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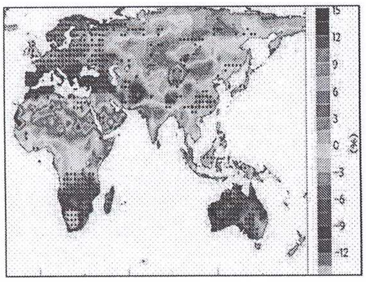
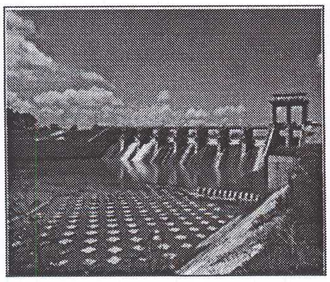

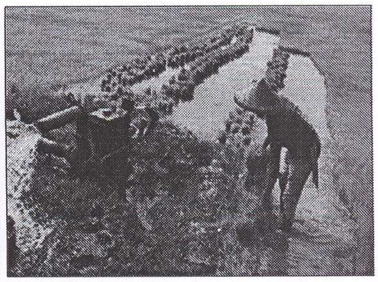

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Viloth Kimala • Ekasit Kositsakulchai

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Keywords: Streamflow, SWAT model, Sedone river basin, Lao PDR.

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Abstract This paper showed the result of the streamflow estimation at Sedone river basin, drainage area of 7,219 Km^2, in Lao PDR by using Soil and Water assessment Tool (SWAT). The basin has different level of terrain as the lowest level of 100 meters to the highest of 2,500 meters. The average of annual rainfall is 1,800 millimeters in the lowland and 3,500 millimeters in the highland within the same river basin. The data for the SWAT model included land use, soil, climate from 1996 to 2010, and the streamflow from 1996 to 2010. Critical parameters were the initial Soil Conservation Service (SCS) runoff curve number for moisture condition II (CN2), available water capacity of the soil (SOL_AWC) and soil evaporation compensation factor (ESCO). Despite data limitation, the result of calibration and validation of the model showed a reliable estimation of monthly streamflow. The value of the coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (NSE) were high which is 0.97 and 0.85, respectively. The model estimated annual streamflow of Sedone basin of 4,420 MCM. This paper reveals the SWAT model is effective to predict hydrological status of river basin. This SWAT model also uses as a tool to analyze hydrological process in order to plan for water resource management in Sedone river basin.

Keywords Streamflow, SWAT model, Sedone river basin, Lao PDR.

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Introduction

Laos PDR is a country with abundant water resources and still has enough to use for the needs of all activities such as supplied for domestic, agriculture and industrial uses and travel we can say that the water resources development is very important, whether it is in the economic and social development. The country consist 11 major watersheds which Sedone river is also an important watershed in economic development of southern of Laos. Therefore, the water resources development is a critical function in line with social economic development. The Sedone basin has different level, lower at 100 meters, and highest at 2500 meters. The average of annual rainfall is 1800 mm in the lowest area to 3,500 mm in the highest area. Most area of the topography of the watershed has a steep and complex mountain, hilly area, slope roofing area from high mountain to the plain. Climate data which is the most critical data using for estimate of the model is limited. In Sedone Basin, there are just four the meteorological stations, Pakse, Salavan, Kongsedone, and Paksong, that daily data is available in term of time series from 1996-2010. Paksong meteorological station is only the station that has highest rainfall, 3500 mm. Therefore, the rainfall of the areas that is in level of 2500 meters and the beginning of the basin effect to most of sub-basins. It makes the estimate streamflow of basin is higher than the reality. According to the report of Water resource and envelopment department on the need of water and decreasing of it which mean the quantity of Sedone River is insufficiency. The level of river lowers than level of irrigation development, and consumption recently with the insufficient water might also affect to the irrigator development project in the future. The monthly average amount of water release of the highest is 1,249 m^3/s and lowest is only 9 m^3/s. Therefore, most of Sedoe basins due to water storage cause of geology.

The quantity of water in dry season is limited which related to lacking of water in this season, about 92% of the annual discharge occurs during the rainy season and about 8% in the dry season. The basin contributes an average annual stream flow of 4,300 MCM, the total stream flow to the Mekong River (DWR and WREA 2008).

Hydrologic model is a very crucial tool for estimation water resource on river basin. Hydrologic models were developed based on the hydrologic cycle imitation. However, there are many components involved in the cycle such as interception, infiltration, depression storage, evaporation, subsurface flow, groundwater flow, overland flow, and channel flow (Chow et al. 1988). Hydrological model including black-box model, lumped (conceptual) model and distributed hydrologic model. In this study, distributed hydrological model select on SWAT model for presented. SWAT is a spatially distributed, physically based hydrological model, which can operate on a daily or monthly time step as well as annual steps for long-term simulations. The SWAT uses spatially distributed data layers for elevation, land use and soil types. Relational databases include soil attributes, weather and crop management data (Bingner 1996; Brown et al. 1996; Arnold et al. 1998; Zhang et al. 2003; Bouraoui et al. 2005; Easton et al. 2008; Ouyang et al. 2008). The SWAT model has been widely applied for simulation of surface runoff, sediment yield, and total phosphorus losses from basin in different geographical locations, conditions and management practices (Saleh et al. 2000; Spruill et al. 2000; Santhi et al. 2001; Van Liew et al. 2003; Qi and Grunwald 2005; White and Chaubery 2005; Wang et al. 2006; Ndomba et al. 2008; Thampi et al. 2010). The purpose of this study to estimate streamflow of Sedone basin, Lao PDR by using Soil and Water Assessment Tool (SWAT) model.

Materials and methods

Study area

The Sedone basin is location between the latitude 15° 00' - 16° 00' N and longitude 105° 35' - 106° 40' E (Figure 1). The Sedone river mainstream has a total length of 240 km. Xeset river is the main tributary with headwater from the Bolaven Plateau. The basin has a total land area of 7,219 km^2 which spans across the provinces of Saravan, (5,160 km^2 or 72% of basin area), Sekong (698 km^2 or 9.7% of basin area) and Champasack (1,354 km^2 or 18% of basin area) provinces and a part in Savannakhet Province (16 km^2 or 0.3% of basin area).

The climate of basin is tropical: hot and humid. The rainy season is mainly affective by the summer monsoon and lasts from mid-May to mid-November most precipitation comes as short, intense thundershowers. Most of the heavy rains take place between July and September. The mean annual precipitation distribute like a coaxial circle ranging from 3,500 mm at Paksong, 1900 at Saravan to less than 1800 mm in the plain area. Mean annual evaporation from 550 mm at Paksong, 2000 mm at Saravan and Pakse, average temperature is 24 - 28°C, (Figure 2).

Description of soil and water assessment tool (SWAT)

Soil and Water Assessment Tool (SWAT) is a river basin scale model developed by Dr. Jeff Arnold for for the United States Department of Agriculture Agricultural Research Service (USDA-ARS) (Arnold et al. 1998) to predict the impact of land management practices on water, sediment and agricultural chemical yields in large and complex watersheds with varying soils, land use and management conditions over long periods of time. SWAT is a public domain model, and is actively supported by the Grassland, Soil and Water Research Laboratory, and Black Land Research Center in Texas (Neitsch et al. 2005). The fundamental concept of the SWAT is Hydrologic Response Unit (HRU). The HRUs are lumped land areas within the sub basin that are comprised of unique land cover, soil and management combinations. Currently, SWAT is embedded in an ArcGIS interface called ArcSWAT. The simulation of the hydrology of a basin is done in two separate divisions. One is the land phase of the hydrological cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. The other division is the routing phase of the hydrological cycle that can be defined as the movement of water, sediments, nutrients and organic chemicals through the channel network of the basin to the outlet. The hydrologic model is based on the water balance equation in the soil profile where the processes simulated include precipitation, infiltration, surface runoff, evapotranspiration, lateral flow and percolation. SWAT partitions ground-water into two aquifer systems: a shallow unconfined aquifer, which contributes to the return flow and a deep and confined aquifer that, besides pumping, is disconnected from the system.

In the land phase of hydrological cycle, SWAT simulates the hydrological cycle based on the water balance equation

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

Where SW_t is the final soil water content (mm), SW_0 is the initial soil water content (mm), t is the time (days), R_{day} is the precipitation on day i (mm), Q_{surf} is the surface runoff on day i (mm), E_a is the evapotranspiration on day i (mm), W_{seep} is the percolation into soil on day i (mm), and Q_{gw} is the return flow on day i (mm).

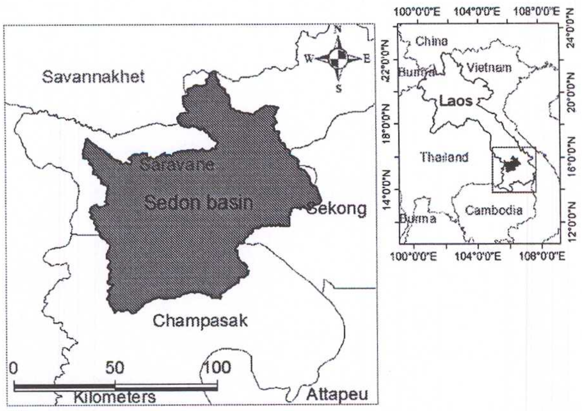


Figure 1 Location of Sedone river basin in Lao PDR.

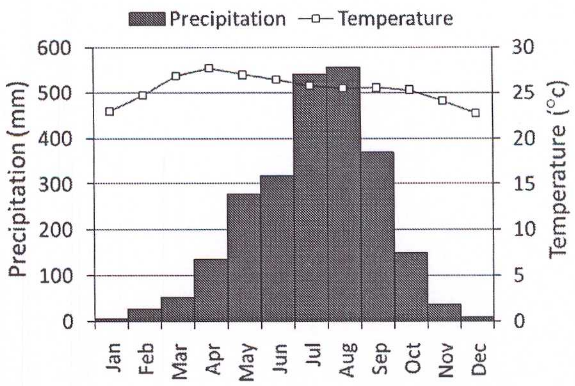


Figure 2 Monthly average temperature and precipitation of Sedone river basin.

SWAT model includes two methods for calculating the retention parameter. In the first one, the retention parameter varies with soil profile water content. This method overestimates runoff in shallow soils. In the second method, the retention parameter varies with accumulated plant evapotranspiration. Calculating daily curve number (CN) as a function of plant evapotranspiration is more dependent on antecedent climate. Three methods are incorporated into SWAT to estimate potential evapotranspiration (PET): the Penman–Monteith method (Monteith 1965), the Priestley–Taylor method (Priestley and Taylor 1972) and the Hargreaves method (Hargreaves et al. 1985).

SWAT provides two methods for estimating surface runoff: the SCS curve number procedure (USDA-SCS 1972) or the Green & Ampt infiltration method (Green and Ampt 1911). Using daily or sub-daily rainfall amounts, SWAT simulates surface runoff volumes and peak runoff rates for each HRU.

In this study, surface runoff is estimated from daily rainfall using modified SCS-CN method which is defined as follows:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \quad (2)$$

Where Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), I_a is the initial abstractions which includes surface storage, interceptions and infiltration prior to runoff (mm), S is the retention parameter (mm). The retention parameter varies spatially due to change in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined as follows:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad (3)$$

Where CN is curve number. The initial abstractions, I_a, is commonly approximated as $0.2S$. Therefore, the SCS curve number equation becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \quad (4)$$

Runoff occurs only when $R_{day} > I_a$.

Preparation of model inputs

The basic spatial input data sets used by the model include the digital elevation model (DEM), land use, soil, climate and observed runoff data.

DEM

Digital elevation model is one of the main inputs of the SWAT Model. Topography was defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution 50m grid in (Figure 3). DEM will be obtained from National Geographic Department, Vientiane Lao PDR. The DEM was used to delineate the boundary of the watershed and to analyze the drainage patterns of the land surface terrain. Terrain parameters such as slope gradient, slope length and the stream network characteristics such as channel slope, length, and width were derived from the DEM.

Land use data.

The most the land use percentage is 70% forest, about 30% agreculture land and others area. The major land use types of the study area are: upper dry evergreen, dry dipterocarp, rice paddy, agricultural plantation, barren land, grassland, urban or built-up area and water bodies, Shows in (Figure 4 Table 1). Land use is one of the most important factors that affect runoff, evapotranspiration in basin. The land use map of the study area was obtained from Ministry of Agriculture and Forests as the agency Lao which is the land use data in 2008.

Soil data

SWAT model requires different soil textural and physic-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content of each soil type. The soil data is obtained mainly from the following sources: Ministry of Agriculture and Forests as the agency Lao PDR, Food and Agriculture Organization of the United Nations FAO (1997), Major Soils of the world FAO (2002). These sources were utilized to extract the necessary soil properties in relation to the major soil type map developed by Lao ministry of water resources. The different sources have helped in correlating and verification of the soil properties. Major soil types in the basin are loam, clay loam, loamy sand, sandy loam and heavy clay, shows in (Figure 5 Table 2).

Climate Data

The climate data variables required by SWAT model for driving the hydrological balance are daily rainfall, minimum and maximum temperature, wind speed, solar radiation and relative humidity data. These data were obtained from Lao National Meteorological Service Agency. The time series data were collected from four stations (Pakse, Paksong, Saravan and Khongsedone) that are located within the watershed and covers a period of fifteen years (January 1996 to December 2010) (Figure 6).

Observed Runoff

The observed daily runoff data at the outlet of the watershed (at point Suvannakhiri station) for the years from 1996 to 2010 were obtained from the Hydrology Department of Ministry of Water Resources of Lao. These data were used for model calibration (1996-2003) and validation (2004-2010).

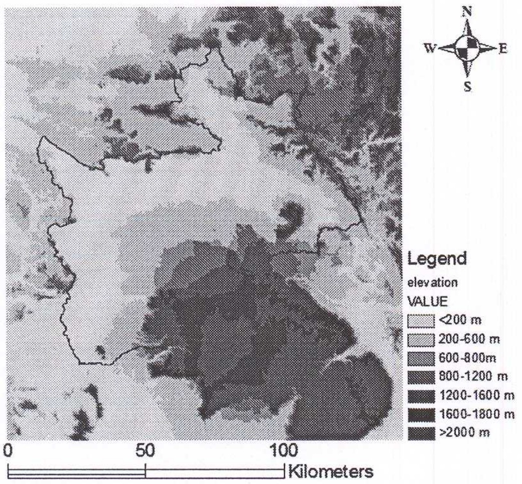


Figure 3 Elevation of Sedone river basin.

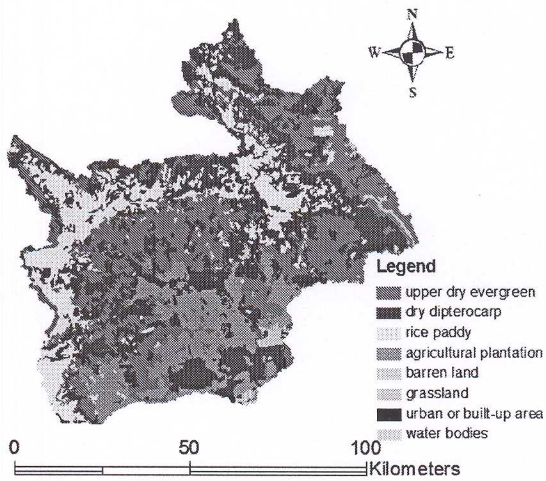


Figure 4 Major of land use of Sedone river basin.

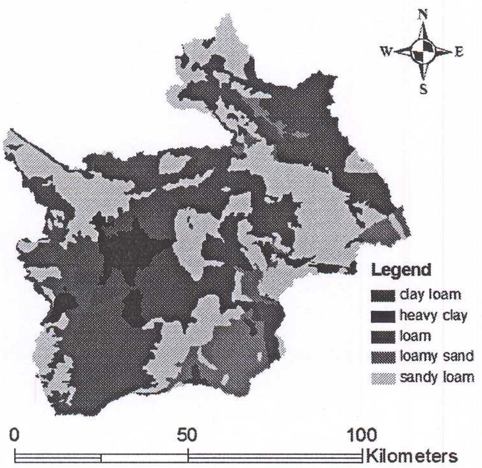


Figure 5 Major of soil of Sedone river basin

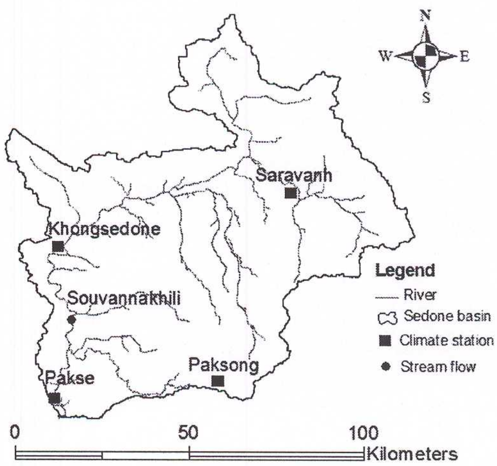


Figure 6 Climate stations of Sedone river basin

Table 1 Major land use of Sedone river basin.

No	Landuse	Area (hectare)	Area (%)
1	upper dry evergreen	226,724.50	31.42
2	dry dipterocarp	267,969.75	37.13
3	rice paddy	124,836.00	17.30
4	agricultural plantation	91,065.00	12.62
5	barren land	105.25	0.01
6	grassland	9,132.25	1.27
7	urban or built-up area	1,664.75	0.23
8	water bodies	200.00	0.03

Table 2 Major of soil of Sedone river basin.

No	Soil	Area (hectare)	Area (%)
1	loam clay	299,548.00	41.51
2	sandy loam	244,755.25	33.91
3	loam	87,253.25	12.09
4	loamy sand	57,722.25	8.00
5	heavy clay	32,418.75	4.49

Model Set-Up

The model set-up processes include steps: data preparation, watershed delineation, HRU definition, definition of weather stations, and editor of model databases, model run and parameter sensitivity analysis. The available time series for daily precipitation covered the period January 1996 to December 2010. Four precipitation stations were chosen for the simulation. Wind speed, maximum, minimum and average temperature, relative humidity and sunshine were available at four stations. Time series for daily surface flow covering the period January 1996 to December 2010 were available at Suvannakhili gauging stations. The DEM, land use and soil map of the study area were also imported into the model and made to overlay to obtain a unique combination of land use, soil, and slope within the watershed to be modeled. The study used the sample with different thresholds for stream definition 1500 hectare, 2500 hectare, 5000 hectare, 7500 hectare, 10000 hectare, 15000 hectare and showed in (figure 7). Therefore, in this study, the minimum threshold area required to discretize the watershed into subbasins was selected as 2500 ha that has resulted in to the definitions of 162 subbasins. In this study, multiple HRUs with 5 percent land use, 5 percent soil, and 2 percent slope threshold were used. The overlay of land use, soil, and slope maps resulted into 22470 HRUs.

Model calibration and validation

Model Calibration

SWAT model includes a large number of parameters that describe the different hydrological conditions and characteristics across the watershed. During the calibration process, model parameters are subject to adjustments, in order to obtain model results that correspond better to measured data sets. After setting up, the model was run for simulation using the default parameter values. The default simulation outputs were compared with the observed data. In this study, the model was calibrated on monthly basis using time series data from January 1997 to December 2003. The first year of the modeling period were used for 'model warm-up'. The warm-up period allows the model to get the hydrologic cycle fully operational

Model Validation

In the validation process, the model is operated with input parameters set during the calibration process without any change and the results were compared against an independent set of observed data. In this study, the model was validated on monthly basis using time series data from January 2004 to December 2010.

Evaluation of the Model

Performance of the model was evaluated in order to assess how the model simulated values fitted with the observed values. Several statistical measures are available for evaluating the performance of a hydrological model. In this study, during calibration and validation periods, the goodness-of-fit between the simulated and measured values were evaluated using the coefficient of determination (R^2) and Nash-Sutcliffe coefficient of efficiency (*NSE*) (Nash and Sutcliffe, 1970)

The coefficient of determination (R^2) describes the proportion of the total variance in the measured data that can be explained by the model. It is an indicator of strength of relationship between the observed and simulated values. It measures how well the simulated versus observed regression line approaches an ideal match and ranges from 0 to 1, with a value of 0 indicating no correlation and a value of 1 representing that the predicted values area exactly equal to the measured values (Krause et al. 2005). It is defined as:

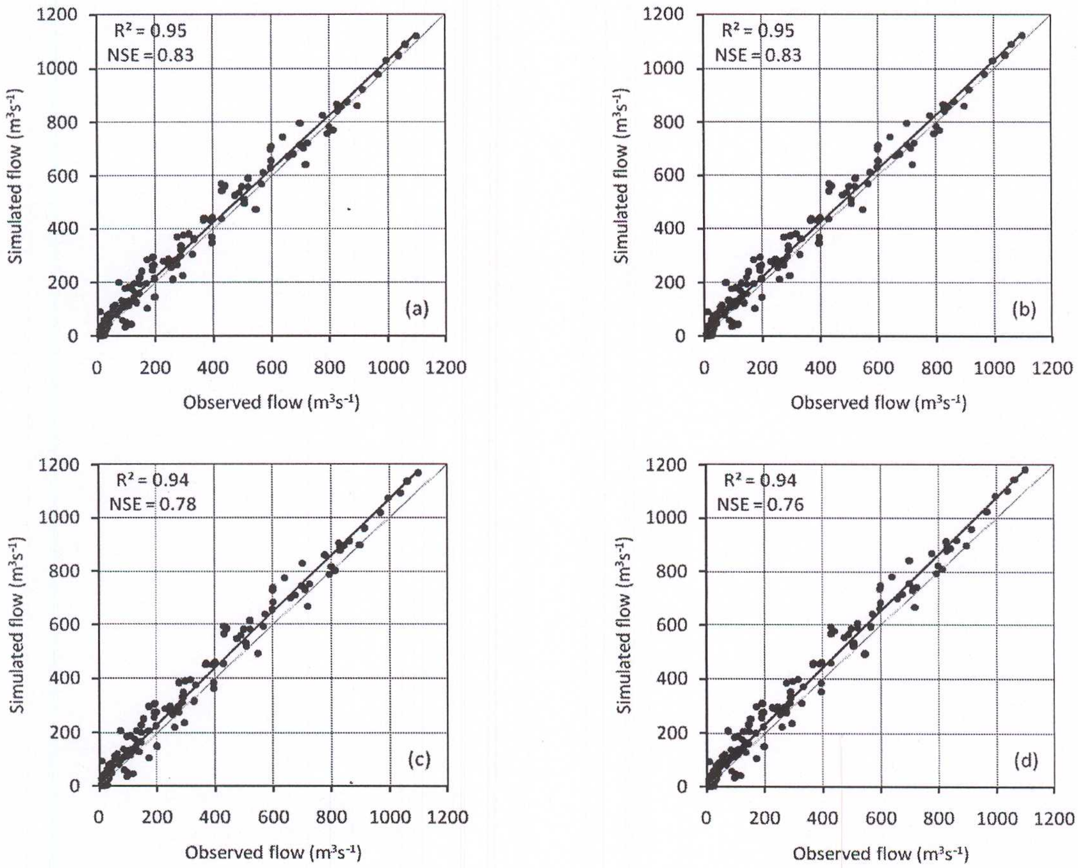
$$R^2 = \left[\frac{\sum_{i=1}^{n} \left[(Q_{obs} - \overline{Q}_{obs})(Q_{sim} - \overline{Q}_{sim}) \right]}{\left[\sum_{i=1}^{n} (Q_{obs} - \overline{Q}_{obs})^2 \right]^{0.5} \left[\sum_{i=1}^{n} (Q_{sim} - \overline{Q}_{sim})^2 \right]^{0.5}} \right]^2 \qquad (5)$$

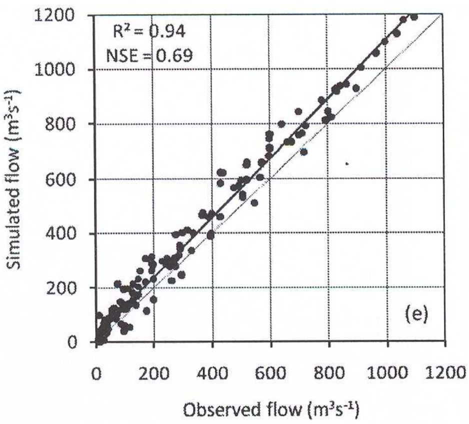
Where, Q_{obs} is the i^{th} observed parameter, Q_{avgobs} is the mean of the observed parameters, Q_{sim} is the i^{th} simulated parameter, Q_{avgsim} is the mean of model simulated parameters and N is the total number of events

The Nash-Sutcliffe coefficient of efficiency (*NSE*) has been reported in scientific literatures for model simulations of flow, and water quality constituents such as flow, sediment, nitrogen, and phosphorus yields (Moriasi et al. 2007). It is used to assess the predictive power of hydrological models and indicates how well the plot of the observed versus simulated values. The closer the model efficiency is to 1, the more accurate the model is. It is defined as:

$$NSE = 1 - \frac{\sum_{i=1}^{n} (Q_{obs} - Q_{sim})^2}{\sum_{i=1}^{n} (Q_{obs} - \overline{Q}_{obs})^2} \qquad (6)$$

Where *NSE* is the Nash-Sutcliffe efficiency of the model; Q_{obs} and Q_{sim} are the observed and simulated values, respectively, and Q_{avobs} is the average observed value.





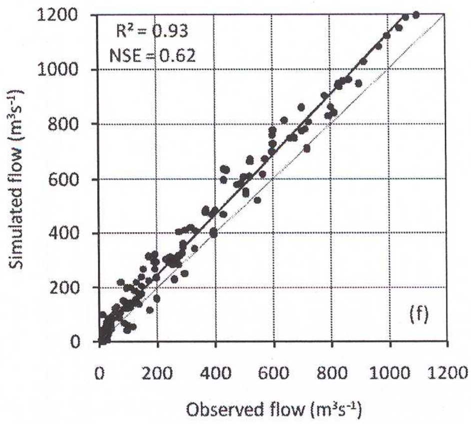


Figure 7 Scatter plot of observed and simulate flows with different thresholds for stream definition (a) 1500 hectare, (b) 2500 hectare, (c) 5000 hectare, (d) 7500 hectare, (e) 10000 hectare, (f) 15000 hectare.

Results and Discussion

Result of study demonstrated the reliable estimate streamflow of The Soil and Water Assessment Tool (SWAT) model has been calibrated and validated on monthly bases to predict the hydrological processes from the Sedone basin using time series data of 15 years from 1996- 2010. The first years of the modeling period were used for 'model warm-up'. Data 1997- 2003 were used for the calibration period and the remaining data sets from 2004 - 2010 were reserved for the validation period. During the delineation process, using a threshold value of 2500 ha, the watershed is subdivided into 162 sub-basins, the overlay of land use, soil, and slope maps resulted into 22470 HRUs. This resulted in a better representation of the hydrological processes and good estimation of simulated values which had a better model efficiency while comparing with the observed values.

Parameter sensitivity analysis

The parameter sensitivity analysis has used ArcSWAT extension for the whole catchment area. The sensitive parameters considered for calibration were CN2: initial SCS runoff curve number for moisture condition II, SOL_AWC: available water capacity of the soil layer (mm H2O/mm soil) and ESCO: soil evaporation compensation factor, many studies select sensitive parameter (Shimelis et al. 2008; Wang et al. 2008; Santosh et al. 2010). (Table 3) describes the most sensitive flow parameters and their fitted values.

Model calibration

During the calibration period from 1997- 2003, the simulated average monthly flow matched well with the average monthly measured flow (with R^2 = 0.97 and NSE = 0.85) (Figure 8) shows the comparison of the simulated versus observed average monthly flow.

It may be observed from the figure that the simulated average monthly flow (shown as solid line) is consistently under the observed average monthly flow. This shows that the trend of seasonal variability and monthly average discharges are generally well captured. The adequacy of the model is further indicated by its clear response to extreme rainfall events resulting in high streamflow in August 2000-2001. However, the model is overestimation, the peak monthly flow during (2000) of the simulation periods. Nevertheless, as it can be clearly seen on simulated versus observed average monthly flow shown in (Figure 10).

Model validation

SWAT model also successfully validated for flow from 2004 to 2010. Monthly flow rates were well predicted and measured and simulated monthly flows matched well (with R^2 = 0.96 and NSE = 0.83) (Figure 9 and 11). This shows that the trend of seasonal variability and monthly average discharges are generally well captured. However, the model is overestimation, the peak monthly flow in 2005 of the simulation periods.

During both calibration and validation periods, the difference between the simulated and observed values might be attributed to difference of rainfall inputs in basin from annual rainfall is 1800 millimeters in the lowest area to 3,500 millimeters in the highest area. The other possible reason might be attributed to lack of data on the management and various water use abstractions from the reservoir such as water for domestic use and irrigation projects. Clearly there is abstraction of water from the reservoir for irrigation and other domestic purposes. However, since there is no available information on the amount of water used for these purpose, these water use were not included in the simulation.

The hydrological water balance analysis showed the total amount of precipitation falling on the subbasin during the time step, actual evapotranspiration from the basin and the net amount of water that leaves the basin and contributes to streamflow in the reach (water yield). The water yield includes surface runoff contribution to streamflow, lateral flow contribution to streamflow (water flowing laterally within the soil profile that enters the main channel), groundwater contribution to streamflow (water from the shallow aquifer that returns to the reach) minus the transmission losses (water lost from tributary channels in the HRU via transmission through the bed and becomes recharge for the shallow aquifer during the time step).

The result showed that overall average annual water yield as simulated by the SWAT model for the entire basin about 1682 mm. The average annual values of various water balance components for the study watershed are: precipitation 2,277 mm, actual ET 522 mm, percolation 1037 mm, groundwater 970 mm and surface runoff 613 mm, in (Table 4) shows annual surface runoff of simulated and annual surface runoff observed.

The thresholds of sub-basin will make the estimation of streamflow close to the actual value of observation because the sample area of study has very different topography and rainfall. The result of study showed the changing of sub-basin component that effect to the estimation of stream. If the threshold of sub-basin is too large, it will effect to streamflow is higher than actual observation. But if it's too small, the estimation process will take too much time and the result will not be better.

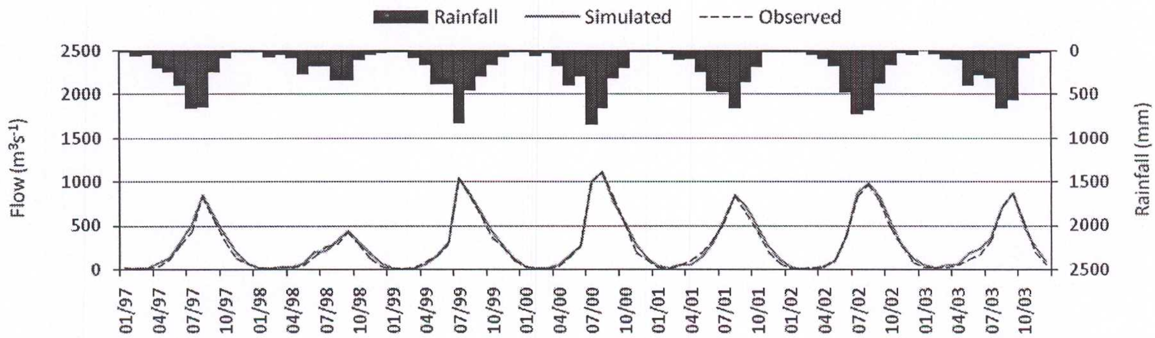


Figure 8 Observed and simulated monthly flow superimposed with monthly rainfall during calibration period (1997-2003).

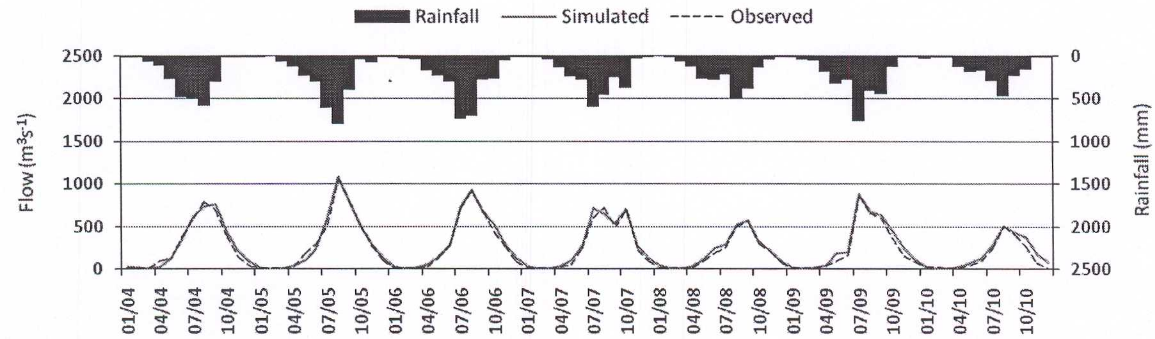


Figure 9 Observed and simulated monthly flow superimposed with monthly rainfall during calibration period (2004-2010).

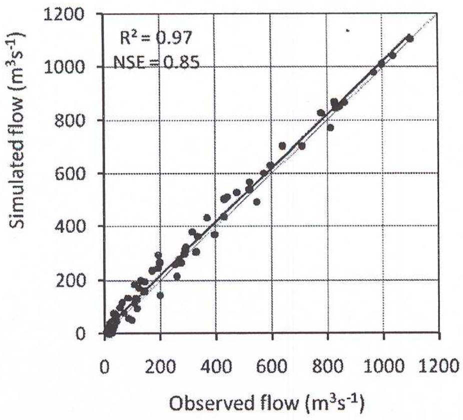


Figure 10 Scatter plot of observed and simulate flows during calibration 1997-2003.

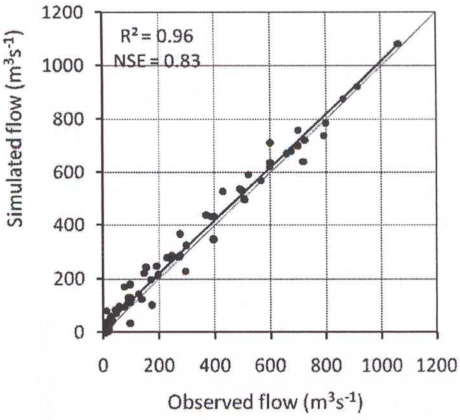


Figure 11 Scatter plot of observed and simulate flows during validation 2004-2010.

Table 3 Calibrated values of model parameters.

Parameter	Description	Model range	Fitted value
CN2	Initial SCS runoff curve number for moisture condition II	±20%	-5%
SOL_AWC	available water capacity of the soil	±20%	+5%
ESCO	soil evaporation compensation factor	0-1	0.4

Table 4 Annual surface runoff of simulated and observed.

No	Description	Annual surface runoff (MCM)
1	Simulated flow	4,420.00
2	Observed flow	4,300.00

Conclusion

The SWAT model was applied to the Sedone Basin for the modelling of the hydrological water balance. It was successfully calibrated and validated for the basin. The model evaluation statistics for streamflows gave well. The results showed reliable estimates of monthly surface runoff yield with relatively high coefficient of determination (R^2) and Nash-Sutcliffe model efficiencies (*NSE*) during both calibration and validation period. The R^2 values were 0.97 and 0.96 respectively for runoff during the calibration and validation period. A good agreement between measured and simulated monthly flow was also demonstrated by *NSE* values of 0.85 and 0.83 respectively for calibration and validation periods. The study shown simulated runoff were close to the measured values during both calibration and validation periods except where the model the predicted values were generally overestimated by the model. However, the overall well captured.

The study used the sample with different thresholds is a good method of estimate streamflow in Sedone basin because its limitation of data and difference of rainfall and condition of the basin. The model needs to use the data of the area close by the control of sub-basin, so the Sedone basin is distribute into many sub-basins to make good proportion. Despite data limitation, the SWAT model produced good simulation results for monthly time steps. In general, SWAT model predictions are acceptable and thus can be considered as a planning tool for watershed management. It is a capable tool for further analyzing of the hydrological processes and water resources planning and management in the study area.

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