

RAINFALL-RUNOFF SIMULATION USING SWAT MODEL A CASE STUDY: BAGO RIVER BASIN IN MYANMAR

SU WAI THIN⁽¹⁾, KOICHIRO OHGUSHI⁽²⁾ & TOSHIHIRO MORITA⁽³⁾

^(1,2,3) Saga University, Graduate School of Science and Engineering, Saga, Japan.
email : 18597002@edu.cc.saga-u.ac.jp; ohgushik@cc.saga-u.ac.jp.

ABSTRACT

Myanmar has numerous flood plains where monsoon flooding is an annual concern. In this study, the Bago River Basin in Myanmar is chosen as a study area. Bago River Basin is located in the lower part of Myanmar, which is frequently damaged by flooding. Soil and Water Assessment Tool (SWAT) model and SWAT-CUP model have been applied to generate runoff of Bago River Basin. The sensitivities of model parameters are symbolic parameters with regard to various precipitation datasets and sub-basin. The SWAT model with the ArcGIS environment is the ArcSWAT and has undergone extensive validation. The SWAT-CUP model parameters for stream flows along the Bago River are calibrated and validated for periods of 2010-2013 and 2014, respectively. The statistical evaluation is calculated for simulated discharges values for calibration and validation flood events. As a result, the statistical analysis showed that the coefficient of determination (R^2) and Nash Sutcliffe Efficiency (NSE) values for runoff estimation were accessed as 0.76 and 0.56 respectively. It is found that SWAT model can appropriately reproduce the peak discharge, flood timing and volume, by rainfall and soil data. This result shows that the SWAT model appears to be reliable to predict the flood events of Bago Watershed.

Keywords: SWAT; Bago River Basin; Calibration and Validation; Sensitivity Analysis; Statistical Analysis; SWAT-CUP SUFI2.

1 INTRODUCTION

Hydrological models are important tools for planning sustainable use of water resources to meet various demands. Some works on the estimation of global water resources are published as early as 1970s (Lvovitch, 1973). Global runoff estimates performed with existing global climate models, (S.L. Neitsch J. A., 2005), among others, suffer from low accuracy due to their low spatial resolution, poor representation of soil water processes, and, in most cases, lack of calibration against measured discharge (P. Doll, 2003). Hydrological models have numerous applications of central importance to society including for planning, design, and management of environmental and water resources. The operation of hydropower systems is mainly constrained by the availability of water resources. Hydrological models play an important role in forecasting the local inflows to the system on scales ranging from hours to years (Aynom T. Teweldebrhan, 2018). Input data uncertainties may arise from measurement limitations and scaling issues, for example, due to forcing data downscaling. Errors of the rating curve affect streamflow estimates and thereby lead to validation data uncertainty. Structural uncertainty may result from the underlying assumptions and simplifications in the model formulation as well as from application of the model to conditions inconsistent with the model structure (Tripp, 2008). Hydrological model such as SWAT model with a water use model can calculate surface runoff and groundwater recharge based on a daily water balance of soil and canopy. The model is calibrated against observed discharge at Bago station by adjusting the runoff coefficient.

The calibration and validation against long-term annual discharge, application of correction factors to the modeled discharges leading to an inconsistent water balance, and lack of quantification of model prediction uncertainty, which could be quite large in distributed models. Uncertainty and sensitivity analyses are critical for decision-making. While calibrating the model, two concepts must be kept in mind: (1) parameter non-uniqueness, which states that there are many other solutions (different parameter values) that produce equally good results; and (2) parameter conditionality, which means that a calibrated model is only locally conditional and cannot be applied globally (Abbaspour, 2008). Using simulations, uncertainties in the management of a watershed can be reduced by evaluating different scenarios before they occur (Young RA, 1989). Sensitivity analyses are then needed in order to accommodate the large number of parameters and multiple output variables (Arnold JG S. R., 1998).

The SWAT model allows water to be applied on an HRU from any water source within or outside the watershed. Water may also be transferred between reservoirs, reaches and sub basins as well as exported from the watershed (S.L. Neitsch J. G., 2009). The objective of the study is to evaluate the SWAT model

performance and sensitivity analysis and calibration and validation process in the watershed of Bago River Basin.

2 LOCATION OF STUDY AREA

The Bago River Basin covering 91% of the Bago district with an area of 4,883.1 km². The basin area lies within latitudes 16° 42' 00" and 18° 30' 00" N, and longitudes 95° 42' 00" and 96° 00' 00" E. Bago River originates from the middle mountainous region named Bago Yoma and the large portion of the river itself is within the Bago township of Bago Region. A small portion of the river (the outlet) is in Yangon Region where Bago River joins the Yangon River and, from there, enters the Gulf of Mottama. The entire river basin is between the two other river systems: the Sittaung River on the east and the Ayeyarwaddy River on the west. The main river is about 331.5 km long.

The Bago River is one of the most important and useful river basins in lower Myanmar for hydropower generation, irrigation use, fisheries and navigation use. In the Bago River Basin, a hydropower dam for electricity and a diversion weir for irrigation use were constructed near Zaung Tu village in 1996 and 1998, respectively. For the purpose of flood control during the rainy season and the irrigation water use for summer paddy cultivation, three earthen dams namely Kodukwe, Salu and Shwelaung were constructed in 2011 and opened in May, 2012 (Shelly Win, August 2014). The location map of the Bago river basin is shown in figure 1.

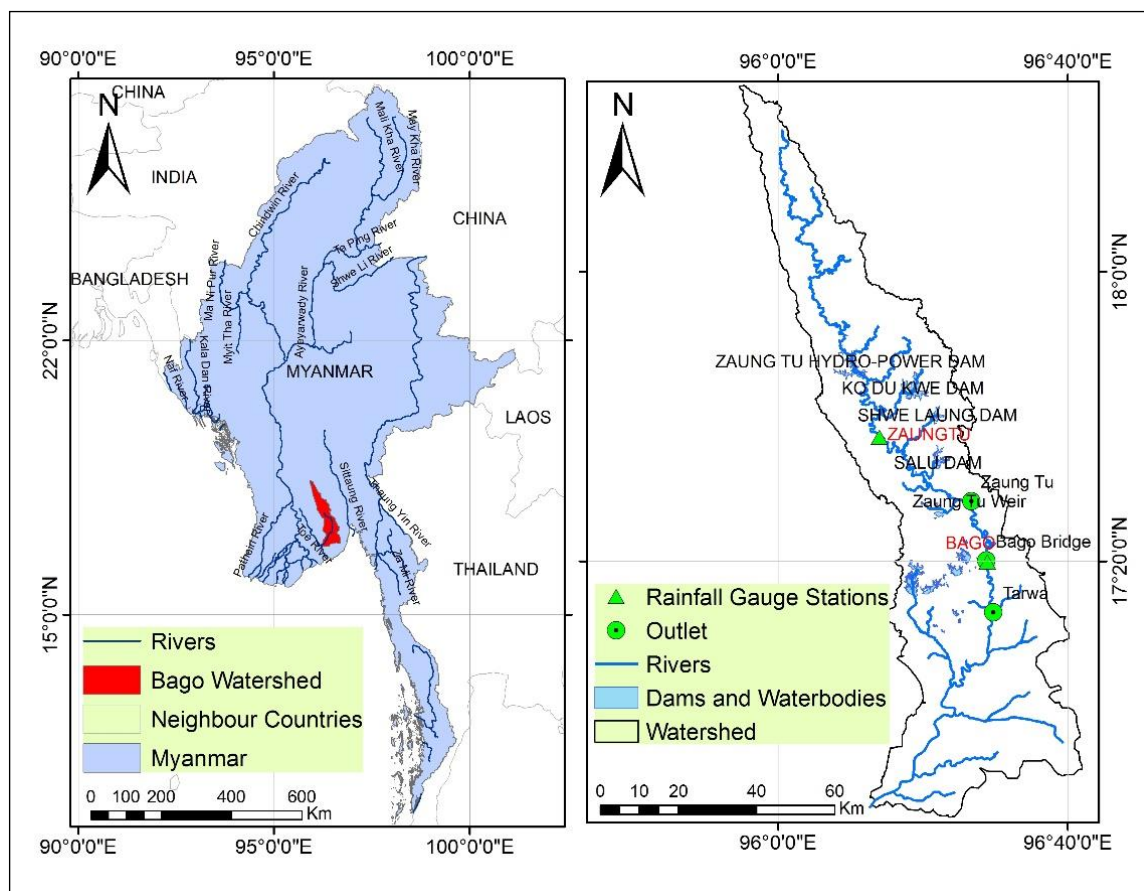


Figure 1. Location of Bago River Basin in Myanmar

3 METHOD AND MATERIALS

3.1 Method

3.1.1 SWAT Model

Soil and Water Assessment Tool, or SWAT, is very flexible and robust river basin hydrological model that can stimulate wide variety of watershed scenarios (Gassman PW, 2007). The model consists of the integration of several physical or conceptual models (Marinoé Gonzaga da Silva, August 21, 2015) for the simulation of a series of physicochemical processes in a watershed, which are the following, along with the corresponding variables: (1) simulation of the climate, such as air-soil-water temperature, solar radiation, wind speed, rainfall, snowmelt, water droplets, relative humidity, weather conditions and climate change; (2) simulation of hydrological processes, such as discharge estimation based on the widely used SCS (Soil Conservation Service) method, evapotranspiration based on the Penman-Monteith method, actual evapotranspiration, water movement in the unsaturated and saturated zone; (3) simulation of sediment materials for erosion and

discharge; (4) simulation of crop growth and cultivation methods and practices; and (5) simulation water movement and pollution in water bodies.

The SWAT model works through in conjunction with Arc GIS (Geographic Information System) environment. Among the existing hydrological models, the SWAT model is one of the most comprehensive models for the simulation of the prevailing processes at the surface of a watershed. The SWAT is a conceptual-distributive model, which has been initially designed for large basins and has gradually been expanded to various applications (Arnold JG S. R., 1998).

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:

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

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). Figure 2 shows the schematic diagram of SWAT model.

The land phase (mainly the soil layer) controls the amount of water and sediment entering the main channel in each sub-basin. A sub-basin's output is treated as input for the following sub-basin (Richard G. Allen, 1998). To calculate surface runoff, we used the SCS curve number method (Agriculture, 1986). The Penman Monteith method, estimation of potential evapotranspiration (PET), and then actual Evapotranspiration was calculated. The SCS curve equation is described as:

$$R_{surf} = \frac{(P_{day} - 0.25)^2}{P_{day} + 0.8S} \quad [2]$$

Where P_{day} is rainfall depth for the day (mm); Q_{surf} is accumulated runoff or rainfall excess (mm); and S is the retention parameter (mm) that can be obtained by the following:

$$s = 25.4 \left(\frac{100}{CN} - 10 \right) \quad [3]$$

The SCS curve number (CN) depends on the soil's permeability, infiltration, land use and, soil-water conditions. The CN value can be defined by three conditions: dry, average moist, and wet (Richard G. Allen, 1998) and the SWAT technical manual (S.L. Neitsch J. G., 2009).

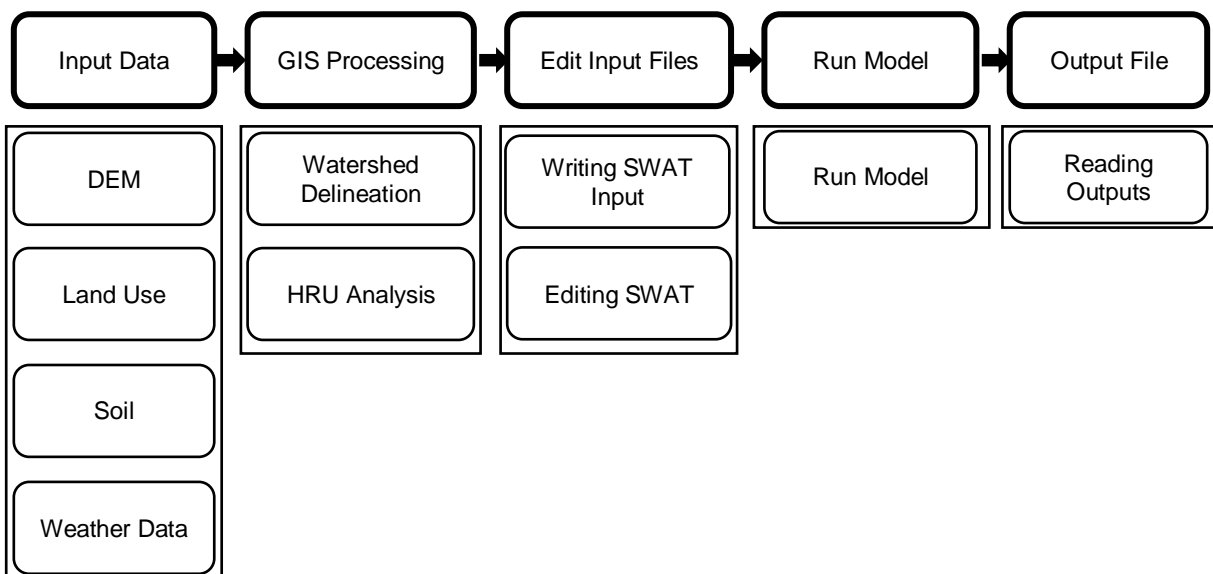


Figure 2. Schematic diagram of SWAT model

3.1.2 SWAT-CUP Model

SWAT-CUP (Calibration and Uncertainty Procedures) (Abbaspour, 2008) is a standalone program developed for calibration of SWAT. 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. The sub-basins, simulated rivers, and outlet, rainfall, and temperature stations can be visualized on the Bing map (Abbaspour, 2008). In this study, the program SUFI-2 was used for model calibration and validation and sensitivity analysis. Figure 3 shows the schematic diagram of SWAT-CUP SUFI2 model.

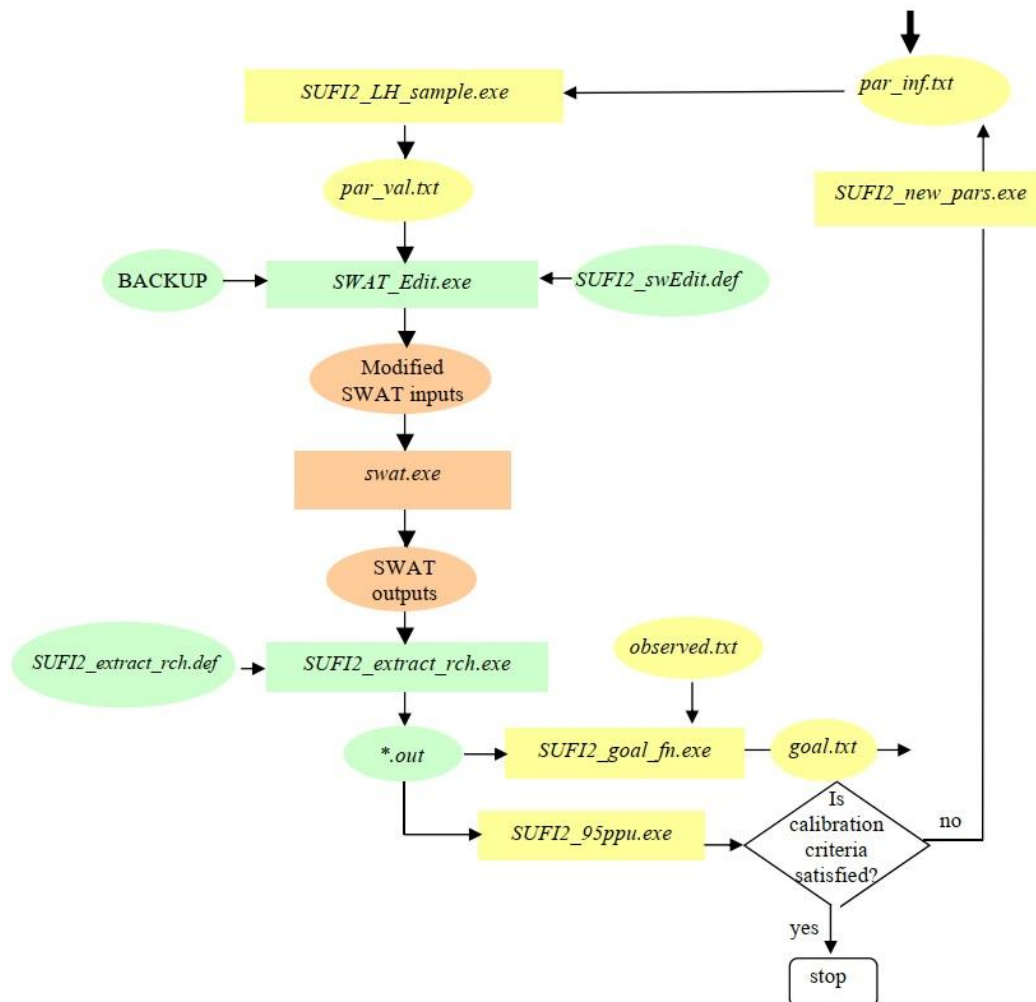


Figure 3. Schematic diagram of SWAT-CUP SUFI2 model
Source: (Abbaspour, 2008)

3.2 Materials

3.2.1 DEM

DEM is the geospatial raster data containing the continuous elevation values a topographic surface by the array of cells or pixels. DEM is used in ArcSWAT to create the watersheds and river networks and streams, sub-basins, and parameters for HRUs analysis. In this study, 90-meter resolution of USGS HydroSHEDS DEM (<https://hydrosheds.cr.usgs.gov/hydro.php>) is processed in a GIS environment using Watershed Delineation and HRU analysis. Figure 4 (a) and (b) show the Bago River Basin and DEM of Bago river Basin.

3.2.2 Land Use and Land Cover Data

In this study, land use and land cover data was applied 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. For Bago River Basin, mainly land is almost forest, agricultural land and water. Figure 4 (c) shows the land use and land cover map of Bago River Basin.

3.2.3 Soil Map

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. Figure 4 (d) shows the soil map of Bago River Basin.

3.2.4 Weather Data

The precipitation data may be observed rainfall from a historical event, it may be a frequency-based hypothetical or design rainfall event, or it may be an event that represents the upper limit of precipitation possible at a given location (Myanmar, 1987). Daily rainfall data for four rainfall-gauge stations in Bago River basin were collected from the Department of Meteorology and Hydrology (DMH) in Myanmar (Myanmar, 1987).

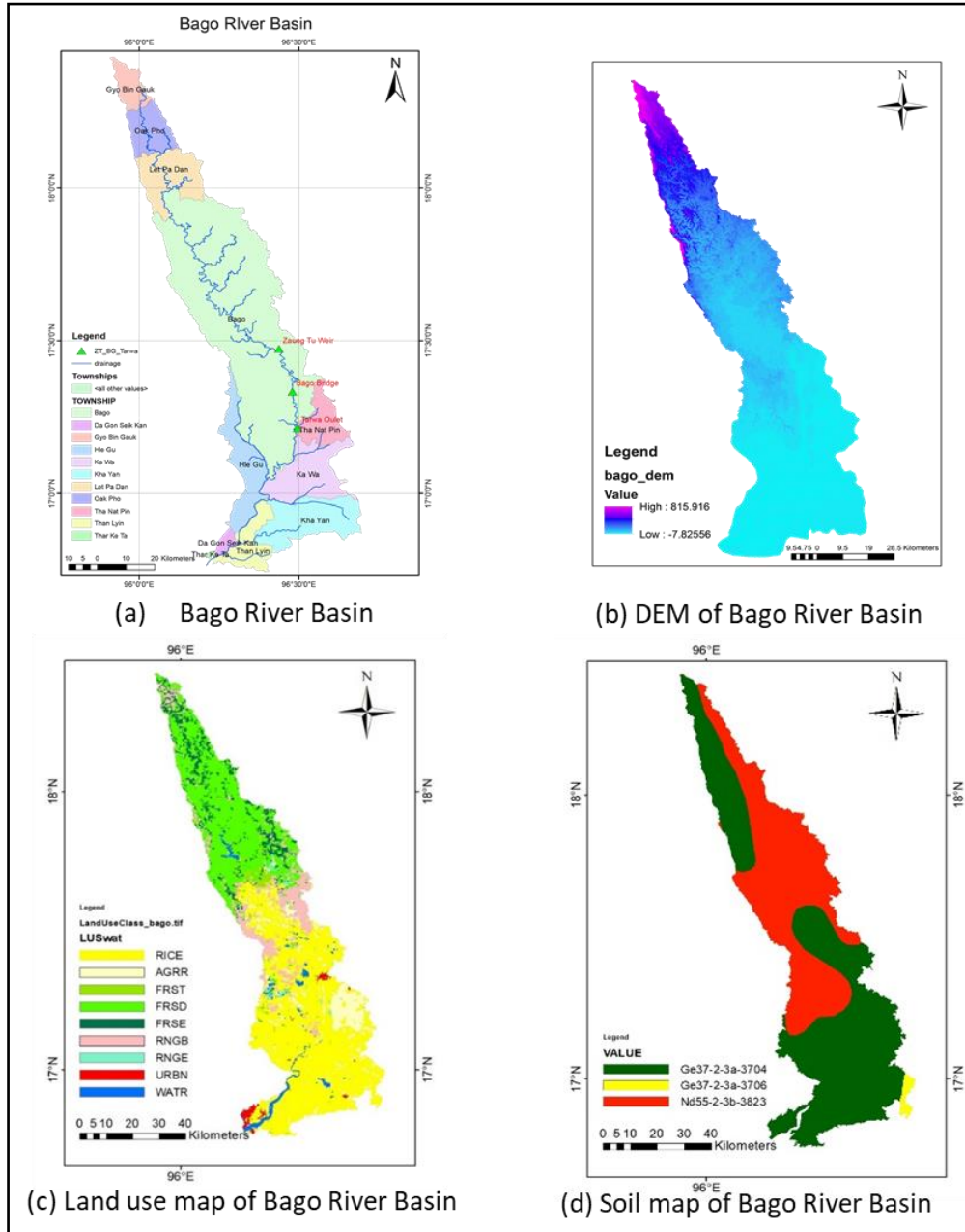


Figure 4. Data input to the model

3.3 Performance Evaluation

The performance of the model checked with the efficiency criteria and error parameter computations. The SWAT model's performance is calculated using graphical representation of observed and simulated discharge values, as well as on the basis of various statistical parameter such as Nash-Sutcliff Efficiency (NSE) and coefficient of determination (R^2) (J.E. Nash, 1970).

Nash-Sutcliff Efficiency (NSE) represents the efficiency of the model in a scale, which goes from minus infinite to 1 (best fit). An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model. (USACE, 2010). The R^2 varies between -1 and 1, where 1 represents perfect positive trend and -1 represents perfect negative/opposite trend. The R^2 and NSE can be calculated by the following equations:

$$R = \frac{[\sum(Q_{m,i} - \bar{Q}_m)(Q_{s,i} - \bar{Q}_s)]^2}{\sum_i(Q_{m,i} - \bar{Q}_m)^2 \sum_i(Q_{s,i} - \bar{Q}_s)^2} \quad [4]$$

$$NSE = 1 - \frac{\sum(Q_m - Q_s)^2 i}{\sum(Q_{m,i} - \bar{Q}_m)^2} \quad [5]$$

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 (J.E. Nash, 1970).

4 RESULTS AND DISCUSSIONS

4.1 Sensitivity Analysis of the Model Parameters

For sensitivity analysis, ten parameters were selected in the SWAT model for the runoff process. The sensitivity of the SWAT input parameters (Table 1) was organized in the sensitivity analysis. T-stat and p-value are used to identify each parameter's relative significance. The t-stat is the ratio of the parameter coefficient to its standard error. Parameters with p-value less than or equal to 0.05 are taken as sensitive (Abbaspour, 2008). Among the ten parameters, three parameters were sensitive to the output variable. The sensitive parameters are SOL_AWC, GW_DELAY, and GW_REVAP.

For the surface response parameter, the available soil water capacity (SOL_AWC) is the volume of water that is available for plant uptake when the soil is at field capacity (Liew, 2007). High values of SOL_AWC signify a high capacity of the soil to maintain its humidity, which reduces the amount of water available for surface runoff and percolation and therefore affects the production of water (Jah, 2011). The parameter value of SOL_AWC for Bago watershed was increased to synchronize between the simulated and observed discharge. For subsurface response parameters, the groundwater "revap" coefficient (GW_REVAP) controls the amount of water moving from the shallow aquifer to the root zone as a result of soil moisture depletion and the amount of direct groundwater uptake from deep-rooted trees and shrubs (Liew, 2007).

The return flow coefficient reduces the base-flow by reason of the increase of water from the shallow aquifer to the plant root zone. Therefore, the value of the GW_REVAP parameter was changed to 0.05. The groundwater delay (GW_DELAY) is the time required for water leaving the bottom of the root zone to reach the shallow aquifer (Liew, 2007). The time to reach the root zone was expanded for the GW_DELAY parameter in the SWAT model.

Table 1. Sensitivity Analysis Table with T-Stat and P-Value

Symbol of Parameter	Descriptions of Parameters	T-Stat	P-value
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0.24	0.81
ALPHA_BF	Base-flow Alpha Factor (days)	0.38	0.72
CH_N2	Manning's "n" value for the main channel	0.46	0.6
CN2	SCS runoff curve number	0.73	0.54
SOL_K	Saturated hydraulic conductivity	1.02	0.41
SOL_BD	Moist bulk density	1.43	0.32
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	1.47	0.06
GW_REVAP	Groundwater "revap" coefficient	1.68	0.04
GW_DELAY	Groundwater delay (days)	3.54	0.02
SOL_AWC	Available water capacity of the soil layer	5.77	0.01

4.2 Calibration of the Model Parameters

In a SWAT-CUP environment, model calibration was performed using the sensitive parameters. The calibration process is executed using observed discharge data from the Bago station with the daily time steps. The model performance using NSE and R^2 values are computed. The statistical analysis results for the calibration period from 2010 to 2013 were performed "very good" for NSE ($0.75 \leq NSE \leq 1.00$), and R^2 ($R^2 \leq 1.00$) value and satisfactory for PBIAS ≤ 15 . The statistical evaluation of parameters was needy to improve, however, the limits for model performance was closed to accept the limits. Table 2 shows the statistical analysis of calibration and validation.

Table 2. Statistical Analysis of calibration and validation

Statistical Evaluation	Calibration		Validation	
	Value	Performance	Value	Performance
NSE	0.76	Very Good	0.56	Satisfactory
RMSE	0.83	Very Good	0.78	Very Good
PBIAS	20%	Satisfactory	25%	Satisfactory

Although during the days between (0-250) and (1210-1461), the simulations were underestimated the peak discharge values, the NSE value of statistical evaluation for calibration steps (2010-2013) was created 0.76 and the simulations for the watershed was very good condition. The days between 600 and 1200, daily streamflow data was indicated the best fit between the simulated and observed data. Figure 5 shows the streamflow hydrograph for the calibration period. At the time of low flood peak duration, the SWAT model contribute the best fit and can use simulations for low flow conditions. Figure 6 shows the streamflow hydrograph for the validation period.

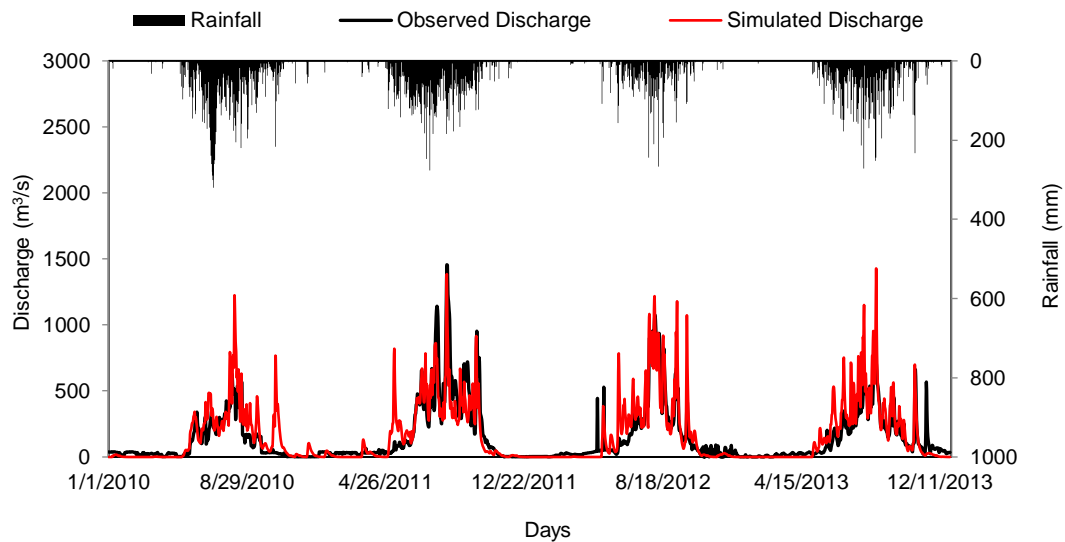


Figure 5. Stream flow hydrograph for calibration period

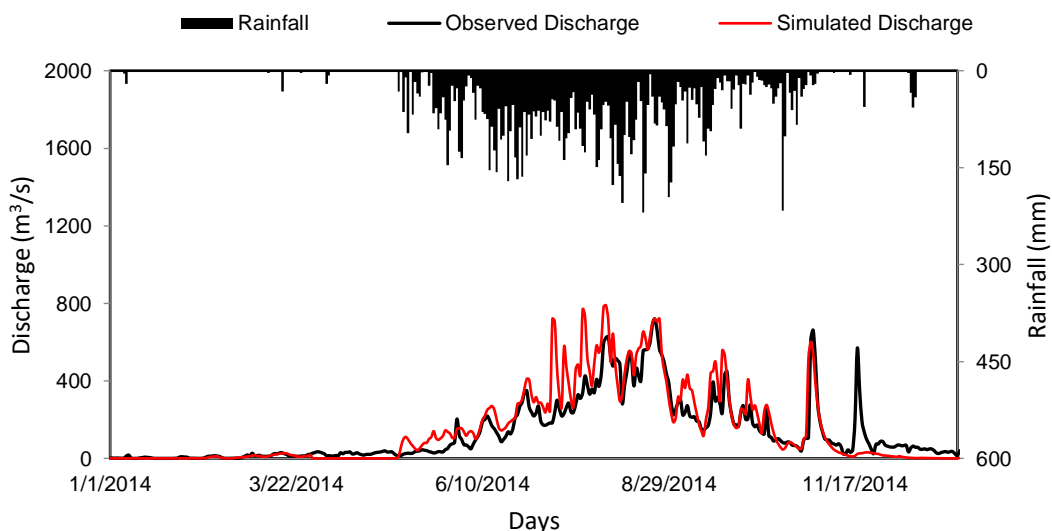


Figure 6. Stream flow hydrograph for validation period

5 CONCLUSIONS

The SWAT model was applied in Bago River Basin to simulate rainfall-runoff analysis in the period for calibration and validation, 2010-2013 and 2014, respectively. The major focus was that how well the simulated flood peak agrees with the observed ones. The SUFI-2 algorithm in SWAT-CUP was engaged to accomplish the sensitivity analysis and calibration process. The sensitivity analysis is the important identification for the most sensitive parameters needed to hydrological process in the Bago River Basin. During the calibration and validation process, the model leads to the best fit between the simulated and observed data for the hydrological process, besides the statistical performance evaluation values were received between very good and satisfactory condition and expressing that the values of parameters could be applied for the Bago River Basin.

ACKNOWLEDGEMENTS

This research was conducted partially by the River Foundation under the research grant in FY 2019 (research representative: Koichiro Ohgushi).

The authors are grateful to the following institutions for necessary data support such as observed rainfall and discharge data from Department of Meteorology and Hydrology, Ministry of Transport in Myanmar and Yangon Technological University (YTU), Yangon, Myanmar.

REFERENCES

- Abbaspour, K. C. (2008). *SWAT_CUP2: SWAT Calibration and Uncertainty Programs - A user manual*. Agriculture, U. S. (1986). *Urban hydrology for small watersheds*. Natural Resources Conservation Service, Conservation Engineering Division.
- Arnold JG, S. R. (1998). *Large Area Hydrologic Modeling and Assessment Part I: Model Development*. J Am Water Resour Association, 34(1): 73-89.
- Aynom T. Teweldebrhan, J. F. (2018). *Parameter uncertainty analysis for an operational hydrological model using residual-based and limits of acceptable approaches*.
- Gassman PW, R. M. (2007). *The soil and water assessment tool: Historical development, applications, and future research directions*. Trans ASABE, (pp. 50(4): 1211-1250).
<http://servir-rlcms.appspot.com/>. (n.d.).
<http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/en/>. (n.d.).
<https://hydrosheds.cr.usgs.gov/>. (n.d.).
<https://hydrosheds.cr.usgs.gov/hydro.php>. (n.d.).
- 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.
- Jah, M. (2011). *Evaluating Hydrologic Response of an Agricultural Watershed for Watershed Analysis*. Water, 3, 604-617.
- Liew, M. V. (2007). *Suitability of SWAT for the Conservation Effects Assessment Project: Comparison on USDA Agricultural Research Service Watershed*. Journal of Hydrologic Engineering, 12, 173-189.
- Lvovitch, M. (1973). *The global water balance*.
- Marinoé Gonzaga da Silva, A. d. (August 21, 2015). *Sensitivity Analysis and Calibration of Hydrological Modeling of the Watershed Northeast Brazil*. Journal of Environmental Protection, Vol.6 No.8.
- Myanmar, D. o. (1987). *Department Report of Rating Curve for Bago River*. Myanmar.
- P. Doll, F. B. (2003). *A global hydrological model for deriving water availability indicators: model tuning and validation*. J. Hydrol., 270 (1–2) (2003), pp. 105-134.
- Richard G. Allen, L. S. (1998). *Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements*. ISBN, 92-5-104219-5.
- S.L. Neitsch, J. A. (2005). *Soil and Water Assessment Tool. Theoretical Documentation, Version 2005*, Springer, Berlin (2005).
- S.L. Neitsch, J. G. (2009). *Soil and Water Assessment Tool – Theoretical Documentation, Version 2009*. Texas: USA.
- Shelly Win, W. W. (August 2014). *Development of Flood Inundation Map for the Bago River*. Yangon, Myanmar.
- Tripp, D. R. (2008). *Evaluating the parameter identifiability and structural validity of a probability-distributed model for soil moisture*. Journal of Hydrology, 353, 93-108.
- USACE. (2010). *HEC_RAS*. Hydrological Engineering Center (HEC).
- Young RA, O. C. (1989). *A Nonpoint- Source Pollution Model for Evaluating Agricultural Watersheds*. J Soil Water Conserv 1989, 44(2): 168-173.