Simulation of Stream Flow Using Soil and Water Assessment Tool (SWAT) in Upper Ayeyarwady Basin

Su Wai Aung[#1], and Nilar Aye[*2]

***Abstract*—**Stream flow is very important in water cycle and useful water resources to sustain human life. Estimation and prediction of the stream flow is used to make stable water use and flood control. This paper focuses on the stream flow estimation for the Upper Ayeyarwady Basin. The area of river basin was delineated into 25 subbasins using Soil and Water Assessment Tool (SWAT 2012) Model. The semi-automated Sequential Uncertainty Fitting (SUFI2) and SWAT calibration and uncertainty program (SWAT-CUP) were used to calibrate the model parameters. The SWAT model simulation is done for the periods of 2003-2013 while it used land use information in 2010. The coefficient of determination (R^2) and Nash Sutcliffe Efficiency (NS) values for daily stream flow were obtained as 0.87 and 0.85 respectively for calibration and 0.61 and 0.56 respectively for validation.

***Keywords*—**Sensitivity Analysis, Stream Flow, SWAT-CUP, SUFI2.

I. Introduction

A watershed is comprised of land areas and channels and may have lakes, ponds or other water bodies. The use of a hydrological model to simulate the stream flow plays a fundamental role in this study. Hydrological models are significant instruments for water resource managements, development and future planning. Therefore, many models have been applied to hydrological modeling and water resource management. Among the hydrological models, the Soil and Water Assessment Tool Model (SWAT) is used in this study. SWAT model was developed by United States Department of Agriculture-Agricultural Research Service (USDA-ARS) and it is a type of semi-distributed model that subdivided the watershed into the smaller subbasins and hydrologic response units (HRUs). It has been successfully used to simulate flows, sediment, and nutrient loadings of watershed. The objective of this study is to build up a hydrological river basin model for the Upper Ayeyarwady Basin to estimate stream flow of the basin.

II. Study Area

The Ayeyarwady River flows through the heartlands of Myanmar. It is Myanmar's largest river (about 2170 km or 1350 miles long) and the main transportation route in of Myanmar depends upon the Ayeyarwady river basin. It originates at the confluence of the Mali Hka and N'Mai Hka rivers in Kachin State. Only the upper part of the Ayeyarwady River is modelled in this study. The area of watershed is 169,917 km^2 and lies between north latitude 20° 22' and 28° 31' and east longitude 94° 56' and 98° 45'. It is covered by Kachin State, Mandalay Division, south eastern part of Sagaing Division and western part of Shan State. Figure.1 shows the location of study area.

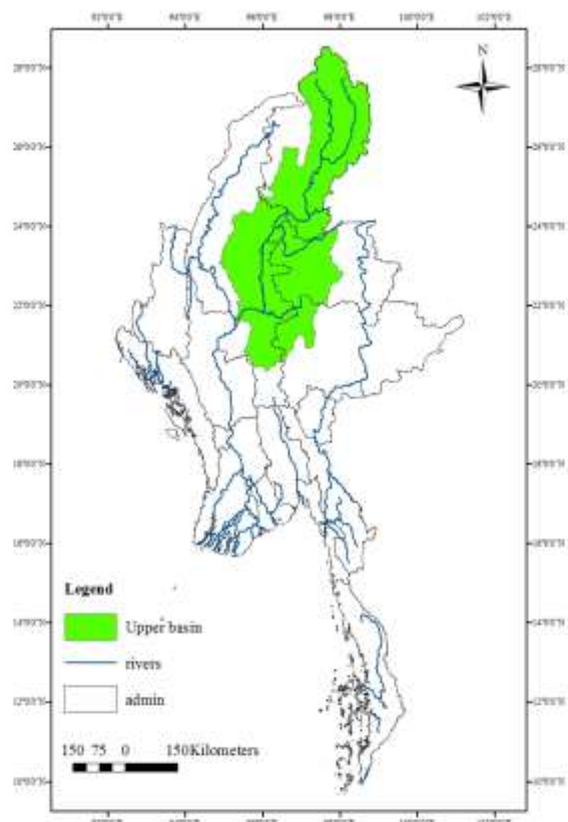

Fig.1 Location map of study area

III. Methodology

A. Hydrologic Models

A number of watershed hydrologic models, namely the Hydrological Simulation Program-Fortran (HSPF),

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Hydrologic Modeling System (HEC-HMS), Chemical, Runoff, and Erosion from Agricultural Management Systems (CREAMS), Erosio-Productivity Impact Calculator (EPIC), Agricultural Non-Point Source (AGNPS) and Simulator for water Resources in Rural Basins (SWRRB) have been extended for basin assessment. Even though these models are helpful, they have their limitations. Some models cannot perform continuous-time simulations without a consistent scale, some are unable to characterize the watershed with enough spatial detail and some cannot provide an optimized number of sub-watersheds. Compared with other models, SWAT can simulate changes in land management, gives high level of spatial detail, is capable of continuous-time reproduction and can perform efficient computation with limitless number of watershed sections.

B. Description of SWAT Model

To simulate the stream flow for the upper Ayeyarwady basin, the semiphysically based, semidistributed, basin-scale model SWAT was selected (SWAT 2012). It is an open source watershed model that is continuously developed and refined by the USDA-Agricultural Research Service and scientists at universities and research agencies around the world. This model requires specific information about weather, soil properties, topography, vegetation and land management practices occurring in the watershed. The physical process associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modelled by SWAT using this input data. Simulation of very large basin or a variety of management strategies can be performed without excessive investment of time of money. SWAT allows a number of different physical processes to be simulated in a watershed. For modelling purpose, a watershed may be partitioned into a number of sub-watersheds or subbasins. The use of subbasins in a simulation is particularly beneficial when different areas of the watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology.

C. Model Input Data

SWAT model requires Digital Elevation Model (DEM), Land Use map, Soil map and meteorological data in daily scale. The brief methodology for preparation of the data is described as follows:

1) Digital Elevation Model (DEM): DEM was obtained from global DEM with 30m resolution. It was used as input for automatic watershed delineation and stream generation. The DEM map for the study area prepared to use with SWAT 2012 is given in Figure 2.

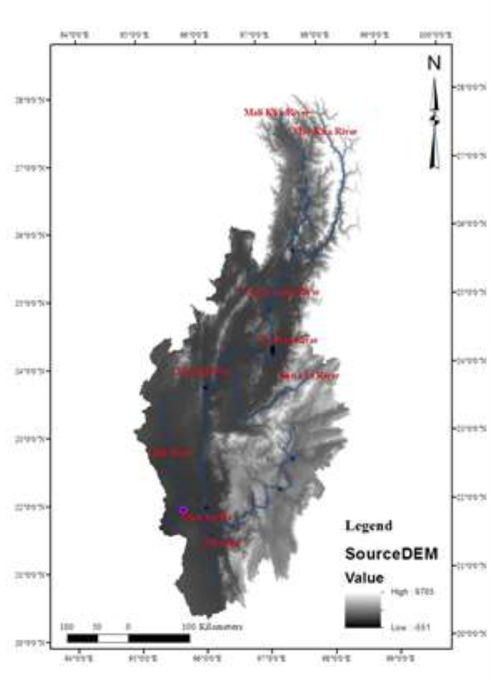

Fig. 2 DEM map of Upper Ayeyarwady Basin

2) Land Use/Land Cover Map: The study area has been classified into five major land use classes namely agriculture (16.81%), waterbody (0.09), scrubland (27.31%), evergreen forest (34.62%) and deciduous forest (21.17%). It has shown in Figure 3.

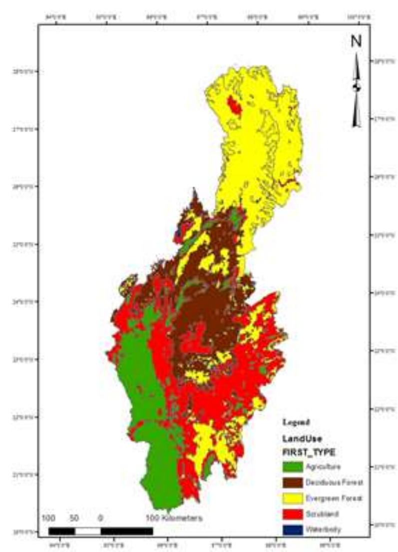

Fig. 3 Land Use map for Upper Ayeyarwady Basin

3) Soil Data: The digitized soil map was used in SWAT and the soil properties for different layers were fed as the input data for the soils. The soil types in this watershed are converted to hydrologic soil group: A (31.79%), B (24.06%), C (11.68%), D (30.56%) and waterbody (1.91%). Soil map of the study area has shown in Figure 4.

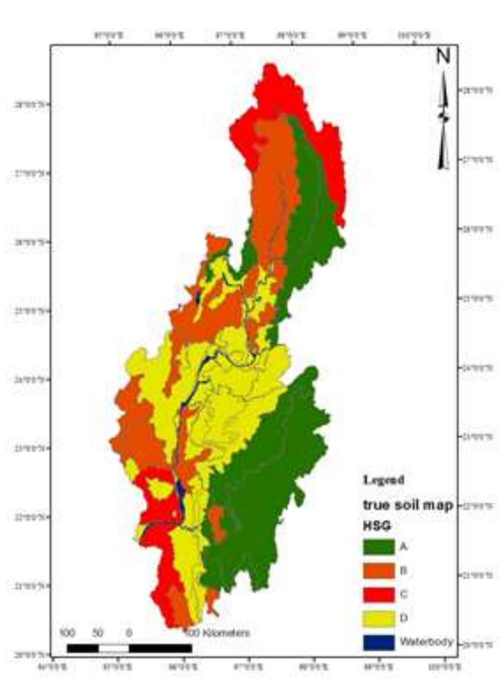

Fig. 4 Soil map for Upper Ayeyaewady Basin

4) Weather Data: Daily weather data from nine stations; Putao, Myitkyina, Katha, Shwebo, Mandalay, Sagaing, Loilem, Homalin and Kengtung were available for this study.

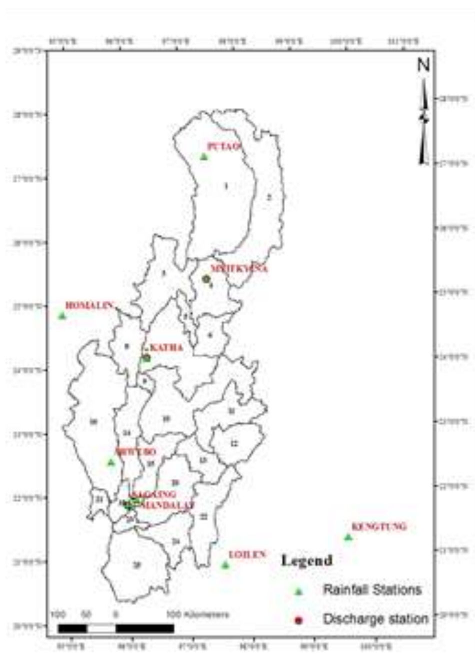

Fig. 5 Location Map of Rainfall and Discharge Stations in Upper Ayeyarwady Basin

5) Stream Flow Data: Three gauges of discharge stations are used in this study namely Myitkyina, Katha and Sagaing. The location map of rainfall stations and discharge stations are shown in Figure 5.

IV. Results and Discussions

According to SWAT model, the following main data were used: DEM, land use, soil and weather data. First the maps (e.g. DEM, land use and soil) were imported in SWAT 2012. In the next step, land use and soil map were overlaid for the watershed. In addition, the weather data were defined. Finally, it was run and simulated 11-year period with 3-years warm-up from 2003 to 2013. Figure 6 represents the hydrologic cycle for this study and TABLE I is the detail results of simulation in the SWAT. These results obtained after the model run.

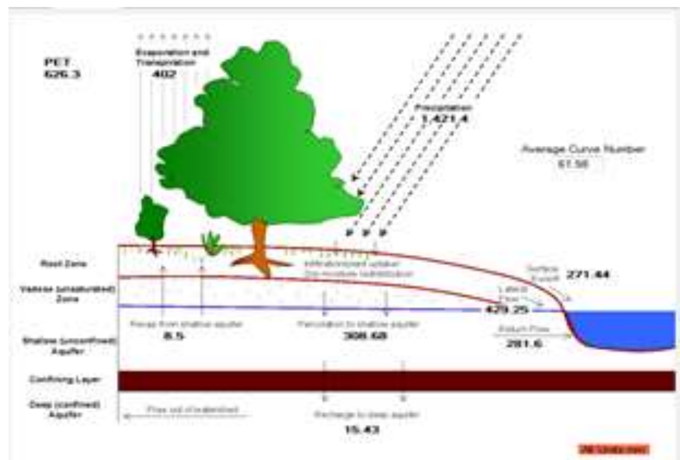

Fig.6 Hydrologic Cycle for the Upper Ayeyarwady by SWAT Model

TABLE I: Simulation Details of SWAT Model Set-up

General Details	
Simulation length (years)	11
Warm up (years)	3
Hydrologic response units	63
Subbasins	25
Watershed area (km^2)	169,917
Hydrology (water balance ratio)	
Stream flow/precipitation	0.69
Base flow/total flow	0.72
Surface runoff/total flow	0.28
Percolation/precipitation	0.22
Deep recharge/precipitation	0.01
ET/precipitation	0.28
Hydrological parameters (all units in mm)	
Average curve number	61.98
ET and transpiration	402
Precipitation	1,421.4
Surface runoff	271.44
Lateral filow	429.25
Return flow	281.6

A. Model Calibration and Validation

SWAT-CUP is a computer programfor calibration of SWAT model. This program links GLUE, Parasol, SUFI 2, MCMC and PSO procedures to SWAT. It enables sensitivity analysis, calibration, validation and uncertainty analysis of a SWAT model. The program structure approach is shown in Figure 7. TABLE II describes sensitivity analysis of parameters. The most sensitive parameters are soil bulk density (SOL_BD) and available water capacity of the soil layer (SOL_AWC) because of P-value close to 0 and t-stat bigger than other parameters. Table III shows the values of P and R factors R^2 and NS in calibration and validation.

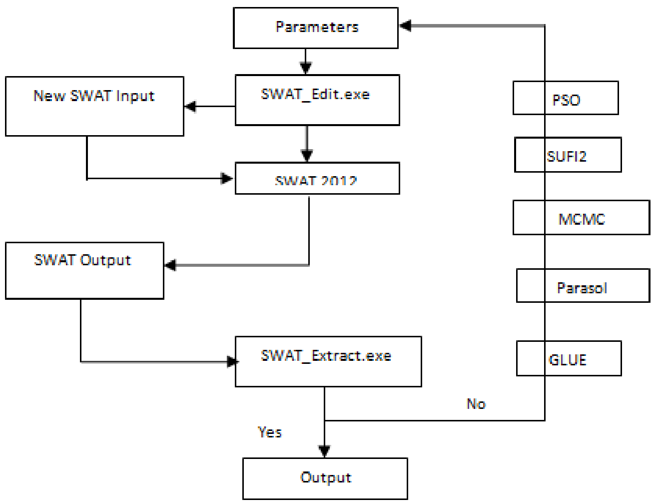

Fig.7 SWAT-CUP Approach for Stream Flow

TABLE II: SENSITIVITY ANALYSIS OF PARAMETERS

Index	Parameter	t_stat	p_value	Process
1	SOL_Z	0.29	0.77	Soil
2	SOL_ZMX	0.53	0.6	Soil
3	ALPHA_BF	0.66	0.51	Groundwater
4	CH_K2	0.73	0.47	Channel
5	HRU_SLP	0.79	0.43	Geomorphology
6	GWQMN	1.02	0.31	Groundwater
7	CN2	1.19	0.23	Runoff
8	GW_DELAY	1.22	0.22	Groundwater
9	SOL_K	1.38	0.17	Soil
10	OV_N	1.54	0.12	Geomorphology
11	CH_N2	1.68	0.09	Channel
12	ALPHA_BNK	1.69	0.09	Channel
13	SOL_AWC	2.75	0.01	Soil
14	SOL_BD	5.59	0.00	Soil

Comparison of observed and simulated stream flow results are presented in TABLE III. Figure 7 shows a matching fluctuations between the observed and simulated stream flow.

TABLE III: COMPARISON OF OBSERVED AND SIMULATED STREAM FLOWS

Time	Observed (m^3/s)	Simulated (m^3/s)
2003	14050	16134
2004	14620	20104
2005	18610	19491
2006	13530	19767
2007	12050	15108
2008	12250	20114
2009	16120	24782
2010	11298.5166	7364
2011	5780.6768	5796
2012	9764.5166	6305
2013	9760.1289	8851

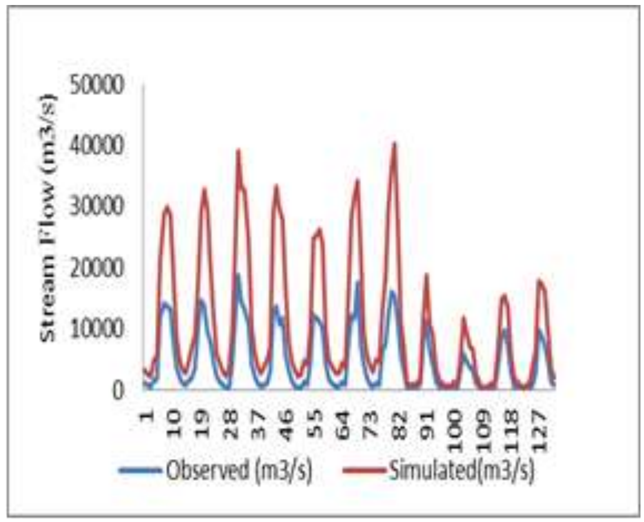

Fig.7 Observed and simulated stream flow in Upper Ayeyarwady Basin

TABLE IV: STATISTICAL ANALYSIS OF STREAM FLOW SIMULATION

	Variable	P-factor	R-factor	R^2	NS
Before calibration	FLOW_OUT	0.35	0.84	0.53	0.28
After calibration	FLOW_OUT	0.59	0.54	0.87	0.85
Validation	FLOW_OUT	0.63	0.49	0.61	0.56

V. CONCLUSION

In this study the well-established semi-distributed model SWAT, in combination with the GIS interface ArcSWAT was successfully applied to simulate the stream flow the upper Ayeyarwady basin. SWAT-CUP program and SUFI-2 algorithm are also used for calibration and sensitivity analysis. The simulated stream flows (between 2003 and 2013) at the Sagaing outlet are 16134 m^3/s, 20104 m^3/s, 19491 m^3/s, 19767 m^3/s, 15108 m^3/s, 20114 m^3/s, 24782 m^3/s, 7364 m^3/s, 5796 m^3/s, 6305 m^3/s, 8851 m^3/s. Comparison of observed and simulated stream flows are shown in TABLE III. The model shows a good performance in the hydrologic simulations, especially during the calibration period. After calibration and validation periods, the P-factor was obtained close to 1 with 0.51 and 0.63 respectively. On the other hand, the calibration and validation model shows better performance of model with Nash and Sutcliffe Efficiency (NS) value of 0.85 and 0.56 respectively. And also, coefficient of determination (R^2) value of 0.87 for calibration and 0.61 for validation. This indicates that the physical processes in the upper Ayeyarwady basin are well represented by SWAT model.

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REFERENCES

[1] M.Winchell, R. Srinivasan, M. Di Luzio, J.Arnold March, 2013. *Soil and Water Assessment Tool. User's Manual. Version 2012*.

[2] M.Winchell, R. Srinivasan, M. Di Luzio, J.Arnold March, 2013. *Soil and Water Assessment Tool, Input/Output File Documentation. Version 2012*. Grassland, Soil and Water Research Laboratory, Agricultural Research Service.

[3] Nathan S. Bosch, J. David Allan, David M. Dolan, Haejin Han, R. Peter Richards. Application of the Soil and Water Assessment Tool for six watersheds of Lake Erie: Model parameterization and calibration.

[4] R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev, in press.

[5] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

http://dx.doi.org/10.1109/TJMJ.1987.4549593

[6] M. Young, the Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.