watershed. The model predicted runoff with the range of acceptable accuracy, which is reflected by the high R^2 values. This indicates that the SCS curve number method is suitable for runoff simulation in the study area. Sediment yield predictions can be considered to be in the range of moderate accuracy. However, the performance of the model to predict sediment yield can be further increased by applying appropriate watershed discretization techniques in order to properly account for spatial variability. In general, the study revealed that the AnnAGNPS model can be used in simulating both runoff and sediment yield in the study watershed and other similar areas to aid the design and planning of different management strategies for soil and water conservation.

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