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Full Length Research Paper

Hydrological modeling of a catchment using SWAT model in the upper blue Nile Basin of Ethiopia

Tewodros Taffese[1*] and Birhanu Zemadim[2]

[1]Bahir Dar University, Bahir Dar, Ethiopia, [2]International Crops Research Institute for the Semi- Arid Tropics (ICRISAT), Bamako, Mali:

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Sustaining upland agriculture and food security has been very much constrained by continuing land degradation brought by soil erosion due to lack of effective rainwater management strategies. Hydrological models are essential to understand the hydrological response of a catchment. The current paper focuses on hydrological modeling of catchment with SWAT model using its two versions, SWAT-CN and SWAT-WB. In addition, the impact of existing land and water management practices on runoff yield and the applicability of the model for the region were also addressed. The model was applied on two watersheds, Mizewa (27 km^2) and Gumara (1278 km^2) that are located in the upper Blue Nile basin of Ethiopia in Fogera district. The results indicated that the model performance was in acceptable range and there are no many changes to predict the flow by the two versions of SWAT model. HRU analysis indicated that agricultural land were the most runoff generating areas. Soil evaporation compensation factor and curve number are the two most sensitive parameters indicating effective rainwater management interventions has a great impact in reducing soil erosion and land degradation.

Keywords: SWAT-CN; SWAT-WB; HRU; Mizewa catchment; Gumara catchment; Blue Nile Basin; Ethiopia

INTRODUCTION

The high lands of Ethiopia are characterized by relatively high rainfall. However, this could not be retained in the form of surface and ground water. Instead the intense precipitations were lost in the form of runoff resulting soil erosion and degraded environment. Recently, the Ethiopian Strategic Investment Frame Work for Sustainable Land Management (ESIF-SLM, 2010) reported that lack of land and rainwater management strategies resulted in improper land use and severs consequent in livelihood though the highlands of Ethiopia.

A large body of research evidence has established that significant potential exists to increase agricultural productivity that are producing far below potential through sustainable rainwater management strategies (Bossio et al., 2007; Molden et al., 2007). Sustainable rainwater management (RWM) is achieved if only there is a focus on the entire watershed and community-based approaches are adopted. Understanding the hydrological processes within the watershed has been crucial to make decisions on better RWM. The current study focused on hydrological modeling of catchments using SWAT model to estimate key hydrological fluxes and to analyze the impact of existing land use on runoff and erosion yield. It also focuses on reviewing existing RWM practices, water use and proposing future RWM interventions.

METHODS

Mizewa River was selected as the study catchment. The river flows roughly south-north. A bridge located on the main road from Woreta to Debre Tabor (11^{o}55.765'N, 37^{o}47.539'E, altitude 1,862 masl), just to the west of Woji provides a good point for flow monitoring. The catchment to this point was 27.0 km^2.
Gumara watershed is highly cultivated region in Ethiopian

*Corresponding authors: E-mail: ttaffese@gmail.com
Phone: +251-912-10-06-10

Figure 1: Multi-use of Mizewa River (i.e. for drinking, irrigation, fishing, and livestock respectively)

Figure 2: Existing RWM practices and location of stone bunds greater than 100 m length

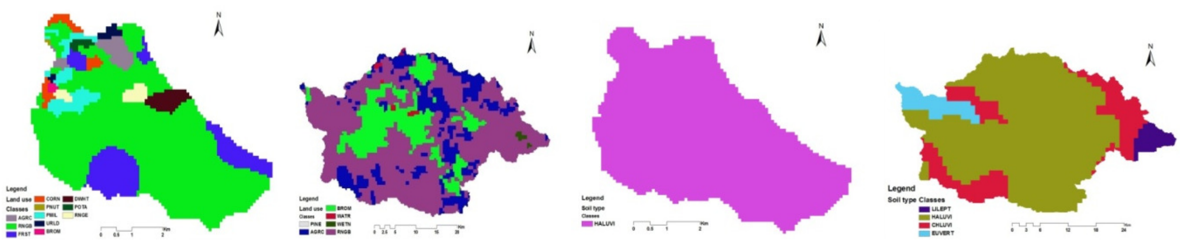

Figure 3: Land use and soil map of Mizewa and Gumara watershed respectively

highlands around 50 km from Bahir Dar. It has 1279 km^2 watershed area draining to Lake Tana. Elevation of the watershed determined from 90 m DEM ranges 1797 to 3708 masl Figure 1.

The source of water in Mizewa watershed (27 km^2) was identified through field observation and found to be ground water and river flow. The ground water was used for drinking water supply through hand-dug-wells. In the lowland areas, the farmers use the river for irrigation of Khat plot along its bank which has been a common practice recently. The practice endangered the existence of the already scare water in the area. The river was also used for drinking water, fishing and livestock. The farmers in the middle land area of the watershed use Mizewa and Gindenewer Rivers for their production of onion, potato, tomato, Khat and vegetable. Irrigating the fields was accomplished through gravity by diverting water and also pumping from Mizewa and Gindenewr Rivers Figure 2.

A detail review of existing RWM practices (watershed characterization) including mapping of locations were performed in Mizewa watershed through surveying and field observation. Discussions were also performed with 10 stakeholders and 30 local farmers on the efficiency of existing RWM practices. The farming practice in the midland and highland watershed is on sloppy and stony ground. The local farmers protected their farmland using stone bunds and contour plowing which probably reduces upland erosion. The bund also acts as farm boundary to protect the entrance of livestock. It seems that in the entire watershed the concept of rainwater harvesting is at an infant stage, though water scarcity and catchment degradation are serious threats. The efficiency of the pond was also poor in which water may not be properly stored. Lack of proper maintenance to the pond resulted in leakage and accumulation of debris at the bottom. Figure 3.

The potential RWM interventions were identified by consulting local farmers and other stakeholders who might think what is needed and feasible in the future. Various sources were also consulted; this includes Agricultural Bureau of the Woreda and reports of different

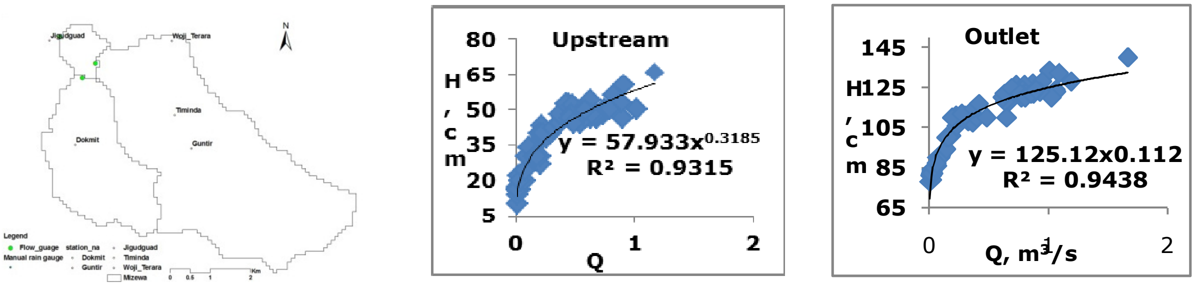

Figure 4: Locations of recently installed stations and rating curve for Mizewa watershed developed for Mizewa river at upstream and outlet of the catchment.

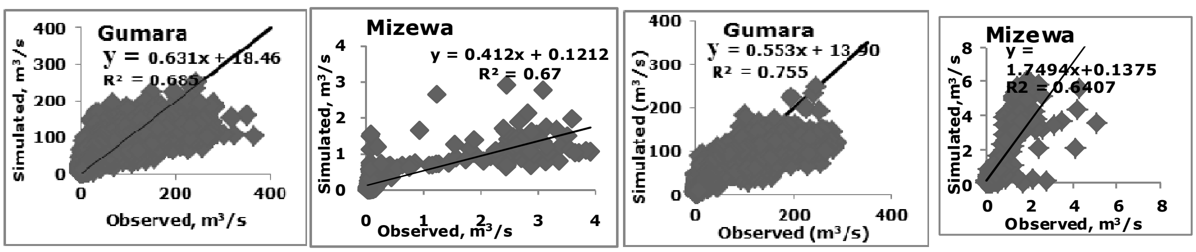

Figure 5: Simulated versus observed flow for calibration and validation period respectively

workshops organized by NBDC program. As a result, level fanya juu, grass strip along contour, check dam, hand-dug-wells with treadle pump, diesel pump with rivers, roof water harvesting together with ponds, diversification of crops, fallowing, well designed stone bund, planting scattered tree on farm land, hill side terrace (with or without trench), forestation, and planting high yielding crops like citreous fruit were also proposed. Some practices were suitable for all landscapes and some others were specific. The watershed was divided in to 3 landscapes and 10 farmers per landscape (total of 30 farmers) were asked to select RWM intervention from the potential for their land and discussed under result section.

SWAT is physically based, conceptual and computationally efficient model that operates on a daily time step at basin scale (Arnold et al., 1998, 2000; Neitsch et al. 2001). It was designed to predict the impact of watershed management practices on hydrology with varying soils, land use and management conditions (Neitsch, et al., 2005). SWAT-CN assumes the runoff occurs whenever the rainfall intensity is greater than the rate of infiltration. In SWAT-WB Method, once the soil in the area saturate to the surface, any additional rainfall that falls irrespective of intensity becomes overland flow. SRTM was obtained from United States Geographic Survey (USGS) with 90x90 resolutions. It is one of essential spatial input for SWAT model which defines well the topography of the area. Soil map prepared by Food and Agricultural organization (FAO) were used for the watershed while land use map were surveyed using high resolution hand-held Geographic Positioning System (GPS) for Mizewa watershed. As a result, 11 land uses and single soil group was identified for Mizewa watershed while 6 land use 4 soil groups were identified for Gumara watershed. Figure-3 presents the result of land use and soil map. The land use map, soil map and slope were overlaid to create Hydrologic Response Units (HRUs). Hydro-meteorological data were obtained from nearby and recently installed stations (1-year) in Mizewa watershed. Rating curve were developed for Mizewa river at upstream and outlet of the catchment (Figure 4).

The model were developed using spatial data (DEM, land use, soil) and hydro-meteorological data. Model comparison was done prior to parameter optimization and the result presented in Table1 below.

After this initial findings parameter sensitivity analysis, model calibration and validation were done for Gumara and Mizewa watershed using SWAT_CN method. For the case of Mizewa, watershed the model were calibrated at the upstream gauging station and validated at the outlet of the catchment while for the case of Gumara watershed, 1995 to 2004 data used for calibration, 2005 to 2009 data used for validation and 1992 to 1994 data used to warm-up the model. And hence reasonable results were obtained (Figure 5, 6 and Table 2).

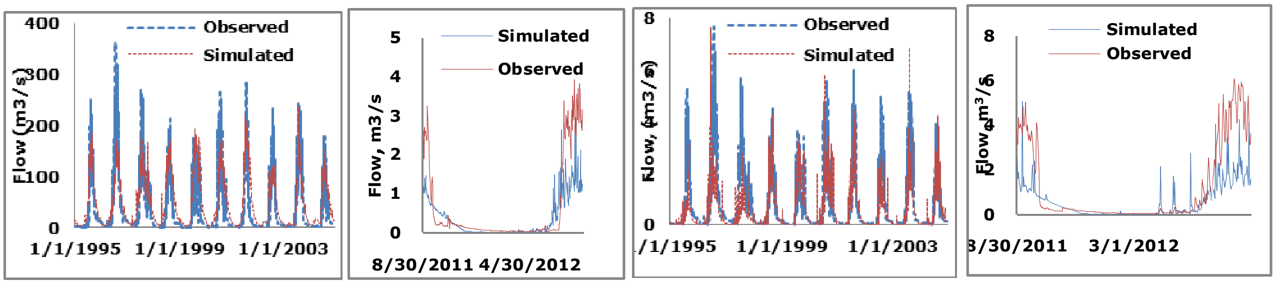

Figure 6: Flow simulation for calibration and validation periods of Gumara and Mizewa respectively

Table 1: Model efficiency before calibration

Objective Function	SAWT_CN		SWAT_WB	
	Gumara	Mizewa	Gumara	Mizewa
Nash-Sutcliffe efficiency (Ens)	0.295	0.25	0.294	0.19
Coefficient of Determination (R2)	0.427	0.42	0.409	0.40

Table 2: Model efficiency for calibration and validation periods of Gumara and Mizewa respectively

Objective function	Gumara	Mizewa	Gumara	Mizewa
Nash-Sutcliffe efficiency (Ens)	0.67	0.50	0.66	0.62
Coefficient of Determination (R^2)	0.68	0.54	0.76	0.66

RESULT

The farmers select RWM what they think might work in the future for their land based on the landscape. In low land, 50 % of the farmers selected diesel pump with river and 20% of them selected well-designed stone bunds due to irrigation of Khat plots in the area and stones were available intensively. Diesel pump has high initial cost and fuel and maintenance as life time cost. However, since Khat is expensive and has great income, the farmers purchase the pump in group and use it having their own fuel cost. Only labor cost is required to construct stone bunds. In middle land, 60% of the farmer's select roof water harvesting together with ponds while 20% of them select diesel pump with river due to Awramba community has metallic roof houses. Furthermore, farmers have Khat plots to some extent. In order to use roof water harvesting, only labor cost for pond excavation and plot of land for the pond is required. At the high land of the watershed, 50% of the framers select hill side terrace and 30% of them selected forestation since the land was much degraded at this landscape and they think hill side terrace and forestation as feasible interventions to regenerate the land. Only labor cost is required to construct hill side terrace, plants are continuously given by local government for forestation. In all of the cases, farmers are the labors for their own land and very cheap.

Predicted flow was found to be most sensitive for soil, land use properties indicating RWM interventions has a significant impact on reducing soil erosion and degradation. The most sensitive parameters include; soil compensation factor (ESCO), initial SCS curve number II (CN2) and ground water parameters: like threshold depth of water in shallow aquifer for "revap" or percolation to deep aquifer to occur (REVAPmin) and groundwater "revap" coefficient (GW_REVAP). The comparison of observed and calibrated flow indicated that there was a good agreement between observed and calibrated flow yielding higher model efficiency. The result of the two models was compared for Gumara and Mizewa watershed with short -term and long-term records there are no many changes to predict the flow.

The surface runoff prediction for each HRU was analyzed for Gumara watershed. Areas with Halpic Luvisols contributed the least surface runoff to the reach. Halpic Luvisols has the highest sand content, the lowest clay content and high hydraulic conductivity of all soil in Gumara watershed. Areas with Chromic Luvisols contributed large amount of surface runoff. Chromic

Luvisols has low hydraulic conductivity and high clay content of all soil with in the watershed. Halpic Luvisols was the only soil group in the case of Mizewa watershed. Areas covered with agricultural land produced large amount of surface runoff of all land uses in Mizewa and Gumara watershed while areas covered with Meadow Brome grass (BROM) and rang-brush (RNGB) contributed small amount of runoff with in the watersheds.

CONCLUSIONS AND RECOMMENDATIONS

In this research, emphasis has been given to hydrological modeling of a catchment using SWAT model. The model performance criteria indicated the model were good and have acceptable performance. Hence, the model can be applied to the watersheds. The result of sensitivity analysis indicated ESCO and CN2 were the most sensitive parameters. Thus, further detail study on soil and land use could possibly improve model performance and accuracy. HRU analysis result indicated agricultural land were the most runoff generating areas. Hence, training farmers through innovation platform in order to adopt selected RWM interventions will result in better agricultural productivity. Further study is recommended on erosion hotspot areas, since not possible to implement RWM interventions for the entire watersheds.

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