Simulation of runoff and sediment yield for the calo watershed, Vinh Phuc province by using swat model

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Abstract. Smallest watershed is considered to be the ideal unit for management of the water resources in a water basin. Extraction of water-shed parameters using Remote Sensing and Geographical Information System (GIS) and use of mathematical models is the current trend for hydrologic evaluation of watersheds. The Soil and Water Assessment Tool (SWAT) having an interface with ArcView GIS software (AVSWAT2005) was selected for the estimation of runoff and sediment yield from an area of Vinh Phuc province, an intermediate watershed of Ca Lo River, located in Western Tam Dao mountain which cover nearly all region of the VinhPhuc province. Base on Hydro Response Unit HRU (as the basin parcel), the performance of the model was evaluated using statistical and graphical methods to assess the capability of the model in simulating the run-off and sediment yield from the study area. Result of the study are informations on quality and quatity of water in each sub basin and also for whole of the basin so it will supply valuable water information for integrated management of the Ca Lo Basin area and also for Vinh Phuc province.

Keywords: SWAT model, Calibration, Validation, Remote Sensing, GIS, Runoff, Hydro Response Unit HRU, basin parcel, Sediment Yield, SWAT model, Hydrological analysis.

1. Introduction

A watershed is a hydrologic unit which produces water as an end product by interaction of precipitation, slope and the land surface. Depending on size of watershed, a big wate shed (or basin) can be devided into various smaller watershed and it called sub-watershed. A smallest sub–watershed can be considered as a basin parcel. The quantity and quality of water produced by the watershed are an index of amount and intensity of precipitation and its impact to watershed characteristics. In some watersheds the aim may be to harvest maximum total quantity of water throughout the year for irrigation and living purpose. In other watersheds the objectives may be to reduce the peak rate of runoff for minimizing soil erosion and sediment yield or to increase ground water recharge. Hence, the modeling of runoff, soil erosion and sediment yield are essential for sustainable development. Further, the reliable
estimates of the various hydrological parameters including runoff and sediment yield for remote and inaccessible areas are tedious and time consuming by conventional methods. So it is desirable that some suitable methods and techniques are used/evolved for quantifying the hydrological parameters from all parts of the watersheds. So that it will be easy to take the practices accordingly.

2. Study Area

With area of 1.362 km², 115.700 peoples in population (statistical data, 2010), Vinhphuc province is located in northern Vietnam (fig.1), contiguous with the Ha Noi capital at north-west direction. Vinhphuc Province is surrounded by Tuyen Quang and Thai Nguyen provinces in the north, Hanoi in the east and in the south, and Phu Tho Province in the west. With picks elevation of 1590 mets, Tam Dao range longate along north west-southeast direction is natural provincial line between Thai Nguyen and VinhPhuc. From north east to south west direction, landform includes low mountain, low hill and plain with elevation about 6 to 8 mets obove sea level. Natual condition of vinh Phuc is various in soil condition, land use, forest cover, climate and water resource. There are four large rivers: Hong (Red), Lo, Pho Day, and Ca Lo. Among this, Ca Lo is a small river having all basin inside boundary of the Vinh Phuc Province. In general, climate of the Vinh Phuc Province is monsoonal with hot and wet summers and cool, cloudy and moist winters. Total annual rainfall ranges from 1100–3000 mm. Average temperature is 25°C, with an average maximum of 39°C (in August) and minimum of 5°C (in January). Southwest monsoon occurs from May to October, bringing heavy rainfall and temperatures remain high. November to April is the dry season with a period of prolonged cloudiness, high humidity and light rain. The vinhphuc province has the red and yellow soil type and soil depth is near about 80 cm. the annual rain fall in this region is near about 1600 mm. Landcover contend difference type as: dense forest (in the Tam Dao range), spart forest, bare land, plantation, bush-grass land, fruit tree, shifting cultivated land, lowland agriculture with rice field, farm fields. This condition is the reason that this area faces a major problem which direct relate to the Ca Lo river basin such as soil erosion, landslide, flooding, water logging in rainy season and drought in drain season. With the concept of integrated management of river basin, there is meaning that good management of the Calo river basin is also good environmental management of the Vinh Phuc province. SWAT model was selected as a efficient tool for water basin management.
Fig. 1. Study area location.
Fig. 2. Meteorological and hydrological stations in the study area.
3. SWAT Model

The SWAT (Soil and Water Assessment Tool) is one of the most recent models developed jointly by the United States Department of Agriculture - Agricultural Research Services (USDA-ARS) and Agricultural Experiment Station in Temple, Texas [1]. SWAT is a comprehensive model that requires information provided by the user to simulate runoff and soil erosion. The first step in initializing a watershed simulation is to partition the watershed into subbasins. The physical processes associated with water flow, sediment transport, crop growth, nutrient cycling, etc. are directly modeled by SWAT [2, 3]. The land area in a small subbasin is divided into hydrologic response units (HRUs). A full model description and operation is presented in Neitsch et al. [4,5]. Hydrologic response units (HRUs) are portions of a subbasin and possess unique land use, slope range, and soil attributes [6]. SWAT has different components. Hydrologic components of the model work on the water balance equation, which is based on surface runoff, precipitation, percolation, evapotranspiration, and return flow data; Weather is one of the model component that needs data on precipitation, air temperature, solar radiation, wind speed, and relative humidity data; Sedimentation is another component of the model that needs information on surface runoff, peak rate flow, soil erodability, crop management, erosion practices, slope length, and steepness; Soil temperature, crop growth, nutrient pesticides and agricultural management are also components of SWAT. Thus, the data required for the model are DEM, soil data, land use data, precipitation and other weather data. For calibrating the model and also for validation purposes, river discharge and sediment yield are required at the outlet of the watershed.

The water balance is the driving force for the simulation of hydrology. SWAT uses two steps for the simulation of hydrology, land phase and routing phase. The land phase is the phase in which the amount of water, sediment, nutrient and pesticides loading in main channel from each subbasin are calculated.

\[ SW_i = SW_0 + \sum_{i=1}^{P_{\text{day}}} (P_{\text{surf}} - AET) - Q_{\text{keep}} - Q_{\text{gw}} \]

Where \( SW_i \) is the final water content in millimeters (mm), \( SW_0 \) is the initial soil water content on day \( I \) (mm), \( P_{\text{day}} \) is the precipitation on day \( i \) (mm), \( Q_{\text{surf}} \) is the surface runoff on day \( i \) (mm), \( AET \) is the actual evapo-transpiration on day \( I \) (mm), \( Q_{\text{keep}} \) is the water entering the unsaturated zone from soil profile on day \( i \) (mm), and \( Q_{\text{gw}} \) is the return flow from the shallow aquifer and lateral flow on day \( i \) (mm).

Daily rainfall, run-off and sediment yield data of 31 years (1973-2003) were used for the study. Apart from hydro-meteorological data, topographical map, soil map, land resource map and satellite imageries for the study area were also used.

A full model description and operation is presented in Neitsch et al. [4,5]. The review indicated that SWAT is capable of simulating hydrological processes with reasonable accuracy and can be applied to large ungauged basin[7]. Therefore, to test the capability of model in determining the effect of spatial variability of the watershed on runoff, AVSWAT 2005 with ArcGIS interface was selected for the present study.
4. Methodology

4.1. Creation of GIS database in SWAT

Digital elevation model is the main input in the SWAT analysis. DEM is used in this study is SRTM DEM (fig 2). The area has the elevation ranges up to 1590 meter. In SWAT the grid format of the DEM is used. It is mainly used to delineate the watershed automatically (fig 3).
Land use map is a critical input for SWAT model. Land use/land cover map was prepared using remote sensing data of SPOT-3 image (fig 5). The intent of the classification process is to categorize all pixels in a digital image into one of several land cover classes, or "themes". This categorized data may then be used to produce thematic maps of the land cover present in an image. Soil plays an important role in modeling various hydrological processes. In the SWAT model, various soil properties like soil texture, hydraulic conductivity, organic carbon content, bulk density, available soil water content are required to be analyzed to make an input in the model for simulation purpose. Based on the analysis of collected 17 soil samples, it was observed that the soils in the study area were mostly clayey soils and alluvial soil and falls in the hydrologic soil group C & D (fig 6). With the rain fall data were taken from the metrological station TAMDAO, the processing of meteorological data was done statistically [8,9]. The simulated daily weather data on maxi-mum and minimum temperature, rainfall, wind speed and relative humidity at all the grid locations for 31 years representing the series approximating 1973 to 2003 time period were processed.
Fig. 5. Landuse map interpreted from SPOT image.

Fig 6. Soil Map.
3.2. Model set up

SWAT automatically delineates a watershed into sub-watersheds based on DEM and drainage pattern (fig3). The land use and soil map in Arc shape format were imported in the SWAT model. Both the maps were made to overlay to subdivide the study watershed into hydrologic response units (HRU) based on the land use, soil types and slope (table1).

| Table 1. Example of parameters for each sub basin extracted from SWAT processing |
|------------------|------------------|------------------|
| SUBBASIN #       | Area [ha]        | Area[acres]     |
| SUBBASIN #       | %Swat.Area      | %Sub.Area       |
| LANDUSE:         |                 |                 |
| Forest-Mixed    | 685.4991        | 1693.9026       |
| ---> FRST       |                 | 0.80            |
| SOILS:           | 653.7093        | 1615.3484       |
| LIGHT YELLOW STAND STONE | 0.76 | 95.36 |
| SLOPE:           | 653.7093        | 1615.3484       |
| 3-9999           | 0.76            | 95.36           |
| HRUs             | 653.7093        | 1015.3484       |
| 1 Forest-Mixed   |                 | 0.76            |
| ---> FRST/LIGHT YELLOW STAND STONE/3-9999 | 95.36 |

In addition to model results, VIZSWAT is a analyze and visualize SWAT model results with number of powerful and convenient functions are available for data analysis in VIZSWAT. Analysis functions include time series aggregation, basic statistics, and correlation, frequency, baseflow and flow duration analyses. Time series data can be extracted from model results and plotted separately. Animations of model data can be produced using graphic layers that can be easily controlled through the hierarchic layer controller. VIZSWAT provides a few types of sub-maps, which can be used for multiple map views, time series and X-Y plots. VIZSWAT also provides the capability for recording movies in various formats and publishing high-resolution maps [10]. Belowing are the results in three way of SWAT and VIZSWAT processing.

Climate data input consists of precipitation, maximum and minimum temperature, wind speed, relative humidity and the weather were generator into .dbf file and then imported in the SWAT model.

4. Result and Analysis

A number of output files generated in every SWAT simulation. Subdividing the areas into hydrologic response units (HRU) enables the model to reflect the evapotranspiration and other hydrologic conditions for different land cover/crops and soils (table 2). There are difference files can be extracted from data base: the summary input file (input.std), the summary output file (output.std), the HRU output file (output.hru), the sub basin output file (output.sub) and the main channel or reach output file (reach. output).
4.1. Precipitation analysis

The precipitation value of each sub basin during the complete time period will be analyzed here (table 3). We will see that there is some sub basin having very high precipitation that’s why their soil water content as well as runoff will be high.

### Table 3. Example of precipitation for sub basins extracted from SWAT processing

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Fig. 7. Precipitation for sub basins extracted from SWAT processing.

By the graph, we can analyze the changing of precipitation in the main basin during a long period from 1973 to 2003.

4.2. Soil Water Content

The graph show about the water in the soil profile at the outlet of each sub basin at the end of the time period in mm (fig 8). By using VIZSWAT, map was created which show soil water content level for each sub basin (fig 9). In the above graph and the map, maximum soil water content were found in basins N° 72-76.

Fig 8. Soil water content for sub basins extracted from SWAT processing.
4.3. Surface Runoff Contribution

This is the result generated by the SWAT. It tells about that how much water is yielded from each of the sub basin to the main reach. fig 11 is map of soil water content, in which, level for each sub basin can be determined. High values of surface runoff are found in sub basins N° 11,21,26,31,36,71,76,81,86,101, which are having more than 350mm of surface runoff.
4.4. Sediment yield

Sediment yield is a parameter that tells about the total amount of sediment (tons per hectare) transported into the reach during the time steps. It is the main important parameter which is needed to take any management action at the sub-basin level. Beside of the graph, map for maximum sediment yield of sub-basin system was established by VIZSWAT. In these, we can observe that sediment is yielded during time step is maximum for the sub-basin no 11, 21, 23, 24, 46, 47, and 48. There are total 14 sub-basins which are having more than 100 tons per hectare during the time period. (Fig. 12,13).
Fig. 12. Maximum sediment yield of sub-basin system established by VIZSWAT.

Fig. 13. Maximum sediment yield of sub-basin system established by VIZSWAT.
4.5. Accuracy assessment

Comparing with the statistic surface runoff data of the Tamdao station (outlet of the basin N°12), the correlation can be presented as the graph and statistic values below (fig 14).

Fig. 14. Comparision between observed and simulated data of surface runoff (sub-watershed N°12).

With $R = 0.9081$, this statistic value presente for good relationship and the simulated data can be confidenced. Correlation function is $Y = 1.057039X + 0.3309$ and by this, prediction can be calculated for each HRU.

4.6. Discussion

With long time period of climate and surface runoff data and land cover change, difference type of output parameter can be extracted from the SWAT processing. Base on this parameters many aspect can be discussed as: role of difference type of landcover or soil to surface runoff, soil water content, topographic characteristic to sediment yield or soil erosion, water polution etc.
In the fig.15, good relationship between forest cover to high value of surface runoff is cleared..If compare between results in fig.8 and 9, 10 and 11,12 and 13 , the result presente that where having high soil water content is the low surface runoff and low value of sedimentation. It meaning that good forest cover is good soil water content and less soil erosion.

5. Conclusion

- The SWAT and components of SWAT as VIZSWAT having an interface with Arc GIS software are the most suitable tool for water basin management. The reason for it is by using the software, many factor of a water basin and its sub-basins can be extracted such as:
surface runoff, peak rate flow, soil erodability, erosion practices, nutrient pesticides … This parameter are important criteria for agriculture management separately and also for environmental management in general.

- In the study, the SWAT and VIZSWAT were applied to the Calo watershed in VinhPhuc province for the calculation of soil water content, modeling runoff and sediment yield. Using the observed data of 1973 to 2003 with a good validation, the model was executed to find soil water content, surface runoff and sediment yield for each sub basin and also for whole of the basin area. These parameters can be referenced for planning purpose of reforestation, slope agriculture cultivation, water management etc.

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