Rainfall-Runoff Modelling of Myitnge River Basin using SWAT Model

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Abstract: This study was set out with aim to test the performance of SWAT hydrological model on Myitnge River Basin and to find out and set up the highly sensitive parameters for the basin. The model was auto-calibrated and validated using SWAT-CUP SUFI2 software. Nash and Sutcliffe Efficiency (NSE) and Coefficient of Determination (R2) were considered as main objective functions during calibration and validation. According to the analysis, threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN.gw), Manning's n for overland flow (OV_N. hru), Average slope steepness (HRU_SLP. hru), Manning's "n" value for the main channel (CH_N2.rte), threshold depth of water in the shallow aquifer for "revap" to occur (REVAPMN.gw), and Average slope length (SLSUBBSN. hru) were figured out to be the highly sensitive parameters. Available hydrological data from 2005 to 2013 was split into two groups for calibrating and validating parameters of the model. The year 2006 was used as warm up period. The model was calibrated at Shwesaryan station both on daily and monthly time scale. The average daily calibration showed good model response with NSE 0.74 and R2 0.8 respectively at year 2008. Also, the monthly validation showed good model fit with NSE of 0.63 and R2 0.72 from year 2005 to 2013 respectively. Principally, the implementation of SWAT model in simulating streamflow at Shwesaryan station can be rated as good and the calibrated model could be used for runoff simulation for power potential estimation and other water related work.

***IndexTerms* – Myitnge, SWAT, SUFI2, NSE, R^2.**

I. INTRODUCTION

Higher standards of living, demographic changes, land and water use policies, and other external influences are increasing pressure on local, regional and national water supplies requisite for irrigation, power generation, industrial uses, domestic purposes, and the environment.[1] There is an urgent need to study the Rainfall-Runoff behavior of the area so as to understand the Hydrological phenomena with regards to their changes in the period of time and how to make an impact on those changes. Hydrological modelling is an important and effective tool for research hydrologists as well as the practicing engineers involved in planning and development of integrated approach for management of water resources.[2] Soil and Water Assessment Tool (SWAT) is a watershed model which is used to evaluate stream flow, transportation of sediment and nutrients. SWAT , developed by Agricultural Research Services of USDA, has gained popularity in the recent past worldwide, witnessing continued refinement and is being used in the present study to quantify basin runoff.[3]The main purpose of the study is to perceive the Rainfall-runoff behavior of the Myitnge river basin and to figure out the most sensitive parameters with the used of SWAT model.

The main datasets needed to formulate and run the model include Digital Elevation Model (DEM) which plays an important role in the distribution and flux of water and energy within natural landscapes, land use, soil and climatic datasets. At first, year 2006 of simulation was considered as warm up period. SWAT-Calibration and Uncertainty Programs Sequential Uncertainty Fitting (SUFI2) was applied for calibration and validation of the model. Calibration was carried out for the year 2008 where a set of parameters commonly responsible for basin Hydrological response in Myanmar conditions were used for model adjustment. Validation was also executed for period of nine years (2005-2013) in order to verify the response of basin using the calibrated fitted values. The model performance was analyzed using the statistical parameters such as Nash Sutcliffe Efficiency (NS) and coefficient of correlation (R^2).

II. STUDY AREA

The Myitnge river originates from the Ayeyarwaddy-Thanlwin watershed and flows westwards through northern Shan Plateau of eastern Myanmar and eventually flows into the Ayeyarwady at Amarapura. The study area has a total area of 29,000 sq.km and its outlet is located near Mandalay Division which is the third capital of Myanmar as shown in (Fig 1). It is located within 20°48'4.44"N, 23°48'21.60"N and 95° 8'0.03"E, 98°29'27.60"E. The climate of this area is semi-arid and annual precipitation is about 1,412 mm. Daily temperature ranges from 27°C to 29 °C in summer and 18°C to 25 °C in winter. Myitnge has both abundant water resources and steep slopes. If harvested and utilized properly, the energy produced can help to meet the local demand and to raise the quality of the living standards of the local people.

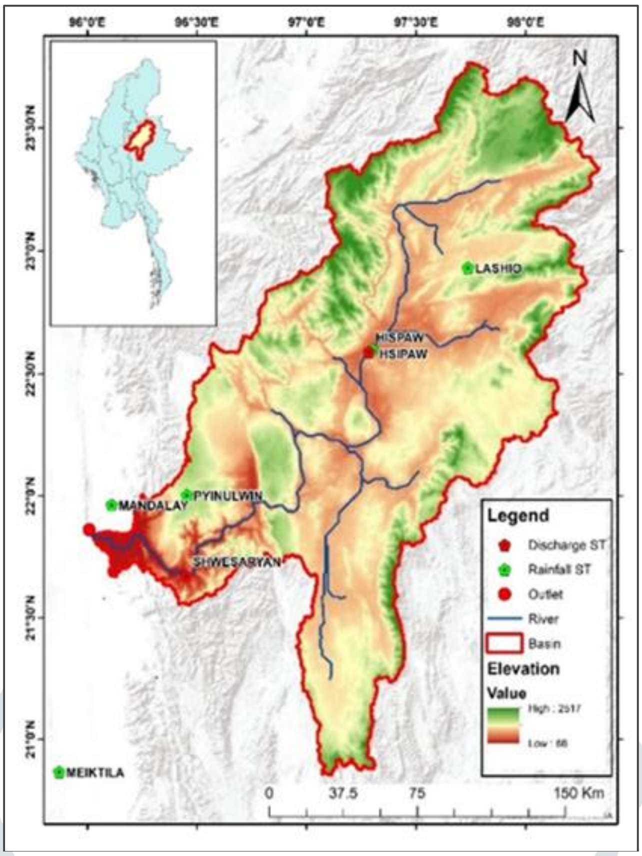


Figure 1 Location Map of Study Area

III. Methodology

3.1 Description of SWAT Model

The SWAT (Soil and Water Assessment Tool) distributed model was conducted by the Agricultural Research Service (ARS) of the United States Department of Agriculture (USDA). It facilitates prediction of the long-term impacts of soil management practices on water, sediments, and pesticide levels in large hydrographic basins with incompatible types of soils, land use, and management practices [4] The model satisfies the integration of several physical or physicochemical processes in a watershed, which are the following criteria: 1) It can be used for conducting Hydrological assessment studies that predicts the effect of land management practices on the water and sediment quantity and quality in large complex watershed. 2) It can be used as a potential tool for runoff, sediment, nutrients and pesticides predictions both from rural and urban land uses.3) It can be used as a media to study the impacts on water quality especially the long-term non-point source pollution on the basis of different land management practices 4) It is a freely available model. Its advantage is that it can run for a very long time period of 150 to 300 years impact. 5) It is a useful tool in areas like water resource planning, management and decision-making policies.

In SWAT model, the river basin is divided into a number of sub-basins and then divided further into a number of HRUs (Hydrological Response Units). For every model in SWAT, the first and required step is the hydrological water balance. This water balance is the driving force behind every process that happens in the river basin. A water balance equation is given as:

$$SW_f = SW_i + \Sigma (P_{day} - R_{surf} - Q_{Seep} - E_a - D_{gw}) \quad [1]$$

Where SW_f = final water content in soil (mm water); SW_i = initial water content in soil on i day (mm water); R_{surf} = surface runoff on i day (mm water); Q_{seep} = water entering the unsaturated zone of soil on i day (mm); P_{day} = precipitation on day I (mm water); D_{gw} = return flow on day i (mm water); and E_a = amount of evapotranspiration on day i (mm water).[5]

3.2 SWAT CUP Model

SWAT- CUP is a SWAT Calibration Uncertainties Program, which is developed to analyze the prediction uncertainty of SWAT model calibration and validation results. Automated model calibration requires that the uncertainty model parameters are systematically changed, the model is run and the required outputs (corresponding to measured data) are extracted from the output files. The main function of an interface is to provide a link between the input/output of a calibration program and the model. In this study, the program SUFI-2 was used for model calibration and validation and sensitivity analysis. Workflow diagram of methodology of present study is shown in Fig 2.

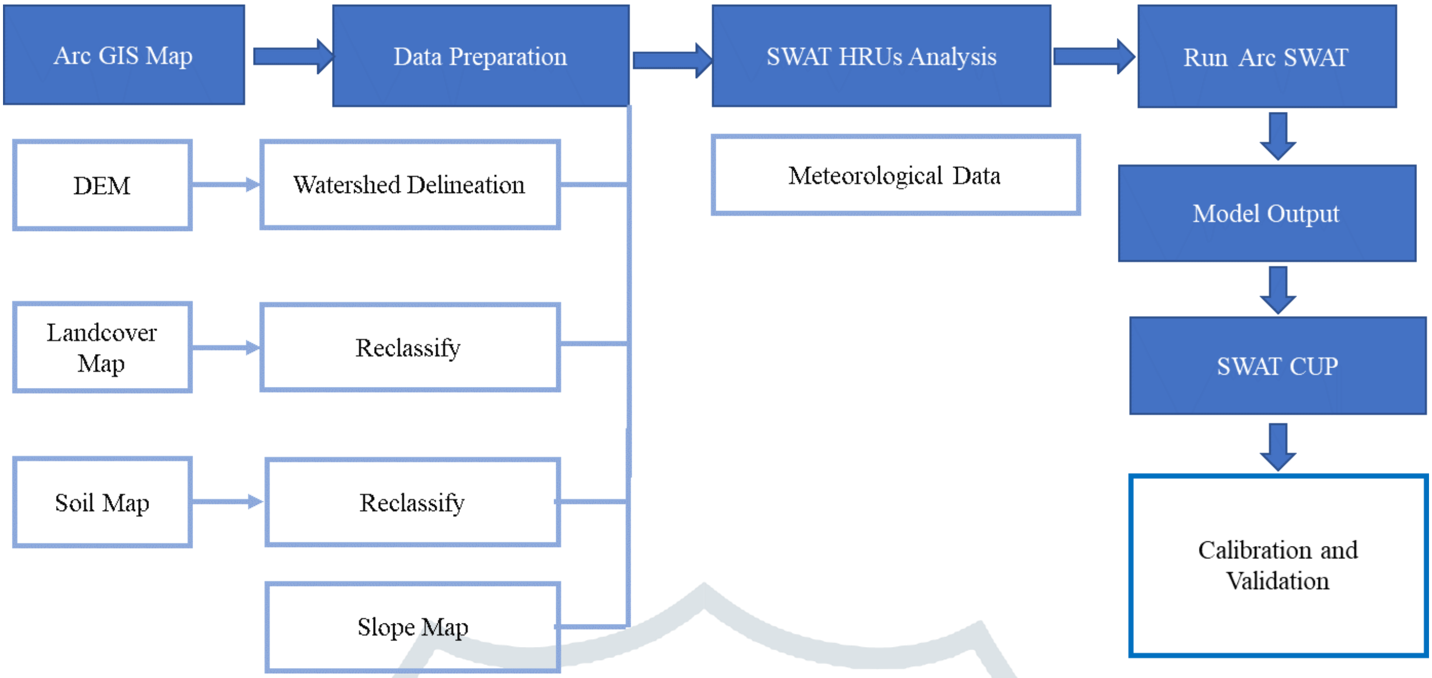
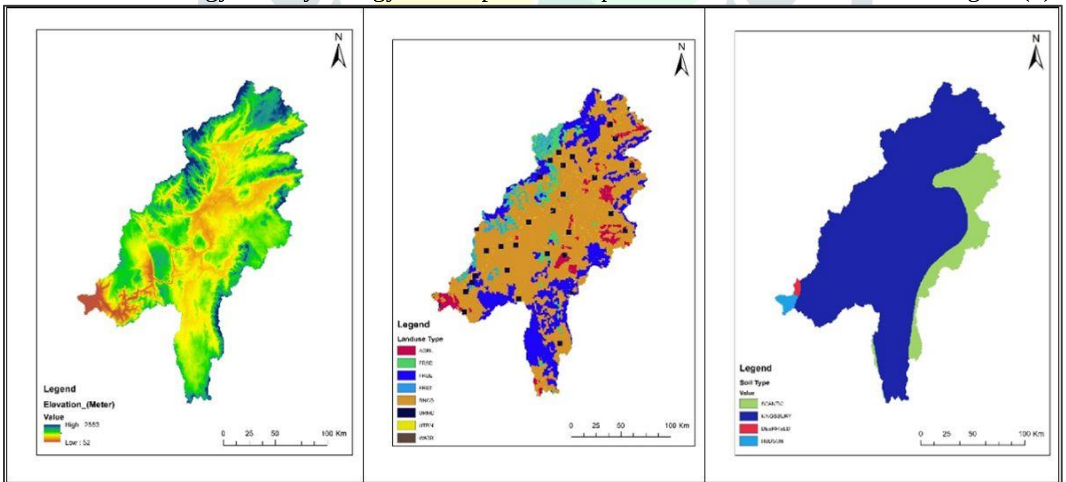


Figure 2 Workflow Diagram of SWAT simulation

3.3 Model Input Data

The major geospatial input data includes Digital Elevation Model (DEM), soil data, land use and stream network layers. DEM is the geospatial raster data containing the continuous elevation values a topographic surface by the array of cells or pixels. It is used in ArcSWAT to create the watersheds and river networks and streams, sub-basins, and parameters for Hydrological Response Units (HRUs) analysis. In this study, 30-meter resolution of ASTER GDEM is processed in a GIS environment using Watershed Delineation and HRUs analysis. In this study, land use and land cover data were acquired from the SERVIR MEKONG LAND COVER image (http://servir-rlcms.appspot.com/, n.d.). This data is used for HRU definition, and then allocate Curve Number (CN) to land areas for estimation of runoff and hydrological analysis. The soil data for the study area was extracted from FAO (Food and Agricultural Organization of the United Nations) Digital Soil Map of the World (DSMW) (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/en/, n.d.). This soil data also used for HRU definition and hydrological analysis. The daily weather variables used in this study are daily rainfall, minimum and maximum air temperature for the period of 2005 to 2013 are collected from the Department of Meteorology and Hydrology. The input data required for the model as shown in figure (3).



(a) DEM of Myitnge River Basin	(b) Landcover Map of Myitnge River Basin	(c) Soil Map of Myitnge River Basin

Figure 3 Data input to the model

IV. Result and Discussion

4.1 Performance Evaluation

The Model performance is evaluated at the Shwesaryan streamflow station. The Hydrological performance was checked with the efficiency criteria and error parameter computations. The Model performance was calculated using Coefficient of Determination(R^2) and the Nash-Sutcliffe efficiency (NSE) and measure at daily and monthly time scales.

For R^2, the closer to 1 R^2 is, the better the simulation result is. For NS, the simulation results are good when NS is larger than 0.75; the simulation results are satisfactory when NS is larger than 0.36 and smaller than 0.75; simulation results are not good when NS is smaller than 0.36. The R^2 and NSE can be calculated by the following equations 1 and 2:

$$R = \frac{[\sum(Qmi-\overline{Qm})(Qsi-\overline{Qs})]^2}{\sum(Qmi-\overline{Qm})^2 \sum(Qsi-\overline{Qs})^2} \qquad \text{Eq. 1}$$

$$NSE = 1 - \frac{\sum(Qm - Qs)^2 i}{\sum(Qmi - \overline{Qm})^2} \quad \text{Eq.2}$$

Where Q_m is the measured discharge value; Q_s if the simulated discharge; Q_m (bar) is the average measured discharge; and Q_s (bar) is the average discharge simulated. [6]

4.2 Model Calibration and Validation

The main purpose of the calibration of the model is to minimize the difference between the observed and simulated daily, monthly and to meet the prediction with observed values with a reasonable goodness of fit. The calibration of parameters of the model has been performed using observed daily data from Shwesaryan station for the year 2008 by adjusting the sensitive parameter such as threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN.gw),Manning's n for overland flow (OV_N. hru), Average slope steepness (HRU_SLP. hru), Manning's "n" value for the main channel (CH_N2.rte), threshold depth of water in the shallow aquifer for "revap" to occur (REVAPMN.gw), and Average slope length (SLSUBBSN. hru).

The comparison of model simulated values with the observed values determines how well a model could simulate hydrological behavior of the study area [7]. The model performance using NSE and R^2 values are computed. The statistical analysis results for the calibration was performed "very good" for NSE ($0.75 \leq NSE \geq 1.00$), and R2 ($R2 \leq 1.00$) value. The result of daily calibration of year 2008 with fitted parameter is as shown in Fig 4. The validation process is executed using observed discharge data from 2005 to 2013 with the monthly time steps. Fig 5 shows observed and simulated monthly discharge at Shwesaryan for validation period. Result obtained for statistical evaluation criteria used for checking model performance are presented in Table 1.

Table 1 Calibration and Validation Statistical Model Results

Statistical Parameter	R^2	NSE
Daily Calibration (2008)	0.83	0.78
Monthly Validation (2005-2013)	0.72	0.63

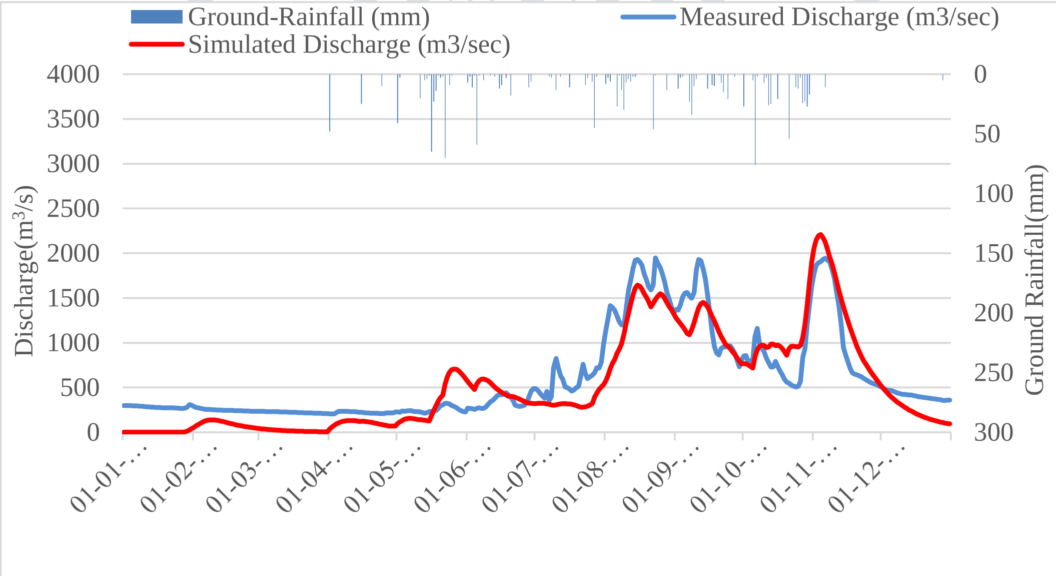


Figure 4 Result of Daily Calibration of Year 2008

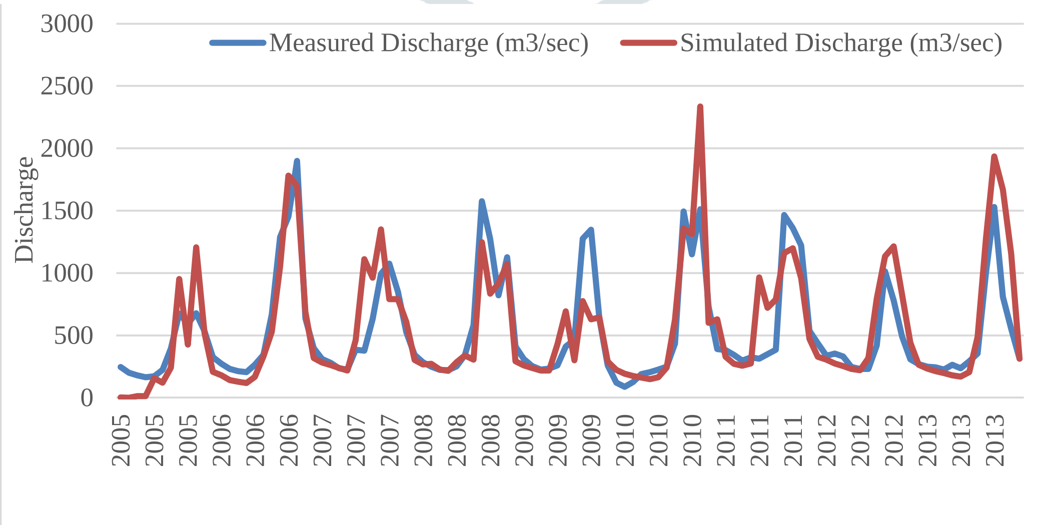


Figure 5 Monthly Validation Discharge at Shwesaryan

V. CONCLUSIONS

The Model was calibrated and validated using the daily observed streamflow at Shwesaryan station for nine years period. The model was calibrated using SUFI2 for year 2008. The validation for observed and simulated flow was from 2005 to 2013. The average Nash-Sutcliffe Efficiency (NSE) for daily calibration was 0.78 and 0.63 in monthly validation. And the coefficient of determination (R2) for daily validation was 0.83 and 0.72 in monthly validation. The accuracy and precision of the model can be improved with better resolution metrological data. Therefore, SWAT can be integrated as an important tool for basin management with respect to water flow. This will bring the potential for power and better water management practices and directly and indirectly helps in improving the socio-economic life of the people.

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REFERENCES

[1] Kløve, B., Ala-Aho, P., Bertrand, G., Gurdak, J.J., Kupfersberger, H., Kvoerner, J., Muotka, T., Mykrä, H., Preda, E., Rossi, P., Bertacchi Uvo, C., Velasco, E., Wachniew, P., Pulido-Velázquez, M., 2014. Climate change impacts on groundwater and dependent ecosystems. J. Hydrol. 518, 250–266.

[2] Schultz GA,1993, Application of GIS and remote sensing in hydrology. LAHS publication ,N.211,pp.127-140.

[3] Mishra et al.2007. Evaluation of the SWAT Model for Assessing Sediment Control Structures in a small Watershed in India. Transactions of the American Society of Agricultural and Biological Engineers (ASABE) 50(2):469-477.

[4] Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R. (2011) Soil and Water Assessment Tool: Theoretical Documentation-Version 2009. Texas Water Resources Institute Technical Report No. 406. Agricultural Research Service (USDA) & Texas Agricultural Experiment Station, Texas A&M University, Temple.

[5] S.L. Neitsch, J.G. (2009). Soil and Water Assessment Tool – Theoretical Documentation, Version 2009. Texas: USA.

[6] J.E. Nash, a.J. (1970). River flow forecasting through conceptual models, Part I: A discussion of principles. Journal of Hydrology, vol. 10, no. 3, pp. 282-290.

[7] Haan CT, Strom D E, Al-Issa T, Prabhu S.Sabbagh G J, Edwards D R.1998. Effect of parameter distributions on uncertainty analysis of hydrologic models. Trans. ASAE 41(1):65-70.