

# Parameter Sensitivity Test of SWAT Hydrological Model On Two Different Resolutions (A Case Study of Upper Cisadane Subbasin, West Java)

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## ABSTRACT

A sensitivity analysis of SWAT parameters was conducted on different spatial resolutions. The sensitivity analysis aimed to determine the input parameters that have the most impact on the output of the model. Resolution of different inputs in the SWAT analysis can produce different input parameters that can affect the output. The purpose of this study was to identify the level of sensitivity of the parameters used in the SWAT model simulated on two different resolutions, *i.e.* 1: 100,000 and 1: 250,000. A sensitivity test was conducted manually using the absolute sensitivity method, *i.e.* a method to test the sensitivity of the parameters of SWAT model that can change (either increase or decrease) one by one while the other parameters are constant. The results show that the Nash-Sutcliffe Efficiency (NSE) coefficients derived after calibration of the SWAT models on both resolutions of maps indicate similar performance of the models, with the category for the daily simulation of excellent (NSE coefficients of 0.55 and 0.54), while the monthly simulation is categorized as very satisfactory (NSE coefficients of 0.80 and 0.82). The sensitive parameters of the SWAT model identified in the current study include CN2 (initial SCS runoff curve number for moisture condition II), Alpha\_BNK (flow recession constant or recession proportional to the banks of the river), CH\_K2 (effective hydraulic conductivity in main channel alluvium), CH\_N2 (Manning's "n" value for the main channel), ESCO (soil evaporation compensation factor), GW\_Delay (groundwater delay), and GW\_Revap (groundwater "revap" coefficient).

**Keywords:** Absolute sensitivity method, parameter sensitivity, daily simulation and monthly simulation, SWAT

## ABSTRAK

Analisis sensitivitas parameter SWAT dilakukan pada resolusi input yang berbeda. Analisis sensitivitas dapat menentukan parameter-parameter *input* yang memiliki peran paling berpengaruh terhadap *output*. Resolusi *input* yang berbeda dalam analisis SWAT dapat menghasilkan parameter-parameter input yang berbeda sehingga dapat menyebabkan pengaruh terhadap *output*. Tujuan penelitian ini adalah untuk mengidentifikasi tingkat sensitivitas parameter dalam model SWAT pada dua resolusi skala yang berbeda yaitu pada skala 1:100.000 dan skala 1:250.000. Uji sensitivitas dilakukan secara manual dengan menggunakan metode *absolute sensitivity* yaitu mengubah (baik menaikkan ataupun menurunkan) data base dalam tiap parameter model SWAT satu persatu sedangkan parameter lain tetap. Nilai NSE dari kalibrasi pada kedua resolusi skala menunjukkan nilai yang sama, dengan kategori pada simulasi harian tergolong memuaskan (nilai NSE 0.55 dan 0.54) sedangkan simulasi bulanan tergolong sangat memuaskan (nilai NSE 0.80 dan 0.82). Tingkat sensitivitas parameter dapat dibagi menjadi tiga kelompok yaitu sensitif, kurang sensitif dan tidak sensitif. Simulasi harian dan bulanan pada kedua skala menunjukkan parameter-parameter sensitif yang sama yaitu Alpha\_BNK (faktor alpha aliran dasar 'bank storage'), CN2 (bilangan kurva aliran permukaan), CH\_K2 (hantaran hidrolis saluran utama), CH\_N2 (Nilai Manning untuk saluran utama), ESCO (faktor evaporasi tanah), GW\_Delay (waktu "delay" air bawah tanah), dan GW\_Revap (koefisien "revap" air bawah tanah).

**Kata Kunci:** Metode *absolute sensitivity*, sensitivitas parameter, simulasi harian, simulasi bulanan, SWAT

## INTRODUCTION

Hydrological model is a mathematical model used to simulate the water balance in a hydrological area (watershed). Soil and Water Assessment Tool (SWAT) is one of the popular model used to predict long-term effects of land-use practices. The model is based on the physical conditions of land so it needs detailed data for each input parameter. SWAT is a model that has a medium complexity and can be used for a continuous analysis. Neitsch *et al.* (2005) suggested that the SWAT model has several advantages, namely among others built on the processes that occur by gathering information on climate, soil properties, plants, and land management belong to a watershed. It also allows the users to evaluate the long-term impacts of environmental change on a watershed. The development of SWAT model consists of several preliminary stages including data collection, database creation and model simulation. The next stage is to analyze the sensitivity test of the models before calibration and validation of the models were performed. Analysis of sensitivity test of a hydrological model is the key to determine the uncertainty of a quantification model (Xiaomeng et al. 2012). If a small change in the input parameter leads to a drastic change on the output, then the output is very sensitive to the input parameter. Therefore, it can be argued that the sensitivity analysis refers to the determination of individual input contribution on the uncertainty in the model output.

A sensitivity analysis will be determined using the input parameters that influence the variability of the output, in which the influential input parameters can be determined based on: 1) the input parameters are important, 2) the parameters interact one another; and 3) a constant parameter or insignificant parameter to the output. Focusing on the sensitive parameters can provide insights and values of forecasts to reduce uncertainty of the models. Thus, the sensitivity analysis aims to streamline the models of complex systems such as efficiency of time, efforts, and costs for using the models. Several studies have compared the use of SWAT model in different watersheds and showed satisfactory results. The use of spatial data based on the literature studies generally use different resolutions. The resolutions of the base maps vary, among others, the use of soil map with a review scale and land use map with a detailed scale. The different input parameters become one of the foundations for comparative resolution of two different spatial data for model simulation. However, comparing the SWAT models, especially the sensitive parameters

used for the same watershed has not been studied intensively. Therefore, in the current study, a SWAT model was developed for a watershed using two different spatial resolutions, then the sensitivity test was applied to determine the input parameters that affect each spatial resolution for the same watershed. This study aims to identify the level sensitivity of parameters used in a SWAT model applied for two different spatial resolutions.

## MATERIALS AND METHODS

### Location of the Study

The study was conducted in the upper Cisadane Subbasin with the outlet located in Batubeulah, West Java. The study was conducted in March 2015 until February 2016. The total area in the upper Cisadane Subbasin is 84,115 ha. The upper Cisadane Subbasin is geographically located at  $106^{\circ}28'53.61''$  -  $106^{\circ}56'42.32''$  E and  $06^{\circ}31'21.54''$  -  $06^{\circ}47'16.87''$  S. The outlet of the watershed was located at  $106^{\circ}41'211''$  E and  $06^{\circ}31'21''$  S in Batubeulah, West Java. According to Schmidt and Ferguson climate classification, the location of the study is included in the climate type A that is very wet (Q value = 0.067). The rainfall analysis in the study area was conducted using Thiessen Polygon method using the rainfall data obtained from several weather stations.

### Data Collection

A set of computer software (10.1 Arc.GIS and software Arc.SWAT 2012) and Global Positioning System (GPS) were used in the study. The data were collected from literature and government agencies, which include 1) soil maps with a scale of 1:100,000 and 1:250,000; 2) land use maps and Indonesia land map; 3) rainfall and climate data from ten-year period of 2004-2014 obtained from several rainfall stations (*i.e.* Dramaga, Kracak, Pasir Jaya, Empang, and Cihideung) and weather stations of Dramaga and Citeko; and 4) the daily discharge data collected from the outlet of the watershed in Batubeulah for the period of 2004-2014.

This study was conducted in two stages. The first stage was the secondary data collection. The secondary data collection is necessary to develop a database containing the model inputs. The second stage was running the simulations for a SWAT model, which were divided into several separated stages (Figure 1).

### Data Analysis

The data analysis was carried out on three levels of data contained in an output file (SWAT

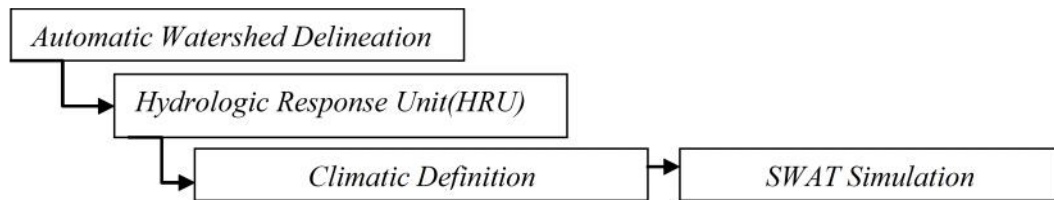


Figure 1. The stages for running the simulations of a SWAT Model.

output file), which were summarized in the file HRU (Hydrologic Response Unit), SUB (Subbasin), and RCH (the results of instream variables, e.g. stream flow). The data analysis conducted in this study includes:

*Sensitivity analysis of model parameters:* The sensitivity analysis was performed automatically using an application SWAT - CUP 2012 version using the procedures of SUFI - 2.

*Calibration:* The calibration was conducted by comparing the model with the streamflow test, which was statistically measured using daily discharge data collected in the period of 2012. The statistical analysis was performed using the coefficient of Nash - Sutcliffe Efficiency (NSE) presented in equation (1) and the coefficient of determination ( $R^2$ ) presented in equation (2).

$$E_{NS} = \left[ \frac{\sum_{i=1}^n (O_i - S_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2} \right] \dots\dots\dots (1)$$

$$R^2 = \frac{(O - \bar{O})^2 - (O - P)^2}{(O - \bar{O})^2} \dots\dots\dots (2)$$

- ENS = Nash - Sutcliffe coefficient
- O<sub>i</sub> = Actual value
- S<sub>i</sub> = Value simulation/prediction
- n = Number of data
- O = The average value of the actual
- P = Simulation data

The sensitivity analysis on the input parameters used in the simulations of a SWAT model for the upper Cisadane Subbasins was conducted on two scales or resolutions of base maps. Each scale of base maps is made up of homogeneous basic maps with the same resolutions, including the soil maps, land use and topographic maps derived from Digital Elevation Model (DEM). The scales of the maps used are 1:100,000 and 1:250,000. The sensitivity test was performed manually using the absolute

sensitivity method. Absolute sensitivity method is a method to test the sensitivity of the parameters of SWAT model that can change (either increase or decrease) one by one while the other parameters are constant. The test was conducted to see the effect of the resolutions or scales of the maps used and to find out the parameters that are sensitive in the evaluation of the models.

*Validation:* The daily discharge data NSE collected in the period of 2014 was used for the validation of the SWAT model developed. The statistical model is widely used to demonstrate the performance of the model because it can provide more accurate information about the model. Nash (1970) provides the statistical value criteria for NSE as presented in Table 1.

**RESULTS AND DISCUSSION**

The delineation of the upper Cisadane Subbasin is automatically performed by entering the results of the models. There is a big difference on the amount of area measured from the two scales of maps, namely on a scale of 1:100,000 the total area measured is 84,115 ha, while on a scale of 1:250,000 the total area measured is 84,089 ha. The difference of the area measured from both scales of maps is 26 ha. If the difference is <5%, then it is relatively negligible for modeling on a daily time span (Indarto 2010). HRU formation method used is the percentage threshold by threshold, i.e. 0% for the soil type, 0% for land use, and 0% for slope. The number of HRU formed for both scales of maps is different, i.e. 1453 HRU for the scale of 1:100,000 and 2149 HRU for the scale of 1:250,000, although the number of subbasin is same, i.e. 37 subbasins

Table 1. Criteria of the model performance based on the NSE coefficient.

Performance Level	NSE
Good (Very Satisfactory )	NSE ≥ 0.75
Satisfactory	0.75 > NSE > 0.36
Less Satisfactory	NSE < 0.36

Source: Nash (1970 ).

Table 2. SWAT model performance after calibration.

Period	Scale	NSE	R <sup>2</sup>	Category
Daily	1:100,000	0.55	0.644	Excellent
	1:250,000	0.54	0.576	Excellent
Monthly	1:100,000	0.80	0.879	Very Satisfactory
	1:250,000	0.82	0.875	Very Satisfactory

for each scale. This is due to the differences in input data for each simulation of different models. The input characteristics on a scale of 1:100,000 are more specific, while the input characteristics on a scale of 1:250,000 are more general. The river flow dynamics that affect the output of the simulated models is the result of interaction between climatic and hydrological characteristics of the watershed as the input parameters. This result is in accordance with the study of Cibin *et al.* (2010), which suggests that the sensitive parameters of a model are mostly related to the hydrological and climatic characteristics.

### Calibration

The parameters used in a model will control the relationship between the input and the output of a system. The parameter values need to be set up so the model can accurately predict or reproduce the behavior of a physical system that is being modeled. The process of matching or setting up parameter values is called calibration (Indarto 2010). The

calibration of the SWAT model for the period of 2010-2012 has been carried out using the warm-up period of 2 years *i.e.* 2010-2011.

*Daily Calibration of Upper Cisadane Subbasin:* There are similarities on the performance category of the models simulated on the scale of 1:100,000 and 1:250,000. The values used for the model evaluation on these two-scales of maps are presented in Table 2 and Figure 2. After calibration, the NSE coefficients for the the two scales of maps are almost the same. It occurs because the hydrological conditions, environmental conditions and the periods are set up for the same simulation on both scales of maps. In addition, it is due to the scales of the soil maps used are not really different. The soil map with the scale of 1:100,000 consists of 13 soil types, which is almost the same as the number of soil types in the soil map with the scale of 1:250,000, *i.e.* 12 soil types.

*Monthly Calibration of Upper Cisadane Subbasin:* A similar pattern was observed for the results of daily and monthly calibrations for the two different scales of maps (Figure 3).

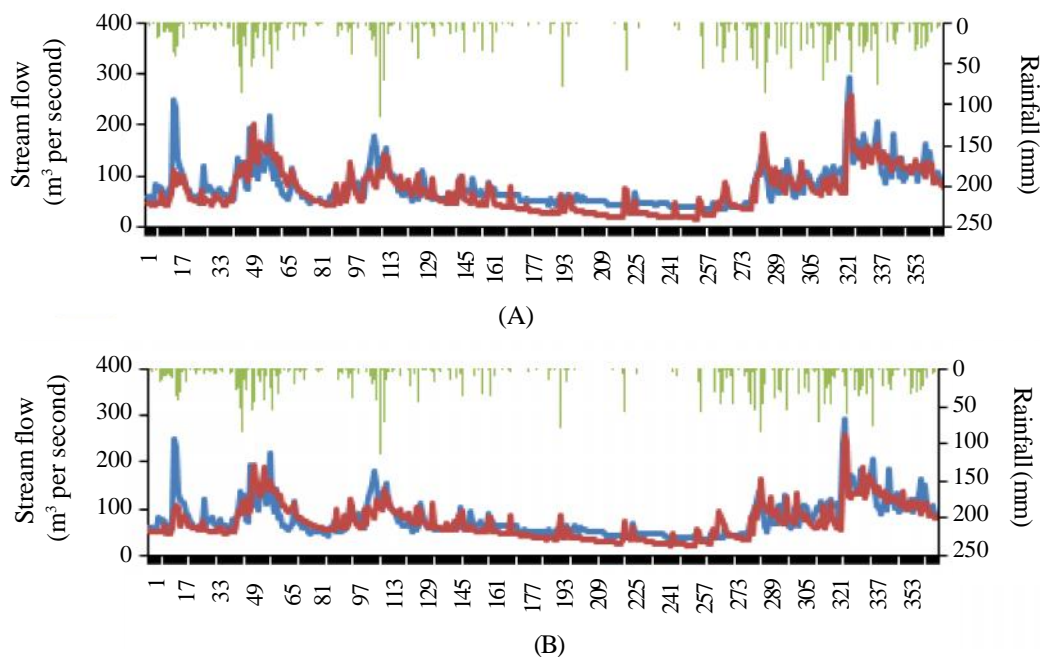


Figure 2. Streamflow for daily calibration (a) scale of 1:100,000 and (b) scale of 1:250,000. ■ : Rainfall (mm), ■ : observation (m<sup>3</sup> per second), ■ : model (m<sup>3</sup> per second).

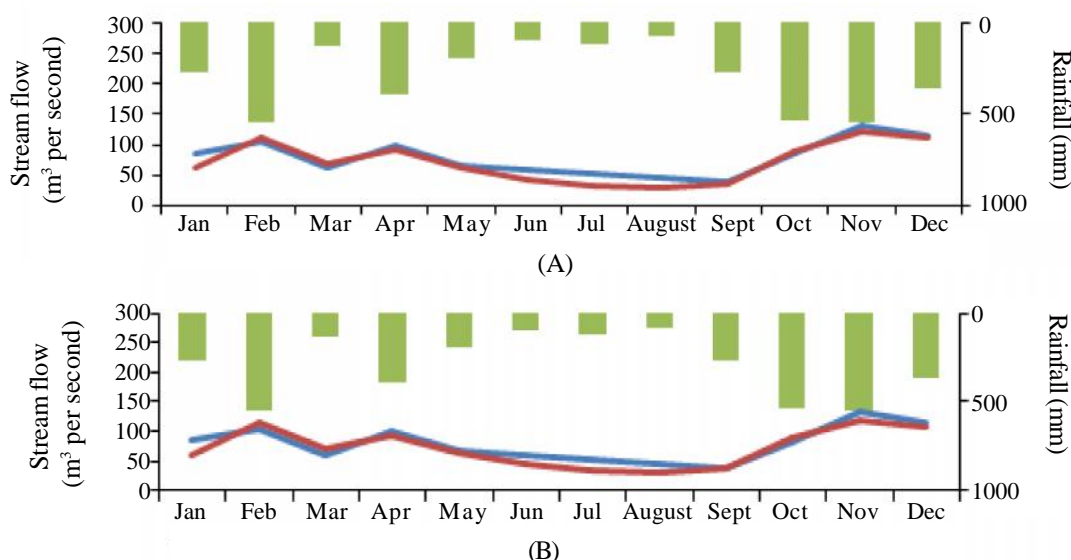


Figure 3. Streamflow for monthly calibration (a) scale of 1:100,000 and (b) scale of 1:250,000. ■ : Rainfall (mm), ■ : observation (m<sup>3</sup> per second), ■ : model (m<sup>3</sup> per second).

### Sensitivity Analysis

The sensitivity of the parameters used in a SWAT model is grouped into sensitive, less sensitive and insensitive. Sensitive parameters are the parameters that contribute a significant effect on the output. Less sensitive parameters are the parameters that have a little effect on the output in the presence of several changes in values, whereas insensitive parameters are the parameters that do not affect the output. The sensitivity of the parameters used in the SWAT model simulated in the current study is presented in Table 3 for different scales of maps.

The input value is the value used to see a change in the output for each parameter used in the model,

which revolves around the default values in the model, either below or above the default value. The greater the difference between the maximum NSE value and the minimum NSE value of the parameter, the more sensitive of the output to change. The results of a daily simulation on a scale of 1:100,000 show that the sensitive parameters include CH\_N2 parameter with the biggest difference of minimum NSE and maximum NSE (0.67), followed by Alpha\_BNK with the NSE difference of 0.45 and CH\_K2 with the NSE difference of 0.26 (Table 3). On the other hand, the results of a monthly simulation show that the sensitive parameters include Alpha\_BNK with the NSE difference of 0.2 and GW\_Delay with the NSE difference of 0.16.

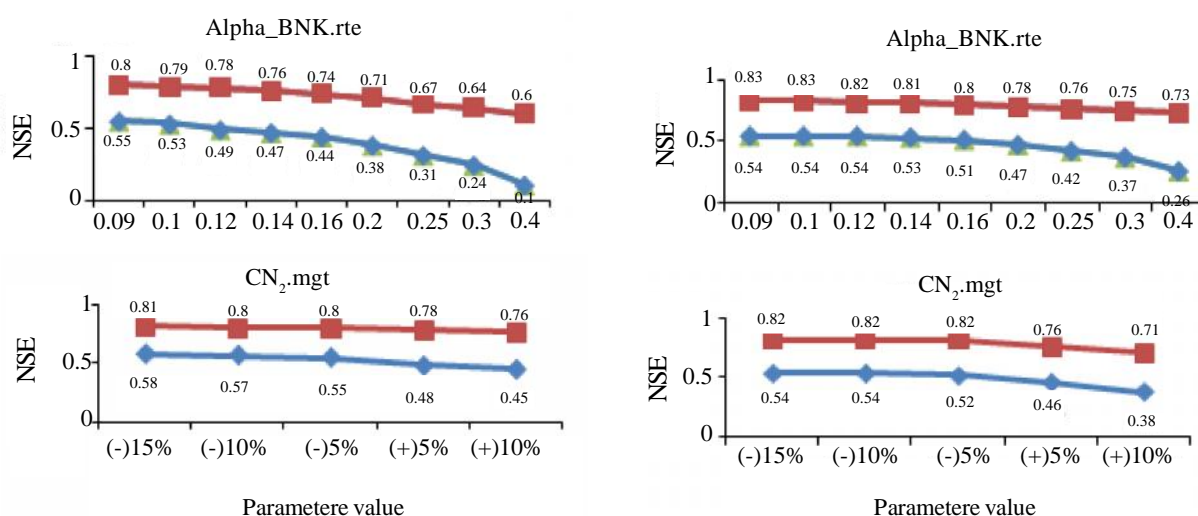


Figure 4. The graphs of the sensitive parameters used in the SWAT model for the scale of the maps of 1:100,000 (left) and 1:250,000 (right). ■ : daily, ■ : monthly.

Table 3. Model parameters grouped based on their sensitivity for the upper Cisadane Subbasin mapped on a scale of 1 : 100,000 and 1 : 250,000.

Parameter	Scale 1:100 000						Scale 1:250 000						
	Value		Daily NSE		Monthly NSE		Daily NSE		Monthly NSE		difference		
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
Alpha_BNK.rte	0.09	0.4	0.1	0.55	0.45	0.60	0.80	0.20	0.54	0.28	0.73	0.83	0.10
CN2.mgt	x0.85	x1.1	0.45	0.58	0.13	0.76	0.81	0.05	0.54	0.16	0.71	0.82	0.11
CH_K2.rte	50	125	0.29	0.55	0.26	0.75	0.80	0.05	0.54	0.36	0.79	0.82	0.03
CH_N2.rte	0.025	0.07	-0.12	0.55	0.67	0.71	0.80	0.09	0.54	0.69	0.76	0.82	0.06
ESCO.hru	0.4	1	0.48	0.56	0.08	0.67	0.82	0.15	0.55	0.1	0.69	0.84	0.15
GW_Revap.gw	0.02	0.2	0.48	0.55	0.07	0.65	0.80	0.15	0.54	0.1	0.68	0.82	0.14
GW_Delay.gw	10	120	0.41	0.56	0.15	0.64	0.80	0.16	0.54	0.19	0.61	0.82	0.21
LAT_Time.hru	0	180	0.53	0.55	0.02	0.71	0.80	0.09	0.54	0.01	0.82	0.82	-
Alpha_BF.gw	0.2	0.7	0.55	0.55	-	0.80	0.80	-	0.54	-	0.82	0.82	-
LAI_Sed.hru	0	2000	0.55	0.55	-	0.80	0.80	-	0.54	-	0.82	0.82	-
EPCO.hru	0.3	1	0.55	0.55	-	0.80	0.80	-	0.54	-	0.82	0.82	-
REVAPMN.hru	450	975	0.55	0.55	-	0.80	0.80	-	0.54	-	0.82	0.82	-
GWHT.gw	2	17	0.55	0.55	-	0.80	0.80	-	0.54	-	0.82	0.82	-
GW_SPYLD.gw.	0.03	0.4	0.55	0.55	-	0.80	0.80	-	0.54	-	0.82	0.82	-
Surlag.bsn	2	20	0.55	0.55	-	0.80	0.80	-	0.54	-	0.82	0.82	-

Notes

- : basic alpha flow factor 'bank storage'
- : Surface flow curve number
- : Main channel hydraulic conduction
- : Manning value for main channel
- : Land evaporation factor
- : The coefficient of groundwater revap
- : Time of "delay" of underground water
- : The travel time of lateral flow

- Alpha\_BF
- Lat\_Sed
- EPCO
- REVAPMN
- GWHT
- GWSPYLD
- SURLAG

- : Baseline flow alpha factor
- : Sediment concentration in lateral flow and ground water flow
- : Plant uptake factor
- : Water depth threshold in shallow aquifers for "revap"
- : High groundwater early
- : Specific results of shallow aquifers
- : Surface flow lag coefficient

Less Sensitive

Not Sensitive

Table 4. SWAT model performance after validation.

Period	Scale	NSE	R <sup>2</sup>	Category
Daily	1:100,000	0.25	0.3994	Less Satisfactory
	1:250,000	0.13	0.0497	Less Satisfactory
Monthly	1:100,000	0.43	0.601	Excellent
	1:250,000	0.49	0.656	Excellent

Parameters that have a large NSE difference for the daily simulation on a scale of 1:250,000 are CH\_N2, CH\_K2, and Alpha\_BNK with NSE difference of 0.69, 0.36 and 0.28, respectively. For the monthly simulation, the parameters with the biggest NSE difference are GW\_Delay, ESCO, and GW\_Revap. The graphs of the sensitive parameters used in the daily and monthly simulations for both scales of maps are presented in Figure 4.

The monthly simulation tends to show good data, so it can improve the correlation on the simulation of a hydrological modeling. The study of Rinaldi (2010) indicates that the use of different base maps and grid sizes does not result in a significant difference on the values of the morphological parameters of a watershed.

### Validation

The validation of the SWAT model for the period of 2013-2014 has been carried out using the warm-up period of one year *i.e.* 2013. The daily streamflow of 2014 (365 data) is used to assess the performance of the model in the model validation. The values used for the model evaluation on the two scales of maps after validation of the models are presented in Table 4. The results show that after validation, there are similarities on the performance category of the models simulated on the scale of 1:100,000 and 1:250,000, which are similar to the results obtained after calibration of the models. The daily simulations of the models on both scales of maps are classified as less satisfactory, whereas the monthly simulations of the models are classified as excellent.

### CONCLUSIONS

There are seven parameters that are sensitive to the performance of the SWAT models simulated on the different scales of maps for the upper Cisadane Subbasin. These sensitive parameters include the flow recession constant or recession proportional to the banks of the river (Alpha\_BNK), initial SCS runoff curve number for moisture

condition II (CN2), effective hydraulic conductivity in main channel alluvium (CH\_K2), the Manning's "n" value for the main channel (CH\_N2), the delay time of groundwater (GW\_Delay), soil evaporation compensation factor (ESCO), and groundwater "revap" coefficient (GW\_Revap).

There are no differences on the sensitive parameters identified for different spatial data resolutions. This is due to the data of soil on both the scales of the maps are not that much different. The soil map with the scale of 1:100,000 consists of 13 soil types, while the soil map with the scale of 1:250,000 consists of 12 soil types.

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