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Sensitive Parameter Analysis of Forest Restoration with Pinus Kesiya On Small Watershed, Northern of Thailand

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Abstract
Most of the northern part of Thailand has undergone forest restoration with Pinus kesiya, which has been deteriorated by monoculture for a long time. Thus, the Pinus kesiya is a fast-growing tree and thrives well in harsh, challenging environmental conditions. Nowadays, the forest restoration area has been replaced with native plants for a long period of time—more than 45 years in some areas—resulting in the ecosystem structure improving accordingly. both in the forest structure. The process of decomposing litter includes the soil hydrologic characteristics, which are crucial to the soil water storage process and affect the water services in the stream. Therefore, the SWAT model was used as a tool for planning the watershed management area of cedar forests that may be affected by land use changes or climate change in the future.

The Huay Nam Kud watershed area represents a small watershed in which forest has been restored with Pinus Kesiya, about one square kilometer. The result showed that the most sensitive parameter analysis used by the SWAT-CUP Program was six parameters that impact runoff, namely GW_DELAY, GWQMN, GW_REVAP, REVAPMN, ESCO, and SOL_AWC, respectively. The model's accuracy was determined through model calibration and validation processing by comparing the observed runoff data from the Huay Nam Kud water level station with the simulated runoff data from the SWAT model. The results were revealed as the coefficient of determination (R2) and the Nash-Sutcliffe efficiency coefficient (NSE). The result of model calibration using runoff data from 2008 to 2010 was R2 and NSE with 0.87 and 0.76, respectively. On the other hand, the model validation by using runoff data from 2017 to 2020 was R2 and NSE with 0.72 and 0.70, respectively.

Keyword: Forest Restoration, Sensitive Parameter, SWAT Model

Introduction

The steeped slope watershed has a crucial impact on the ecosystems on the ecosystems surrounding the top area and below it. Thus, that area must be a completely forest area since the forest area was used to absorb rainfall and release water body by the watershed flow path to the stream, which provided a sufficient, ordinarily streamflow amount and satisfied quality. However, it was found that the forest ecosystem was exploited on a large scale, including encroachment for monoculture agriculture and cultivation of the head watershed area in northern Thailand in the past. As a result, the ecosystem uninterrupted to deteriorate, which affects soil erosion, rapid floods, high turbulence weather, etc. Therefore, reforestation of the head watershed area is crucial. The government organization responsible for improving and restoring watershed areas prefers to be covered by Pinus kesiya because it is a fast-growing tree species that is resistant to drought, shallow soil, and low soil fertility. It is suitable for highly variable weather conditions and is an evergreen tree species that helps reduce severe weather conditions. It can also assist with the process of environmental restoration in terms of improving soil nutrients to be suitable for replacement by the native plant community, soil characteristics in the area, and the physical properties of the soil by increasing porosity and reducing soil bulk density. Currently, the forest restoration with

Pinus Kesiya has been succession by native species for a long period, resulting in the ecosystem structure gradually improving in terms of forest structure, canopy layers, decomposition of plant debris, and soil hydrology, which are significant for soil water storage, and the provision of stream discharge. This study is one component of determining the influence of climate change on the amount and characteristics of runoff in forest restoration watershed by applying the Soil and Watershed Assessment Tool (SWAT). Therefore, the model used must be examined to see if it can be applied in the study area. This is to improve more efficient watershed management and sustainable watershed management planning that has been restored with Pinus kesiya.

The SWAT model is one of the most commonly used hydrological models, which is a continuous-time, spatially distributed simulation developed by the United States Department of Agriculture-Agriculture Research Service. This model has been employed frequently since its development and is now one of the most widely used hydrological models. The studies based on the SWAT model for streamflow simulation have been conducted all over the world, and parameter optimization of streamflow simulation has been conducted widely using this model. In addition to streamflow simulation, the SWAT model can also apply to studies of climate change, land use change, non-point source pollution, and sediment simulation. Therefore, the main reasons for deciding the SWAT model in this study are applicability and functionality.

Study Site

The Huaynamkud watershed is a 1 sq.km catchment that occupies the northern part of Thailand. (Fig 1) The mainstream stretches for 1.48 km and has a total stream length of about 2.45 km. The elevation of the watershed ranges from 1,286.9 to 1,550.7 msl, and the average is approximately 1,430 msl. The percent of slope range from 3.08 to 78.64, and the average is approximately 28.41. The average rainfall amount is 1,821.5 mm, the highest is about 337.2 mm (September), and the lowest is in February (7.9 mm).

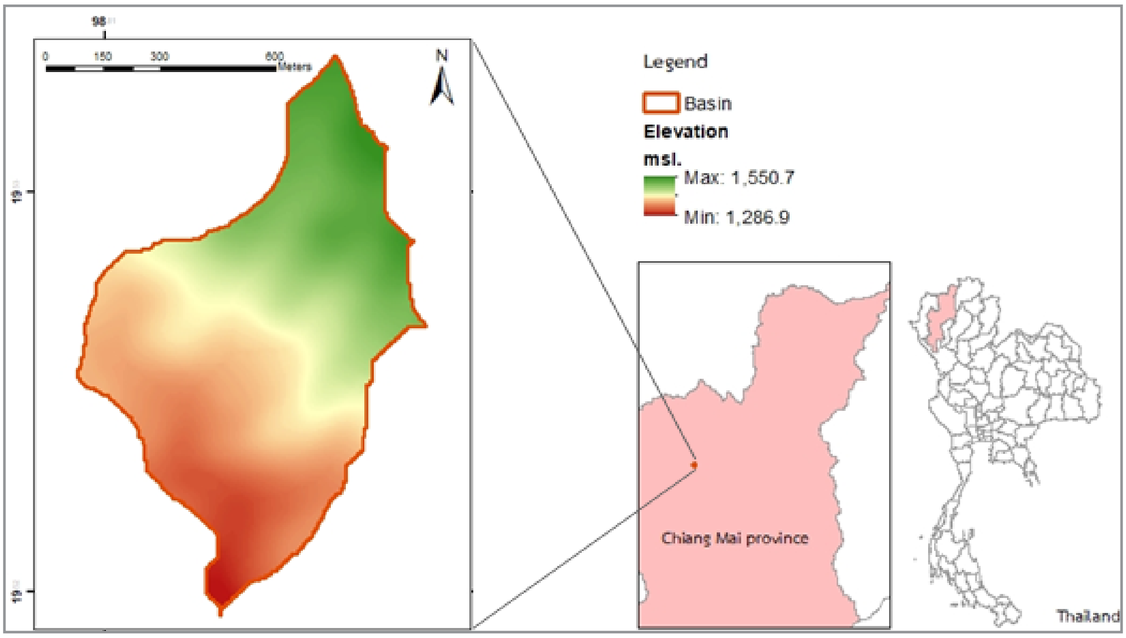

Figure 1: Huaynamkud watershed in the Chiang Mai Province, Thailand

Model Setup and Simulation

The SWAT model is implemented in ArcMap software. Firstly, the SWAT model extracts the river networks based on digital elevation model (DEM) data and divides them into sub-basins. Then, the model inputs the soil type, land use, and terrain slope data, before further partitioning the sub-basin into hydrological response units (HRUs) according to the thresholds for these three information types. The SWAT model uses a series of conceptual model to calculate the daily, monthly, or yearly flow at every sub-basin outlet. Finally, sub-basin flows are summarized to obtain the streamflow, which depends on topography, soil, land use, and climate conditions. Thus, the parameters in the SWAT model need to improve the regional applicability of the model.

After spatial input data includes DEM, soil data, and land use data. In this study were used the daily weather variables includes precipitation (mm), minimum/maximum air temperature (°c), and air humidity (%) for the period 1999 to 2022. Daily stream discharge for Huaynamkud water level station were obtained from a weir 120-V-Notch.

The watershed was divided into 7 sub-basins and 8 numbers of HRUs. After setting up the model, the default simulation of streamflow was conducted in the Huaynamkud watershed. For the calibration, we used monthly streamflow data for the period 2008 to 2011, and for the validation, we used monthly streamflow data for the period 2017 to 2020. The sensitivity analysis of the study was based on this calibration period. The SWAT-CUP enables sensitivity analysis, calibration, validation, and uncertainty analysis of the SWAT model. The model performance was evaluated using the coefficient of determination (R2) (1) and the Nash-Sutcliffe efficiency (NSE) (2). The R2 value is an indicator of the strength of the linear relationship between the observed and simulation data. The NSE simulation coefficient indicates how well the plot of observed versus simulated value fits the 1:1 line and +1 being in perfect agreement between the model and observed data. Both of R2 and NSE are sensitive to high flows. The equations are shown below.

$$R^2 = \left[\frac{\sum_{i=1}^{n}(o_i - \bar{o})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(o_i - \bar{o})^2}\sqrt{\sum_{i=1}^{n}(P_i - \bar{P})^2}} \right]^2 \quad (1)$$

$$NSE = \frac{\sum_{i=1}^{n}(o_i - P_i)^2}{\sum_{i=1}^{n}(o_i - \bar{o})^2} \quad (2)$$

Where Oi is the measured data on day i, Pi is the simulated output on day i, o¯is the average of the measured value during the simulated period, P¯is the average of the simulated value during the simulated period.

Base on model evaluation performance ratings adopted from Moriasi et.al. and Liew and Garbrecht (2007), streamflow simulations were considered reasonable if R2>0.5 and NSE>0.5 [1].

Sensitive Parameter Analysis

The sensitivity parameter assessment using SWAT Calibration and Uncertainty Program (SWAT-CUP) will determine which parameters should be adjusted to respond to the hydrological process and make the simulation runoff as close to the observed runoff as possible. The SWAT-CUP program uses the trial and error principle to assess the sensitivity of the parameters. Since the SWAT model uses many variables, the SWAT-CUP program can adjust the parameters as needed, making it convenient for users and reducing the adjustment time. The parameters used to adjust the error values related to the runoff, which are mostly the parameters, are shown in Table 1.

Table 1: Input parameter of SWAT model

No.	Input parameter	Category	Description of parameter	Min-Max range
1	CN2	MGT	SCS runoff curve number	0.5-1.5
2	ALPHA_BF	GW	baseflow recession factor (1/days)	0.0-1.0
3	REVAPMN	GW	Threshold depth of water in the shallow aquifer for percolation to the deep aquifer (mm)	0.0-500.0
4	GWQMN	GW	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0.0-5000.0
5	SOL_AWC	SOL	Available water capacity of soil layer (mm H2O/mm soil)	0.5-1.5
6	SOL_Z	SOL	Depth from soil surface to bottom of layer (mm)	0.0-800.0
7	SOL_K	SOL	Saturated hydraulic conductivity (mm/hr)	0.5-1.5
8	GW_REVAP	GW	Groundwater “revap” coefficient	0.02-0.2
9	GW_DELAY	GW	Groundwater delay (days)	0.0-500.0
10	Surlag	BSN	Surface runoff lag coefficient	0.05-24.0
11	CANMX	HRU	Maximum canopy index	0.0-100.0
12	ESCO	BSN	Soil evaporation compensation factor	0.01-1.0

Result

The result found that the six most sensitive parameters to runoff were GW_DELAY, GWQMN, GW_REVAP, REVAPMN, ESCO, and SOL_AWC, respectively, with p-values close to zero and the highest t-Stat values shown in Table 2. The results found that there was only one parameter in the .SOL category because additional soil data was collected in the study area and the model database was adjusted. The most category factor was the .GW so the baseflow and peak of runoff had to be reduced.

The results of the model calibration found that the R2 and NSE values were 0.87 and 0.76, respectively (Fig 2), which is considered a very good criterion for the NSE value. The results of the model validation found that the R2 and NSE values were 0.72 and 0.70, respectively (Fig 2), which is considered a good criterion for the NSE value [2-4].

Table 2: Summary of Sensitivity Analysis

SWAT input parameter	Category	Local sensitivity		
		t-stat	P-value	Ranking
SOL_AWC	.sol	-21.7642	0.0000	1
ESCO	.hru	-16.9401	0.0000	2
REVAPMN	.gw	-5.2341	0.0000	3
GW_REVAP	.gw	-1.9396	0.0275	4
GW_DELAY	.gw	-1.6161	0.0306	5
GWQMN	.gw	-1.4712	0.0415	6

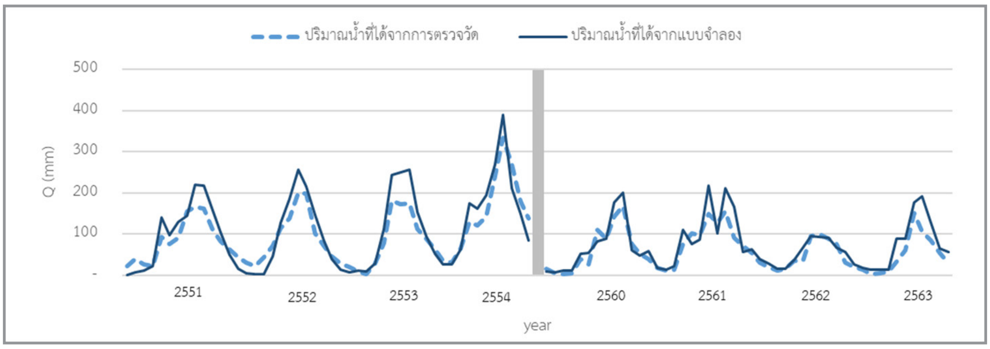

Figure 2: Model calibration and model validation

Summary

The SWAT model can be applied to a good level of small watersheds in Thailand to consider each hydrological factor. The Huaynamkud watershed, SOL_AWC.sol, ESCO.hru, REVAPMN.gw, GW_REVAP.gw, GW_DELAY.gw, and GWQMN.gw were evaluated to be most sensitive input parameter. These parameters are also recommended to utilize for the similar physical pattern of another tropical watershed [5].

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