American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402
© Global Society of Scientific Research and Researchers
http://asrjetsjournal.org/

# Sediment Yield Simulation in Upper Ayeyarwady Basin

Su Wai Aung[a]*, Nilar Aye[b]

[a,b]*Department of Civil Engineering, Mandalay Technological University, The Republic of the Union of Myanmar*

[a]*Email: suwai17@gmail.com*

[b]*Email: dnilaraye@gmail.com*

**Abstract**

This study was undertaken to examine the applicability of Soil and Water Assessment Tool (SWAT) model for the Upper Ayeyarwady Basin for simulating sediment yield. The SWAT model is hydro-dynamic and physically-based model for the application in complex and large basins. The required input data for this study were Digital Elevation Model (DEM) with spatial resolution of 30 m x 30 m, land use/land cover map and soil map. And also the hydro-meteorological data around the basin were used. The model has been calibrated and validated using observed sediment data of eight years at the basin outlet (Sagaing). The automated calibration process was used to calibrate the model parameters using time series data from 2003 to 2007. Data from 2008 to 2010 were used to validate the model using the input parameter set. The model predicted the annual sediment in the watershed as 272.8 million ton per year. The average annual values of sediment yield for Nash-Sutcliffe efficiency (NSE) and $R^2$ were found to be 0.89 and 0.82, respectively for calibration and 0.88 and 0.80, respectively for validation, which were within the allowable limit.

***Keywords:*** MUSLE; Sediment yield; SWAT; Watershed delineation.

## 1. Introduction

Sediment yield is the amount of erosional debris from drainage basin deposited in river. Sediment yield increases with increasing annual rainfall and drainage basin slope and its magnitude depends upon the nature of surface material. This study was the evaluation of sediment yield for the upper Ayeyarwady basin. Ayeyarwady River is largest river in Myanmar. It has been affected by several soil erosion which contributes to a high sediment load.

------------------------------------------------------------------------

* Corresponding author.

There are many models for predicting and estimating sediment yield. The sediment yield model that is used in this study is the Soil and Water Assessment Tool (SWAT) model. Input data of the SWAT model were prepared using remote sensing (RS), geographical information system (GIS) and image processing software. Sediment yield is estimated for each Hydrologic Response Units (HRUs) with the Modified Universal Soil Loss Equation (MUSLE). The purpose of this study was to examine the applicability of the soil and water assessment tool (SWAT) model in estimating the sediment yield in the upper Ayeyarwady basin.

## 2. Description on Study Area

The Ayeyarwady River is one of the great rivers in Asia. It flows through the heartlands of Myanmar. It is the fifth largest river in the world in terms of sediment discharge. It is conventionally divided into two basins; Upper and Lower Basin. Only upper part of the river is modeled in this study. The upper basin starts from its source to the river confluence with the Chindwin River. In the Upper Basin, the tributaries of Ayeyarwady River joining it from left are Mu River whereas Shweli River, Tapaing River and Myitnge River join from Right. The upper Ayeyarwady basin extends between latitudes 20'22" N to 28'31" N and longitude 94'45" E to 98'56" E. From a physical point of view, the study area is covered by Kachin State, western part of Shan State, Mandalay Division and south eastern part of Sagaing Division. The watershed has an area of 169,917 $km^2$ and 25 subbasins. Figure 1 shows the location map of study area.

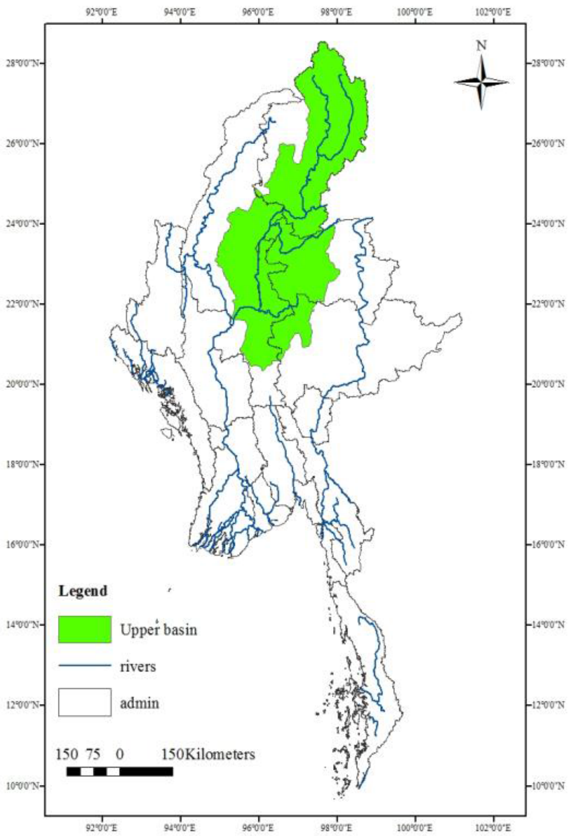


**Figure 1:** location map of upper Ayeyarwady basin

## 3. Methodology

In order to estimate the sediment yield, there are many hydrologic models. The GIS-based software Soil and Water Assessment Tool (SWAT) model with the version of 2012 was used to calculate sediment load in this study. The model predicts the hydrology at each HRU using the water balance equation which includes daily precipitation, runoff, evapotranspiration, percolation, and return flow component [3]. The following sections describe the brief description of SWAT model and model inputs.

### *3.1 Description of SWAT Model*

SWAT is a river basin, or watershed scale model developed by Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT is a daily time step, hydrologic simulation model that simulates the impacts of climate, land use, and land management in a watershed, which is usually divided into several subbasins. It was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. It is a physically based model which requires specific information about weather, soil properties, topography, vegetation and land management practices occurring in the watershed. In the SWAT model, the watershed is divided into a number of subbasins. Subbasins further partitioned into Hydrologic Response Units (HRUs) based on soil types, land use and slope classes. The simulation of sediment yield is computed with the MUSLE (Williams, 1995):

$$Y = 11.8 \times (Q \times q_p)^{0.56} \times K \times LS \times C \times P \tag{1}$$

where Y is the sediment yield in tones, Q is the surface runoff volume in cubic meter, $q_p$ is the peak flow rate in cubic meters per second, K is the soil erodibility factor , LS the slope length and gradient factor, C is the land cover and management factor and P is the support practice factor.

### *3.2 Model Inputs*

The version of SWAT used in this study was SWAT 2012, which requires an ArcGIS interface to perform initial model configuration. This model requires three GIS maps such as Digital Elevation Model (DEM), land cover/ land use map and soil map.

#### *3.2.1 Digital Elevation Model (DEM)*

DEM is one of the main inputs in the SWAT model. It was used to identify different basin characteristics such as drainage area, elevation, slope steepness, slope length and streams relief ratio. In this study, the DEM map was extracted from ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) GDEM (Global Digital Elevation Model) with a spatial resolution of 30 m. The elevation of the study area ranges from 6705 m to 551 m. The DEM was used to delineate the boundary of the watershed and analyze the drainage patterns of the land surface terrain. Terrain parameters such as slope gradient and slope length, and stream network characteristics such as channel slope, length and width were derived from the DEM. DEM map of the upper Ayeyarwady basin is shown in Figure 2.

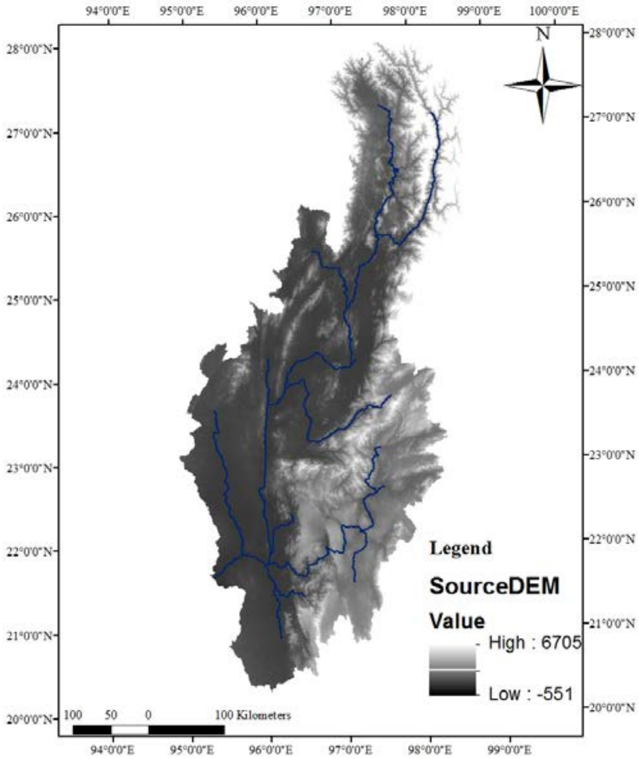


**Figure 2:** digital elevation model (DEM) of the study area

### *3.2.2 Land Use/Land Cover Map*

The original land use data obtained from a land use map of 2010 was reclassified and naming used by ArcSWAT hydrologic model. The major land use classes of the study area are presented in Table 1 and shown in Figure 3.

**Table 1:** Major land use classes in upper Ayeyarwady basin

| Land use | Area (ha) | % Total |
|---|---|---|
| Agricultural land | 2856.3 | 16.81 |
| Scrubland | 4640.4 | 27.31 |
| Waterbody | 15.3 | 0.09 |
| Evergreen Forest | 5882.5 | 34.62 |
| Deciduous Forest | 3597.2 | 21.17 |
| Total | 16991.7 | 100.00 |

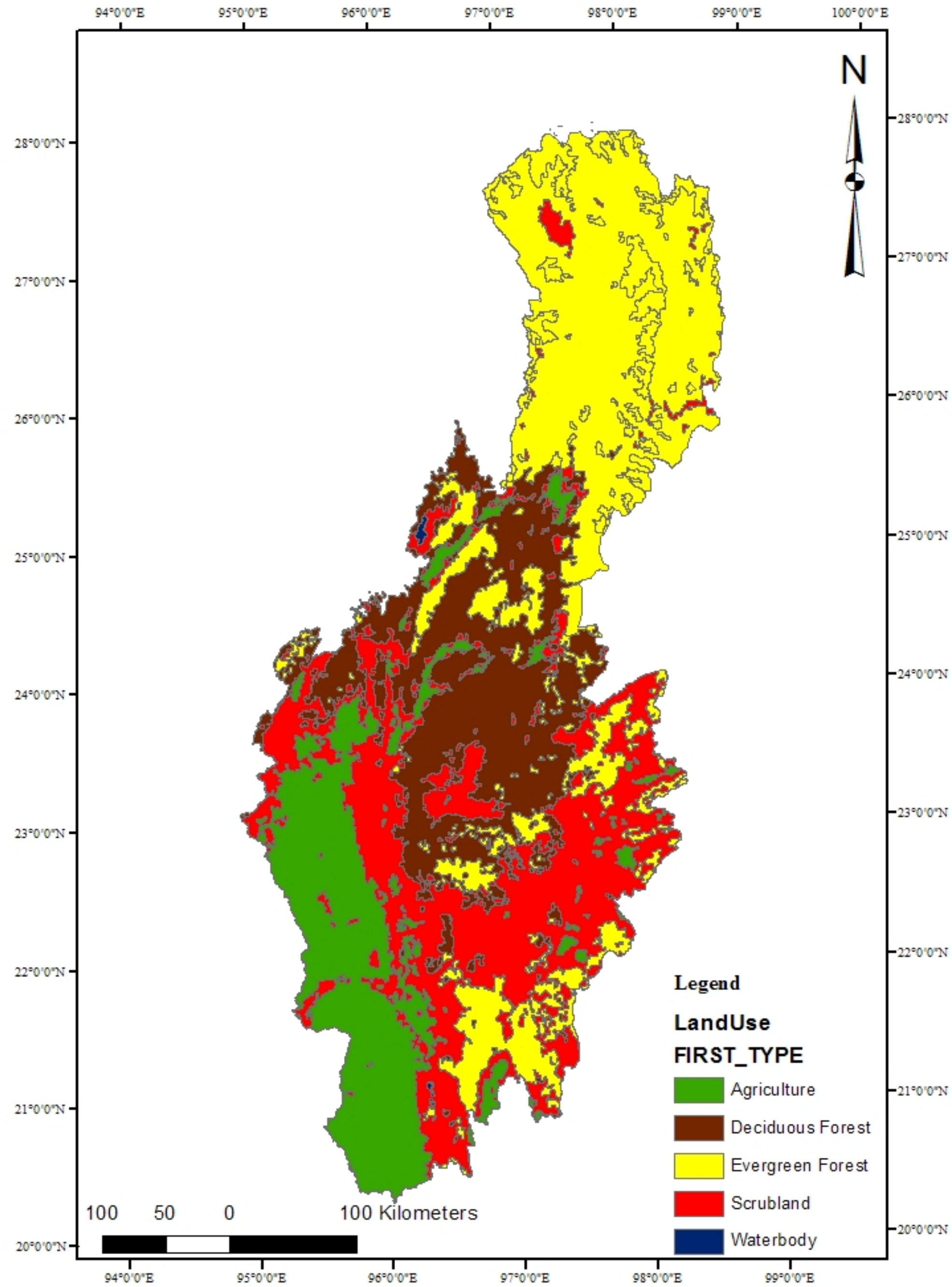


**Figure 3:** land use map of upper Ayeyarwady basin

### *3.2.3 Soil map*

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 basin under this study has six types of soil, namely meadow & meadow alluvial soil, mountainous brown forest soil, savanna soil in slopes, red earth & yellow earth, red brown forest soil and waterbody. The soil types in this watershed are converted to hydrologic soil group: Group A (31.79%), Group B (24.06%), Group C (11.68%), Group D (30.56%) and waterbody (1.91%). This hydrologic soil group map is shown in Figure 4.

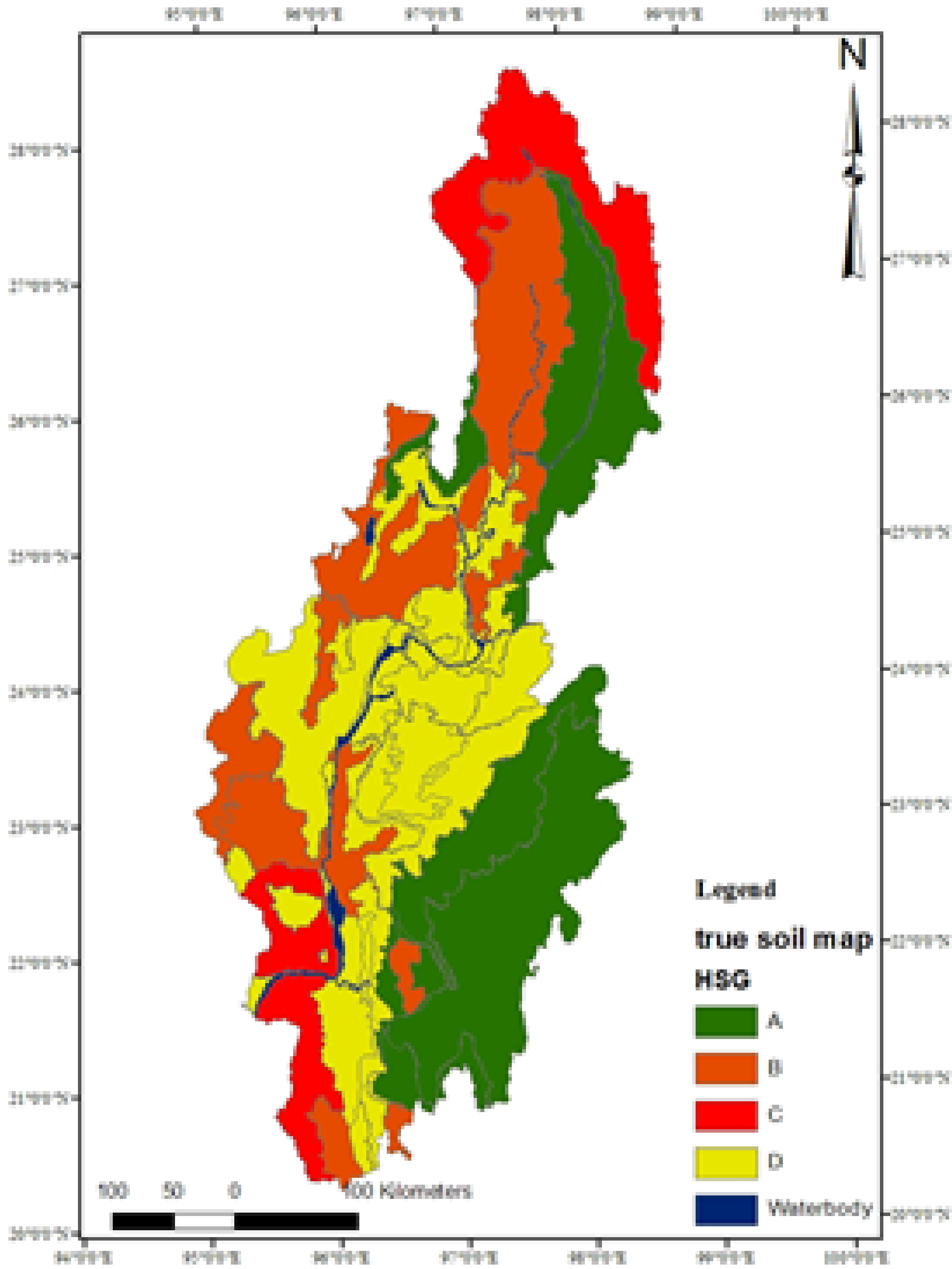


**Figure 4:** hydrologic soil group map of upper Ayeyarwady basin

### *3.2.4 Meteorological data*

Meteorological data is needed by the SWAT model to simulate the hydrological conditions of the basin. The weather variables required by the SWAT model for driving the hydrological balance are daily rainfall and minimum and maximum temperatures. These data were obtained from Department of Meteorology and Hydrology. Based on duration and data quality of meteorological monitoring stations in upper Ayeyarwady basin, weather data are available from nine gages as Putao, Myitkyina, Katha, Mandalay, Sagaing, Homalin, Loilen and Kengtung.

### *3.2.5 Hydrological data*

The observed daily runoff and sediment yield data at the outlet of the watershed were obtained from the Department of Hydrology. These data are required for calibration and validation of the SWAT model.The location map of rainfall stations and discharge stations within the basin is shown in Figure 5.

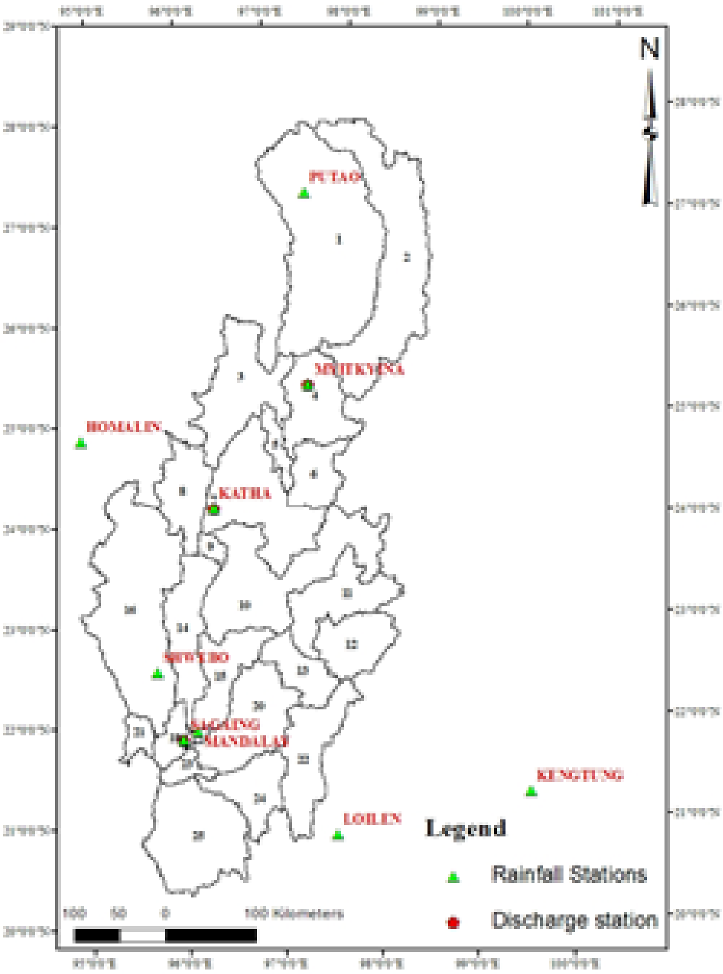


**Figure 5:** location map of rainfall and discharge stations

### *3.2.6 Model set-up*

The Arc-SWAT2012 is an ArcView extension. It provides a graphical user interface that allows for GIS data to be easily formatted for use in SWAT model simulations [5]. ArcSWAT breaks preprocessing into four main steps: watershed delineation, HRU analysis, weather data definition and SWAT simulation. The first step in DEM processing is removal of errors from DEM which is achieved by using fill sinks method. The next step is

DEM hydro processing which involves the estimation of flow accumulation, flow direction and slope, etc. The upper Ayeyarwady basin with the outlet at Sagaing has been delineated according to elevation data derived from the global digital elevation model. The hydrologic response units (HRUs) have been defined based on land use categories, soil properties and slope characteristics. The watershed was delineated into 25 subbsains and 63 HRUs.

### *3.3 Model calibration and validation*

The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given watershed or subwatershed. Sensitivity analysis is the process of determining the rateof change in model output with respect to changes in model inputs (parameters). The second step is validation for the component of interest (stream flow, sediment yields, etc.). Validation involves running a model using parameters that were determined during the calibration process and comparing the predictions to observed data not used in the calibration [1]. The observed daily runoff and sediment yield data at the outlet of the watershed were obtained from the Department of Hydrology. These data are required for calibration and validation of the SWAT model.

## 4. Results and Discussions

As a result, average annual sediment production in the watershed was 272.8 million tons per year. The sediment yields for each month for the period of 2003 to 2010 are shown in Figure 6 and Table 2. Monthly sediment yield at the outlet of the study area watershed was simulated for the whole watershed. Months of June, July, August, September and October resulted in greater sediment load delivered into the basin. Total sediment yield for each of the 25 subbasins is shown in Figure 7. The highest sediment yields were recorded in subbasins 15, 16, 25 and 9 with values of 6867.2, 5903.7, 5553.3 and 4212.6 t/ha respectively. Lowest sediment yields were obtained in subbasins 2, 20, 11, 22, 13 and 24 with values of 2, 2.7, 4.8, 5.3, 5.6 and 8.2 t/ha respectively. And then, the annual result of the sediment yield for the watershed is shown in Figure 8.

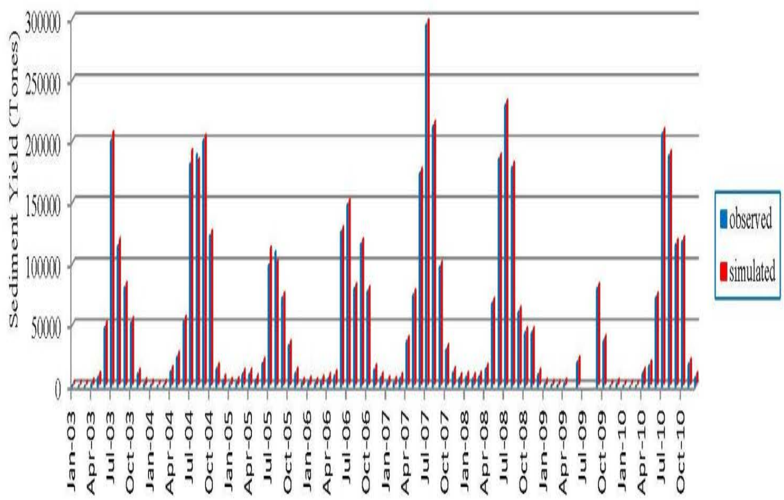


**Figure 6:** monthly sediment yield for the upper Ayeyarwady basin

**Table 2:** Monthly sediment yield for the upper Ayeyarwady basin (Tones)

| Time | Observed | Simulated | Time | Observed | Simulated |
|---|---|---|---|---|---|
| Jan-03 | 1067 | 1102 | Jan-07 | 4114 | 4528 |
| Feb-03 | 974 | 1003 | Feb-07 | 3785 | 3961 |
| Mar-03 | 830 | 945 | Mar-07 | 6837 | 7065 |
| Apr-03 | 2621 | 2834 | Apr-07 | 37201 | 37462 |
| May-03 | 7990 | 8234 | May-07 | 75148 | 75368 |
| Jun-03 | 48349 | 49623 | Jun-07 | 174660 | 174836 |
| Jul-03 | 201491 | 204863 | Jul-07 | 295953 | 296107 |
| Aug-03 | 115162 | 117421 | Aug-07 | 212933 | 213153 |
| Sep-03 | 81047 | 81591 | Sep-07 | 97958 | 98283 |
| Oct-03 | 52438 | 52762 | Oct-07 | 30483 | 30684 |
| Nov-03 | 10469 | 10623 | Nov-07 | 11569 | 11749 |
| Dec-03 | 2666 | 3013 | Dec-07 | 6968 | 7132 |
| Jan-04 | 1327 | 1645 | Jan-08 | 7898 | 7986 |
| Feb-04 | 669 | 789 | Feb-08 | 6736 | 6945 |
| Mar-04 | 1354 | 1567 | Mar-08 | 8076 | 8392 |
| Apr-04 | 12345 | 12735 | Apr-08 | 14710 | 14937 |
| May-04 | 24261 | 24682 | May-08 | 68290 | 68403 |
| Jun-04 | 53542 | 53874 | Jun-08 | 186035 | 186256 |
| Jul-04 | 182217 | 189945 | Jul-08 | 230303 | 230536 |
| Aug-04 | 189801 | 182431 | Aug-08 | 179234 | 179579 |
| Sep-04 | 201613 | 201976 | Sep-08 | 61314 | 61482 |
| Oct-04 | 123533 | 123932 | Oct-08 | 44311 | 44621 |
| Nov-04 | 14919 | 15018 | Nov-08 | 44311 | 44621 |
| Dec-04 | 5240 | 5835 | Dec-08 | 10246 | 10562 |
| Jan-05 | 2556 | 3124 | Jan-09 | 2271 | 2483 |
| Feb-05 | 3346 | 3681 | Feb-09 | 1380 | 1586 |
| Mar-05 | 10435 | 10756 | Mar-09 | 1274 | 1363 |
| Apr-05 | 10383 | 10681 | Apr-09 | 2657 | 2735 |
| May-05 | 5739 | 5972 | May-09 | 2918 | 3086 |
| Jun-05 | 19225 | 19547 | Jun-09 | 20448 | 20573 |
| Jul-05 | 99685 | 110581 | Jul-09 | 98099 | 130625 |
| Aug-05 | 110373 | 99754 | Aug-09 | 130510 | 98257 |
| Sep-05 | 73022 | 73216 | Sep-09 | 80586 | 80738 |
| Oct-05 | 33896 | 34045 | Oct-09 | 37765 | 37935 |
| Nov-05 | 11257 | 11482 | Nov-09 | 888 | 972 |
| Dec-05 | 2979 | 3142 | Dec-09 | 2329 | 2468 |

| | | | | | |
|---|---|---|---|---|---|
| Jan-06 | 4169 | 4372 | Jan-10 | 851 | 912 |
| Feb-06 | 2845 | 2986 | Feb-10 | 420 | 548 |
| Mar-06 | 4855 | 5036 | Mar-10 | 837 | 903 |
| Apr-06 | 6611 | 6872 | Apr-10 | 11347 | 11473 |
| May-06 | 9100 | 9428 | May-10 | 17368 | 17586 |
| Jun-06 | 126628 | 126943 | Jun-10 | 72898 | 72975 |
| Jul-06 | 149106 | 149367 | Jul-10 | 206841 | 207023 |
| Aug-06 | 80412 | 80518 | Aug-10 | 188768 | 188954 |
| Sep-06 | 116838 | 117102 | Sep-10 | 116202 | 116483 |
| Oct-06 | 77942 | 78023 | Oct-10 | 118660 | 118971 |
| Nov-06 | 13930 | 14104 | Nov-10 | 18951 | 19104 |
| Dec-06 | 7519 | 7735 | Dec-10 | 7625 | 7864 |

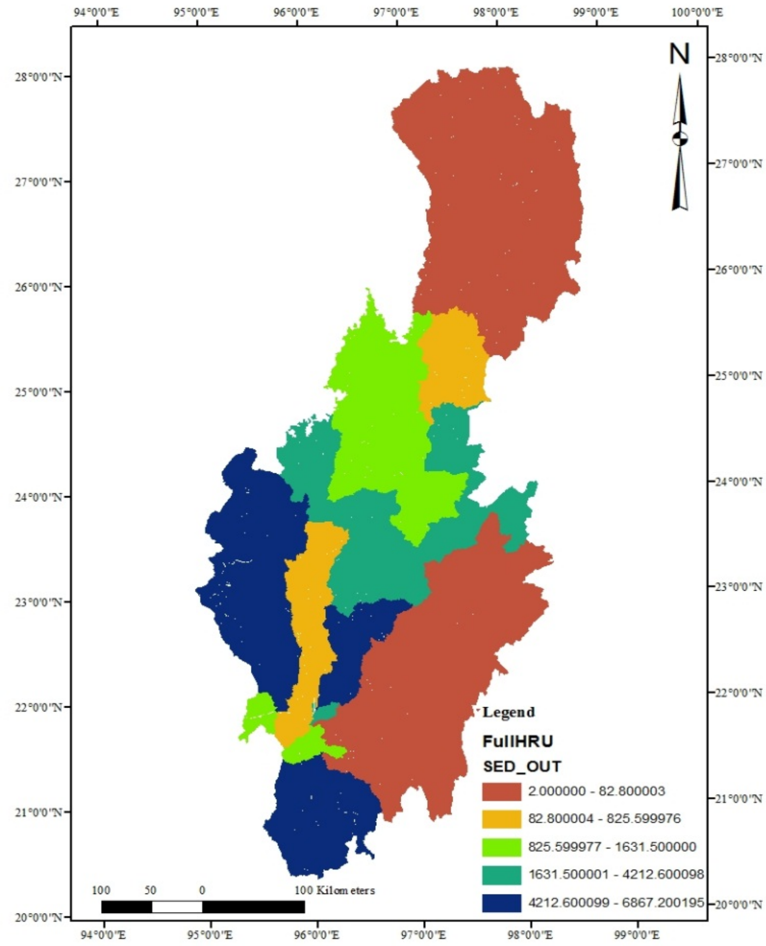


**Figure 7:** annual sediment yield for each of the subbasins in the watershed

**Table 5**

| Subbasins | Area (ha) | Sediment (ton/ha) |
|---|---|---|
| 1 | 2327.3 | 2 |
| 2 | 1689.5 | 82.8 |
| 3 | 881.1 | 1462.6 |
| 4 | 632.7 | 400.9 |
| 5 | 155.5 | 1035.7 |
| 6 | 364.2 | 3847.2 |
| 7 | 1093.2 | 1210.4 |
| 8 | 501.1 | 3236.4 |
| 9 | 73.8 | 3268.5 |
| 10 | 1390.6 | 2877.6 |
| 11 | 629.9 | 4.8 |
| 12 | 483.0 | 21.5 |
| 13 | 364.9 | 5.6 |
| 14 | 621.1 | 825.6 |
| 15 | 498.0 | 6867.2 |
| 16 | 1822.7 | 5903.7 |
| 17 | 37.5 | 3164.8 |
| 18 | 175.5 | 705.1 |
| 19 | 0.3 | 4212.6 |
| 20 | 792.8 | 2.7 |
| 21 | 128.0 | 1631.5 |
| 22 | 697.5 | 5.3 |
| 23 | 126.1 | 1520.4 |
| 24 | 457.1 | 8.2 |
| 25 | 1048.3 | 5553.3 |

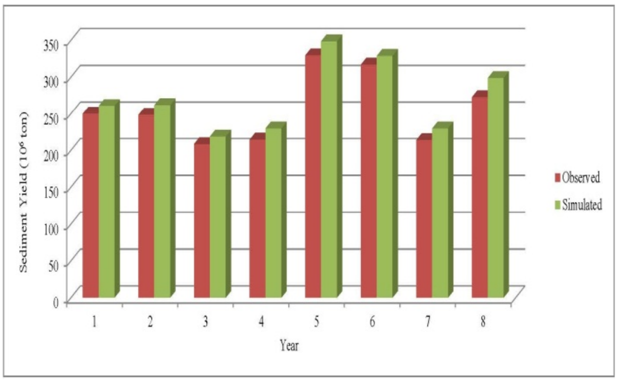


**Figure 8:** annual sediment yield for the upper Ayeyarwady basin

**Table 6**

| Year | Sediment ($10^6$ Tones) | |
|---|---|---|
| | Observed | Simulated |
| 2003 | 250.251 | 260.976 |
| 2004 | 248.586 | 261.985 |
| 2005 | 208.767 | 218.998 |
| 2006 | 214.667 | 229.986 |
| 2007 | 329.697 | 348.995 |
| 2008 | 317.228 | 328.978 |
| 2009 | 214.2593 | 229.977 |
| 2010 | 272.945 | 298.985 |

### *4.1. Sediment calibration and validation*

SWAT model was also calibrated in this study using a time series dataset of eight years from 2003 to 2010 and found to be a good predictor of sediment loads into the watershed [2]. The first two years of the modeling period were used for ‘model warm-up'. Data for the period 2003 to 2007 were used for calibration and the remaining part of the dataset was reserved for validation.

The sediment yield from a watershed is associated with the complicated interaction between land use, soil, vegetation and topography [4]. The sediment parameters contemplated during the calibration were the USLE cover factor (USLE_C), the coefficient in the sediment transport equation (SPCON), the channel cover factor (Ch_COV) and the channel erodibility factor (Ch_COV2).

These parameters were adjusted to particular levels in different iterations where they were able to signify the features of the present land use and topography of the watershed. Overall, the performance of the model for the sediment modeling was efficient. The $R^2$ and NS values were 0.82 and 0.80; respectively during the calibration period. For the validation period, $R^2$ and NS values were 0.80 and 0.78; respectively, which demonstrate the model closely predicted the observed values of sediment yield. Parameter values for sediment calibration are shown in Table 3.

The calibration and validation results of monthly and annual observed and simulated sediment yield is shown in Table 4.

The results of calibration have been reported the values of $R^2$ are 0.82 and 0.89 for monthly and annual, respectively for calibration and 0.80 and 0.88 for monthly and annual validation. The values of Nash and Sutcliffe efficiency (NSE) for monthly and annual were found to be 0.80 and 0.87 for calibration and 0.78 and 0.80 for validation, respectively. Therefore, it can be seen that the annual comparison indicate a better correlation than the monthly values.

**Table 3:** Parameter values for sediment calibration

| Parameter | Name | Range | Final Value |
|---|---|---|---|
| Ch_COV | Channel cover factor | 0.05~0.6 | 0.5 |
| Ch_COV2 | Channel erodibility factor | 0.001~1 | 0.18 |
| SPCON | Linear parameter for calculating the maximum amount of sediment | 0.0001~0.01 | 0.0025 |
| USLE_C | USLE cover factor | 0~0.1 | 0.02 |

**Table 4:** Calibration and validation results of monthly and annual observed and simulated sediment yield

| Parameter | Time | Calibrated (2003-2007) | Validated (2007-2010) |
|---|---|---|---|
| Correlation coefficient ( $R^2$) | Monthly | 0.82 | 0.80 |
| | Annual | 0.89 | 0.88 |
| Nash and Sutcliffe efficiency (NSE) | Monthly | 0.80 | 0.78 |
| | Annual | 0.87 | 0.80 |

**6. Conclusions**

The study has demonstrating how the integration of SWAT model, Remote Sensing and GIS can be a powerful tool in simulating watershed variables such as the sediment yield of a large river basin. Sediment yield is an important measure of geomorphic activity which represents the amount of sediment exported at the basin outlet over a period of time. This study was carried out for the upper Ayeyarwady basin. The SWAT model MUSLE was used to estimate the sediment in the basin. DEM, land use map, soil map and weather data were used in this analysis. The study area was divided into 25 subbasin and 63 HRUs. In this study, the parameters of SWAT model have been calibrated (period 2003-2007) and validated (period 2008-2010) for estimation of sediment yield at the outlet of the upper Ayeyarwady basin.

The results of calibration have been reported the values of $R^2$ are 0.82 and 0.89 for monthly and annual, respectively for calibration and 0.80 and 0.88 for monthly and annual validation. The values of Nash and Sutcliffe efficiency (NSE) for monthly and annual were found to be 0.80 and 0.87 for calibration and 0.78 and 0.80 for validation, respectively. It can be seen that the annual comparison indicate a better correlation than the monthly values. The using of SWAT model for this study is able to predict sediment yield values, which might be beneficial for future planning and management.

**Acknowledgement**

First of all, the author thanks to all of the teachers from Civil Engineering Department, Mandalay Technological University, for their great support and discussions. The author would like to express deep gratitude to Dr. Kyaw Zaya Htun, Lecture, Department of Remote Sensing, Mandalay Technological University for giving the suggestions to carry out this research. Finally, the author would like to thank all the persons who were involved towards the successful completion of this paper.

**References**

[1] Abbaspour, K.C. 2014. SWAT-CUP 2012: SWAT Calibration and Uncertainty Programs — A User Manual: Swiss Federal Institute of Aquatic Science and Technology, Switzerland.

[2] Alansi, A. W., Amin, M. S., Abdul Halim, G., Shafri, H. Z., & and Aimrun, W. (2009). Validation of SWAT model for stream flow simulation and forecasting in Upper Bernam humid tropical river basin, Malaysia. Hydro Earth Syst. Sci. Discuss., 7581-7609.

[3] Arnold, J.G., J.R. Kiniry, R. Srinivasan, J.R. Williams, E.B. Haney, and S.L. Neitsch. 2011. Soil and Water Assessment Tool input/output file documentation, Version 2009. TWRI Tech. Rep. TR-365. Texas Water Resour Inst., Texas A&M Univ., College Station.

[4] D. Matamoros, E. Guzman, J. Bonini and P.A. Vanrolleghem, “AGNPS and SWAT Model Calibration for Hydrologic Modeling of an Ecuadorian River Basin under Data Scarcity,” IWA Publishing, London, UK, ISBN: 184339510X, 2005.

[5] Maski, D., K.R. Mankin, K.A. Janssen, P. Tuppad, and G.M. Pierzynski. 2008. Modeling runoff and sediment yields from combined in-field crop practices using the Soil and Water Assessment Tool. J. Soil Water Conserv. 63:193–203. doi:10.2489/jswc.63.4.193.