# UNCERTAINTIES OF SWAT MODEL IN IRRIGATED PADDY FIELD WATERSHED

*KETIDAKPASTIAN MODEL SWAT DI DAERAH ALIRAN SUNGAI BERLAHAN SAWAH IRIGASI*


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***ABSTRAK***

*Soil and Water Assessment Tool (SWAT) merupakan model hidrologi yang sangat berpotensi digunakan untuk memodelkan daerah aliran sungai yang didominasi lahan pertanian. Namun demikian, struktur model ini dapat menyebabkan ketidakpastian khususnya apabila diaplikasikan untuk lahan sawah beririgasi. Hal ini dikarenakan SWAT pada awalnya dikembangkan untuk memodelkan lahan pertanian yang tidak memiliki genangan sehingga asumsi ataupun struktur modelnya berbeda dibandingkan dengan konsep pemodelan yang biasa digunakan di lahan sawah. Namun demikian, tingkat pengaruh ketidakpastian ini terhadap performa model secara keseluruhan belum teridentifikasi secara detail. Penelitian ini bertujuan untuk menganalisa performa, kesesuaian aplikasi dan ketidakpastian SWAT (model awal dan modifikasinya) untuk memodelkan daerah aliran sungai berlahan sawah irigasi. Analisa dilakukan dengan mengevaluasi struktur model dan menganalisa ketidakpastian menggunakan metode Sequential Uncertainty Fitting (SUFI-2) pada beberapa tipe model, yaitu model orisinil dan termodifikasi. Berdasarkan hasil penelitian, dapat disimpulkan bahwa struktur model pada SWAT tidak mengakomodir proses genangan, rembesan, dan irigasi di lahan sawah. Pengaruh dari ketidaktepatan struktur model ini dapat dikurangi dengan melakukan kalibrasi sehingga menghasilkan indeks performa yang baik. Namun demikian, perbedaan performa secara signifikan dapat diamati setelah dianalisa lebih lanjut dengan memperhatikan ketidakpastian. Reliabilitas model termodifikasi lebih baik karena menghasilkan rentang ketidakpastian yang lebih sempit khususnya pada periode debit rendah. Hasil ini juga menunjukkan bahwa genangan, rembesan, dan irigasi merupakan proses yang sangat penting untuk pemodelan hidrologi di daerah aliran sungai berlahan sawah irigasi.*



*Kata kunci:* ***SWAT, SWAT termodifikasi, sawah, debit sungai, analisis ketidakpastian, SUFI-2***



**ABSTRACT**

Soil and Water Assessment Tool (SWAT) is a very promising model in an agricultural watershed. However, the modeling approach could include uncertainties in its model structures especially if it is applied in watershed consisting irrigated paddy fields. This is due to SWAT was initially developed to model dry land agricultural area so that there were some different assumptions or model structures compared to common understanding in paddy field. However, the significance of model structure uncertainty to overall model performance is not yet clearly be understood. This study is aimed to analyze the performance, applicability, and uncertainties of SWAT (original/modified) to model watershed containing irrigated paddy field. The analysis was conducted through model structure evaluation and uncertainty analysis using the Sequential Uncertainty Fittin (SUFI-2) method by considering several SWAT model configurations, i.e. original and modified version. As the result, SWAT model structure cannot adequately represent the surface storage, seepage, and irrigation process in paddy field. Through calibration, these inadequate representation could be improved to have a better overall model performance indexes. However, significant difference in performance could be observed through uncertainty analysis. Modified SWAT model have better reliability i.e. narrower uncertainty band especially during low flow period. These results also imply that surface storage, seepage, and irrigation are some of the most important processes for hydrological simulation in irrigated paddy field watershed.



Keywords: **SWAT, modified SWAT, paddy field, streamflow, uncertainty analysis, SUFI-2**

## I. INTRODUCTION

Soil and Water Assessment Tool (SWAT) is a very promising model in an agricultural watershed. SWAT is a basin scale time-continuous model that operates on a daily time step and is designed to predict water, sediment, nutrients, pesticides dynamics, and the impact of agricultural management practices on them. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods, and has been proved by many researches to give reasonable performance in assessing non-point source pollution (Gassman et al., 2007). Furthermore, SWAT is an open source model thus it is continuously tested and developed by many researchers around the world.

SWAT modeling approach can comprise many sources of uncertainties. It could be come from the error in observed data being used for calibration, spatial or temporal variation of parameter, or the model structure itself (Abbaspour, 2014; Refsgaard et al., 2006). Regarding the model structure uncertainty, SWAT could introduce uncertainty if it is applied in a watershed that contains paddy field. This is because SWAT was initially developed to model dry land agricultural area so that there were some different assumptions or model structures compared to common understanding in paddy field.

However, the significance of model structure uncertainty to overall model performance is depend on various factors, including paddy field area and the extent of analysis. In some researches, SWAT has been successfully validated in watersheds containing irrigated paddy field (Somura et al., 2012; Luo et al., 2011). In other researches, SWAT showed some limitation that produced significant error so modified version of SWAT model is more preferable (Kim et al., 2003; Xie & Cui, 2011; Boulange et al., 2014; Sakaguchi et al., 2014a). The modification was claimed successfully increased model performance. However, the performance has not been evaluated by considering the uncertainty analysis.

This study is aimed to analyze the performance, applicability, and uncertainties of SWAT (original/modified) to model watershed containing irrigated paddy field. The analysis was conducted based on the application in the upper part of Kashima river watershed, Inbanuma Basin, Japan. Parameter that will be considered is streamflow.

## II. LITERATURE REVIEW

### 2.1. SWAT Model

SWAT is a semi lumped hydrological model. Spatial heterogeneity is simplified by dividing watershed into sub-watersheds. Each sub-watershed is further discretized into Hydrological Response Unit (HRU). Watershed and sub-watersheds are generated based on Digital Elevation Model (DEM). HRU are generated by overlaying land use, soil, and slope data. Each HRU in sub-watershed has specific combination of land use, soil, and slope category. Calculation of hydrological component is conducted in each HRU. Afterwards, the outflow of each HRU is accumulated and routed as streamflow. SWAT model framework was documented in details by Neitsch et al. (2011).

By default, HRU simulation is based on the Soil Conservation Service Curve Number (SCS CN) procedure to divide rainfall into surface runoff and infiltration (Neitsch et al., 2011). This is an empirical procedure that calculates runoff based on rainfall-runoff relationships from small rural watershed. Runoff is calculated by equation:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \quad (1)$$

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad (2)$$

Where, $Q_{surf}$ is the runoff (mm), $R_{day}$ is rainfall (mm), $I_a$ is initial abstractions (mm), $S$ is retention parameter (mm), and $CN$ is curve number of the day, representing the overall watershed response characteristics to rainfall.

Pothole module can be used to model impounded condition of paddy field. This module was developed to represent storage dynamics of closed depression area (pothole). This is common feature in areas of low relief and/or young geologic development when drainage network is poorly developed.

### 2.2 Uncertainty Analysis

Uncertainty analyses employing probabilistic descriptions of model inputs to derive probability distributions of model outputs and system performance indices (Loucks et al., 2005). Comprehensive uncertainty analysis should be done by addressing model context, model structure, model input and boundary conditions, prior uncertainty in model factors, dependencies in model factors, methodology to asses uncertainty, observation data for model calibration/conditioning, variability in future prediction, and method to communicate with the user (Pappenberger & Beven, 2006).

Hydrological modelling approach is subject to uncertainty. It could be come from the error in observed data being used for calibration, spatial or temporal variation of parameter or model structure itself (Abbaspour, 2014; Refsgaard et al., 2006). For the use of future prediction, uncertainty may also come from inadequate information, incorrect assumptions, and also natural process variability (Loucks et al., 2005). Thus for the model use in decision making process, uncertainty analysis is important.

Abbaspour et al. (2004) developed the SUFI-2 (sequential uncertainty fitting) method to consider all sources of uncertainty during model calibration, such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data. SUFI-2 started with some initial range of parameter value. Simulation was then conducted based on parameter generated by the Latin Hypercube Sampling within the initial range. At the end of each calibration round, SUFI-2 generates new parameter range that can give better model performance. The calibration is repeated until simulation results good performance, adjudged through p-factor, r-factor and goodness of fit criterion. This method has proven to be efficient compared to other uncertainty method since it can achieve good prediction result with smaller model runs (Yang et al., 2008; Luo et al., 2011). Detailed description of the algorithm are available in Abbaspour et al. (2014).

## III. METHOD

### 3.1. Study Area

The study was conducted for the upper part of Kashima river watershed (Figure 1) in Chiba Prefecture, Japan. The River conveys drainage water from upstream agricultural area that is used for paddy irrigation into Inbanuma Lake, which has serious water quality problem due to mixing with river water polluted by inflows from agricultural lands and inhabited areas. This watershed has an area of 166 km$^2$ or approximately 25% of total that contributing flow into Inbanuma Lake. Major soil types in this area are Humic Andosol (63.2%) and Strong Gley soil (25.7%) that has high permeability. The Gley soil lies around the river where almost all paddy field located. Land slopes are ranging from 0 to 47% with median of 2.6%.

Major land use in research area is agriculture, comprising upland (38.9%) and paddy field (8.9%) as in Figure 2. Paddy field is located along the river side and uses river water for irrigation and the river for drainage. Pumped water from river or deep aquifer is used for irrigation. Based on data from local irrigation office, gross irrigation for about one third of paddy field in research area is shown in Figure 3. River is a major source of irrigation that comprises around 75% of total irrigation and maximum 45% of river outflow. Thus, due to its significant amount, paddy field irrigation can affect greatly to streamflow. This emphasizes the importance of water management in paddy field to maintain streamflow as well as its water quality.

Model input file was generated using ARC-SWAT 2009 using following data:

a. Digital Elevation Model (10 m mesh) by Geographical Survey Institute, Japan
b. Land use (100 m mesh) by Ministry of Land, Infrastructure, Transport and Tourism, Japan
c. Soil map by Japan Soil Association with soil vertical data by Eguchi et al. (2011)
d. Weather data by Japan Metrological Agency (Automated Meteorological Data Acquisition System)
e. Management data (irrigation, fertilizer rate, cropping season, etc.) from local authorities

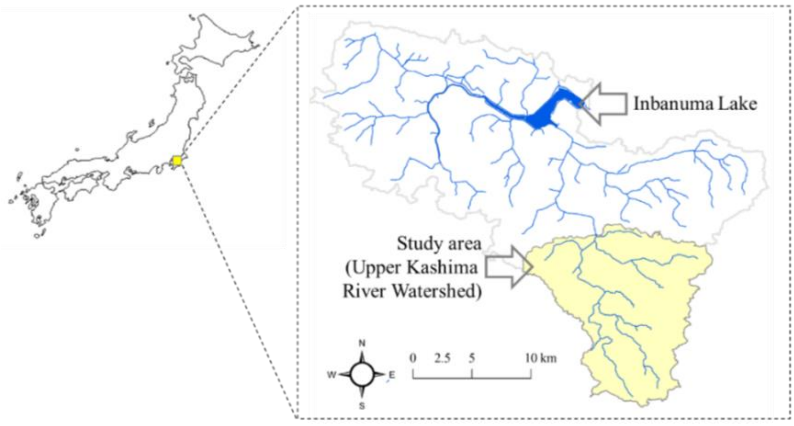


**Figure 1** Research location (Upper Kashima River watershed), Chiba Prefecture, Japan

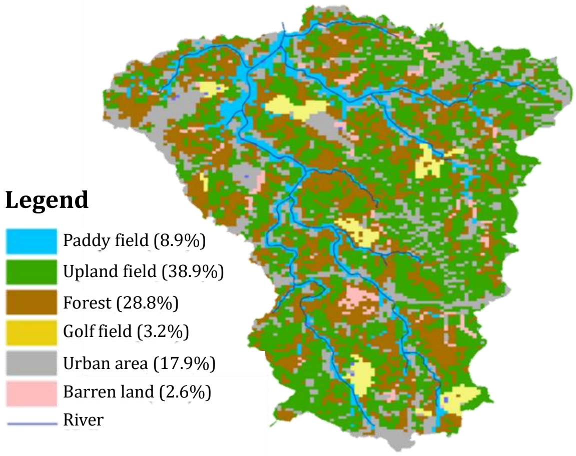


**Figure 2** Land use map of the research area

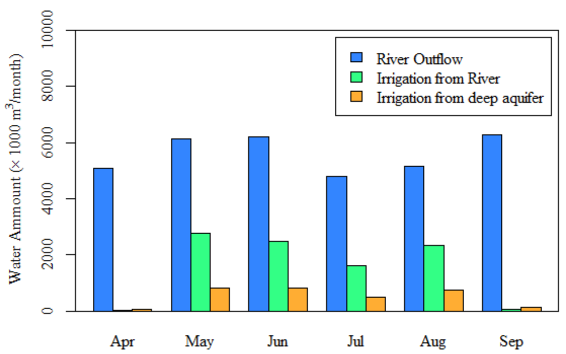


**Figure 3** Monthly river outflow and irrigation

Watershed delineation was conducted by setting maximum area of sub-watershed as 500 Ha. Land use, soil and slope were overlaid by threshold as consecutively 5%, 25%, and 25%.

## 3.2. Model evaluation and uncertainty analysis

This study evaluated SWAT by means of model structure evaluation and uncertainty analysis. Evaluation of model structure was conducted by examining the theoretical documentation (Neitsch et al., 2011) and its source code. Model version which was being used in this research is SWAT 2009 revision 528. The existing model structure was compared to the common approaches in paddy field modeling based on literatures. Some key points that evaluated were runoff, surface storage, seepage, and irrigation.

Uncertainty analysis was conducted to evaluate the effect of model structure to its performance. This study included several SWAT configurations, i.e. original and modified version. For easy understanding, the configurations were named and arranged as in as in Table 1. Detailed explanation of each configuration are elaborated in Chapter 3.1.

**Table 1** SWAT model configuration

| Configu-ration name | Hydrological process | Irrigation |
|---|---|---|
| CN | Original SWAT with default option, i.e. only using Curve Number method | Manual irrigation (consecutive irrigation from river and deep aquifer) |
| POT | Original SWAT using Curve Number and pothole for paddy field | Manual irrigation (consecutive irrigation from river and deep aquifer) |
| MOD | Modified SWAT | Manual irrigation (consecutive irrigation from river and deep aquifer) |
| MOD-AUTO | Modified SWAT | Modified auto irrigation |

Calibration and uncertainty analyses were conducted using SUFI-2 (sequential uncertainty fitting) method with SWAT-CUP software. Parameters which will be calibrated were based on the suggested parameters that directly affect streamflow in ARC-SWAT 2009 software. Additionally, some parameters that considered being important in literatures were also added (van Griensven et al., 2006; Cibin et al., 2010; Somura et al., 2012; Luo et al., 2011; Nossent & Bauwens, 2012).

In each SUFI-2 calibration round, model performance assessment were conducted by examining p-factor, r-factor and goodness of fit criterion. This research uses goodness of fit criterion proposed by Moriasi et al. (2007), i.e. RSR, NSE, and PBIAS.

The p-factor is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). When all measured data are bracketed in 95PPU band, p-factor will be 100%. The r-factor is the average thickness of the 95PPU band divided by the standard deviation of the measured data.

$$\text{r}-\text{factor}=\frac{\frac{1}{k}\sum_{i=1}^{k}(X_i^U-X_i^L)}{\sigma_{obs}} \quad \text{.......} \quad (3)$$

where $k$ is number of the data; $X_i^U$ and $X_i^L$ is upper and lower boundary of uncertainty band of the $i$-th data; and $\sigma_{obs}$ is standard deviation of observed data. The p-factor range between 0 and 100% and r-factor ranges between 0 and infinity. A p-factor of 1 and r-factor of 0 means that simulation exactly corresponds to measured data. Calibration is considered successful if r-factor is less than 1 while maintaining high enough p-factor (more than 80% for high quality data or more than 50% for low quality data) and best simulation has satisfactory goodness of fit (Abbaspour et al., 2007).

RSR (Root Mean Square Error to observed Standard Deviation Ratio) is the measure of magnitude of the error that defined as root mean square error divided by standard deviation of observation data.

$$\mathrm{RSR} = \frac{\mathrm{RMSE}}{\mathrm{STDEV_{obs}}} = \frac{\sqrt{\frac{1}{k}\sum_{i=1}^{k}(Y_i^{obs} - Y^{sim})^2}}{\sqrt{\frac{1}{k}\sum_{i=1}^{k}(Y_i^{obs} - \overline{Y^{obs}})^2}} \quad \text{......................................} (4)$$

where $Y_i^{obs}$ is observed data; $Y_i^{sim}$ is simulated value; $\overline{Y^{obs}}$ is mean of observed data; $k$ is the number of data.

NSE (Nash Sutcliffe model Efficiency) is the measure of how well the observed and simulated data fits 1:1 line. NSE ranges between -∞ to 1. NSE less than 0 means that average value of observed data is the better predictor than simulation result while NSE equal to 1 means that the simulated and the observed data are exactly equal.

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{i=1}^{k}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{k}(Y_i^{obs} - \overline{Y^{obs}})^2}\right] \quad \text{.................................................} (5)$$

PBIAS (Percent BIAS) is the measure of tendency of simulated data to overestimate or underestimate the observed value. Positive value indicates model underestimation while negative value indicates model overestimation. Generally, model simulation can be judged satisfactory if RSR ≤ 0.7, NSE > 0.5 and PBIAS ± 25% for streamflow (Moriasi et al., 2007).

$$\mathrm{PBIAS} = \frac{\sum_{i=1}^{k}(Y_i^{obs} - Y_i^{sim}) \times 100}{\sum_{i=1}^{k}(Y_i^{obs})} \quad \text{............................................} (6)$$

## IV. RESULT AND DISCUSSION

### 4.1. Model structure evaluation

Theoretically, there are some differences in the assumption between the modeled process in SWAT and commonly modeling approaches in paddy field, especially in the aspect of ponding storage, runoff, seepage/percolation and irrigation (Figure 4).

SCS CN method was originally developed to model upland agricultural area. Using this method, runoff is generated directly as a fraction of rainfall that does not infiltrate to the soil (as in Equation 1 and 2). Thus, this method does not consider surface storage (ponded water), which is an important component to model runoff in paddy field. Moreover, the resulting runoff might not be realistic since in paddy field runoff is as the result of overflow process (Kim et al., 2003).

Many other modeling approaches configure paddy field differently from other land use and explicitly simulated the process in ponded water situation. For example, Hayase (1999) modeled a watershed hydrology using tank model where paddy field was configured differently than any other land use and a tank was assigned separately to model ponding storage. Khepar et al. (2000) modeled intermittent paddy field hydrology using water balance equation, process in ponding storage was explicitly modeled and runoff from paddy field was modeled as overflow which varied with the outlet height and initial ponding depth.

To model ponded water, pothole module is available in SWAT. However, there are also some different assumptions that can lead to model structural error. This module was originally developed by Du et al. (2005) to model closed depression area in young glacial till plains (pothole). In pothole module, storage is assumed cone shaped so surface area is not constant as in Equation 7 (Neitsch et al., 2011).

$$SA = \frac{\pi}{10^4} \cdot \left(\frac{3 \cdot V_{pot,1}}{\pi \cdot slp_{hru}}\right) \quad \text{.....................................................} (7)$$

where $SA$ is the surface area of the pothole (Ha), $V_{pot,1}$ is the volume of water in the impoundment at the beginning of the day ($m^3$ $H_2O$), and $slp_{hru}$ is the slope of HRU (m/m). Since surface area is used to calculate evapotranspiration, the cone shaped storage can lead to underestimation of evapotranspiration because of in paddy field the storage is almost cuboids with constant surface area (Xie & Cui, 2011).

Another different assumption is in seepage into the soil profile and hydrological process during non-ponding period as described by Sakaguchi et al. (2014b). Seepage is calculated only when the soil moisture is below field capacity as in Equation 8, 9, 10). Since in paddy field seepage occurred continuously when the water is ponded, this approach can lead to underestimation of the seepage value.

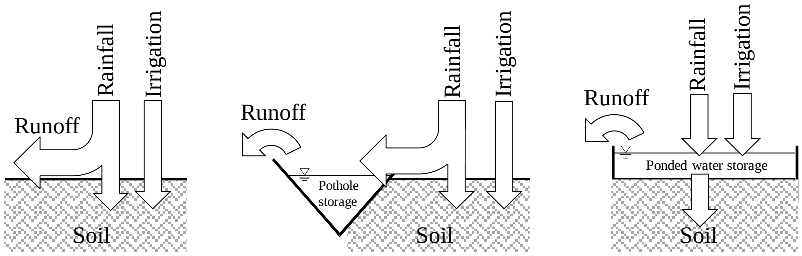


**Figure 4** Schematic Representation of Simulated Process in SCS CN (left), Pothole Module (middle) and Paddy Field (right)

$$V_{potseep} = 240 \quad K_{sat} \quad SA$$

if $SW_{sum} < 0.5\ FC_{sum}$ ............(8)

$$V_{potseep} = 240 \quad 1 \quad \frac{SW_{sum}}{FC_{sum}} \quad K_{sat} \quad SA$$

if $0.5\ FC_{sum} \leq SW_{sum} < FC_{sum}$ ............(9)

$$V_{potseep} = 0$$

if $SW_{sum} \geq FC_{sum}$ ............(10)

To simulate irrigation, SWAT provides two option i.e. manual irrigation and automatic irrigation. The user must input the time, amount, source, and efficiency parameter to use manual irrigation. To use auto irrigation, the user should provide threshold for irrigation to occur instead of time. Using manual irrigation is somewhat tedious to be done since user should define time and amount in each irrigation event. This also may add to uncertainty since the time and correct value is difficult to specify. Auto irrigation option seems to have better applicability. By assuming the threshold, SWAT automatically decides whether irrigation should be conducted or not. This mechanism is closely representing the real process in the agricultural field. However in the original SWAT model, automatic irrigation option was developed for upland field. Irrigation is conducted when soil moisture reach certain level below field capacity and stopped when soil moisture reach field capacity. This approach is not applicable for the use in paddy field since it is commonly irrigated by considering the height of ponded water as the threshold.

Futhermore, SWAT cannot simulate simultaneously irrigation from two sources or more. Thus, irrigation in the research area which is come from river and deep aquifer could not be easily modeled. Furthermore, Irrigation from the river is treated differently which it is given in the next day.

Due to these model structure differences, SWAT may produce significant error. Thus, some researches have modified SWAT to suit the application in irrigated paddy field. Modification concepts in several literatures are available in Table 2. Xie & Cui (2011), Boulange et al. (2014), and Sakaguchi et al. (2014b) modified the hydrological process in pothole option.

**Table 2** Concepts of SWAT Modification in Literatures

| Author | Key points of modification |
|---|---|
| Xie & Cui (2011) | a. Shape of pothole (modified from cone to cuboid)<br>b. Evapotranspiration (when pothole is dry included also evapotranspiration from soil)<br>c. Pond routine as alternative source of irrigation<br>d. Yield calculation using simple approach |
| Boulange et al. (2014) | a. Hydrological process in pothole was modified based on concept by Xie & Cui (2011)<br>b. Pesticide simulation in paddy field was modified according to the PCPF-1 model (Watanabe et al., 2006) |
| Sakaguchi et al. (2014b) | a. Shape of pothole (modified from cone to cuboid)<br>b. Seepage set to constant rate (in official SWAT version, seepage rate is decreasing until 0 when soil is at field capacity)<br>c. Added ponding releasing process during drainage command (ponding storage is not released in official SWAT version)<br>d. Irrigation process was modified to avoid overflows<br>e. Evapotranspiration (when pothole is dry included also evapotranspiration from soil) |

Xie & Cui (2011) and Sakaguchi et al. (2014b) stated that the pothole option in SWAT can produce significant error especially in simulated runoff, irrigation, and evapotranspiration. Thus, the shape of pothole and evapotranspiration process was modified. Additionally, ponding releasing process was added to simulate artificial drainage. Sakaguchi et al. (2014b) was also found inappropriate process in the seepage. Seepage is occurred only when soil moisture is below field capacity. This is not appropriate since in paddy field seepage occurred even when the soil is saturated. Thus, Sakaguchi et al. (2014b) introduced constant seepage rate.

By considering the scope and conditions in research area, modification which will be included in are employing the ideas in Sakaguchi et al. (2014b) with additional modification in irrigation process as in Table 3.

In this research, two approaches were conducted to represent irrigation from river and aquifer. The first approach (MOD) is by setting manual irrigation from both sources consecutively (river in the 1st day and deep aquifer in the 2nd day). The second approach (MOD-AUTO) is by using modified auto irrigation module. Several modifications of this module were made to enable the threshold as ponding depth and multisource irrigation (river and deep aquifer).

### 4.2. Uncertainty analysis

Uncertainty and calibration by SUFI-2 method were conducted for 10 rounds for each model configuration. The Figure 5 resume the overall performance indexes. The dashed line is threshold of satisfactory criteria as suggested by Abbaspour et al. (2014) and Moriasi et al. (2007).

All model configurations, with different model structure and parameter set, can be satisfactorily calibrated by SUFI-2 method. As performance indexes converged, the simulation tends to give similar result with satisfactory performance. This implies the capability of SUFI-2 method to calibrate SWAT model and also the equifinality characteristic of SWAT model. The equifinality is a common characteristic in multi parameter hydrologic model when different value set of parameter could resulting similar hydrograph or model performance (Beven, 2012).

However, modified version of SWAT (MOD and MOD-AUTO) need more round to generate r-factor less than 1. This is due to the modified model have the additional process and calibration parameter (in pothole and irrigation). This additional round seems to not affect the overall performance of modified model. As in Figure 6, modified model was resulting slightly better p-factor at almost every r-factor. The modified model also have better best simulation performance indexes (RSR, NSE, and PBIAS) after 7th round. The best representing SUFI-2 round was chosen as the round that have highest p-factor while r-factor relatively small (< 1) and best simulation performance indexes has converged as in Table 4 with the hydrograph as in Figure 7.

There were some differences in the shape of lower band especially in the low flow period. CN and POT can be considered less reliable to model low flow period compared to the modified model. CN does not simulate ponding storage during irrigation period thus it generated wider band at around 8/2013 until 10/2013. POT generated unrealistic simulation which was the highly fluctuating streamflow during the irrigation period. This was due to inappropriate mechanism of seepage and drainage process. Seepage was very small since it stopped when the soil moisture was higher or equal to the field capacity. The drainage command also only held ponded storage inactive and the water still remained in the storage until next cropping season. Thus, the ponded storage was almost constant at the maximum capacity so that the irrigation will be directly overflowed.

**Table 3** Modifications Conducted in This Research

| Component | Original process | Modified process |
|---|---|---|
| Shape | Cone | Cuboid |
| Seepage | Until field capacity | Constant rate |
| Drainage | Stop routing runoff to storage without draining water from storage | Stop routing runoff to storage and drain water from storage |
| Evapotrans-piration | When pothole is dry, evapotranspiration from the HRU is 0 | When pothole is dry, evapotranspiration from soil is calculated |
| Irrigation | Threshold as soil moisture below field capacity and only irrigation from 1 source at a time | Enable setting of threshold as ponding depth and irrigation source from river and deep aquifer (at the same time) |

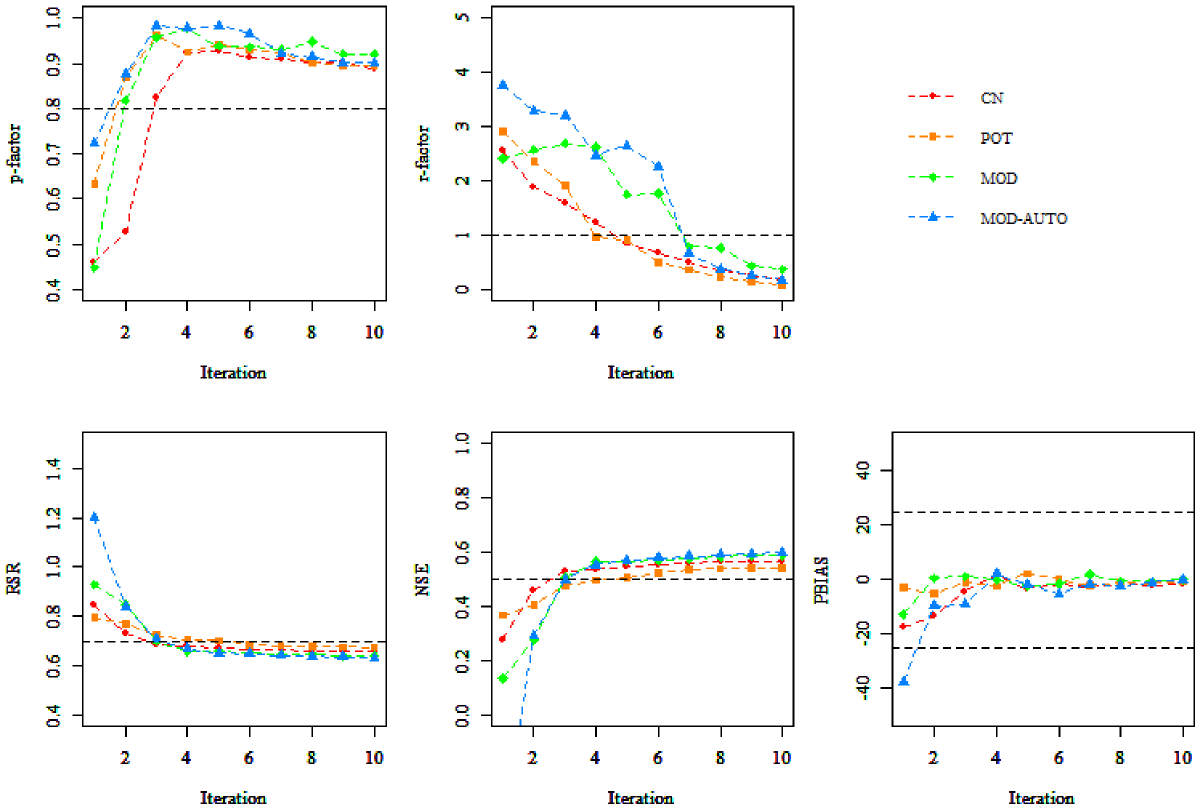


**Figure 5** Performance Indexes of Each SUFI-2 Round

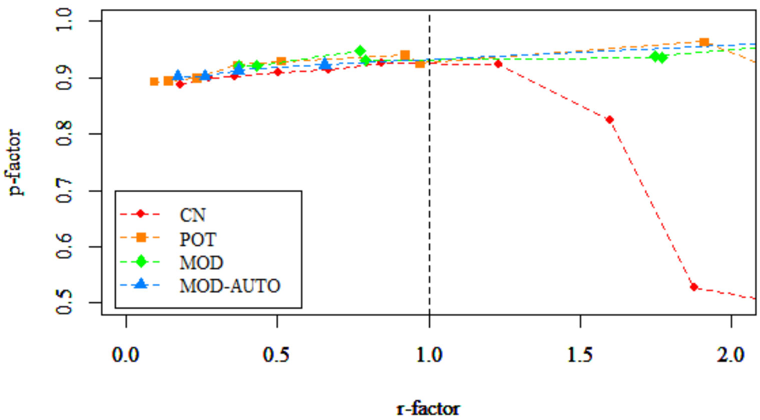


**Figure 6** r-factor and p-factor of Each SUFI-2 Round

**Table 4** Best Representing SUFI-2 Round

| Model | Round | p-factor | r-factor | Best simulation | | |
|---|---|---|---|---|---|---|
| | | | | RSR | NSE | PBIAS |
| CN | 5 | 93% | 0.84 | 0.67 | 0.55 | -3.5 |
| POT | 5 | 94% | 0.92 | 0.70 | 0.51 | 2.2 |
| MOD | 8 | 95% | 0.77 | 0.64 | 0.58 | -0.6 |
| MOD-AUTO | 7 | 92% | 0.66 | 0.64 | 0.59 | -1.9 |

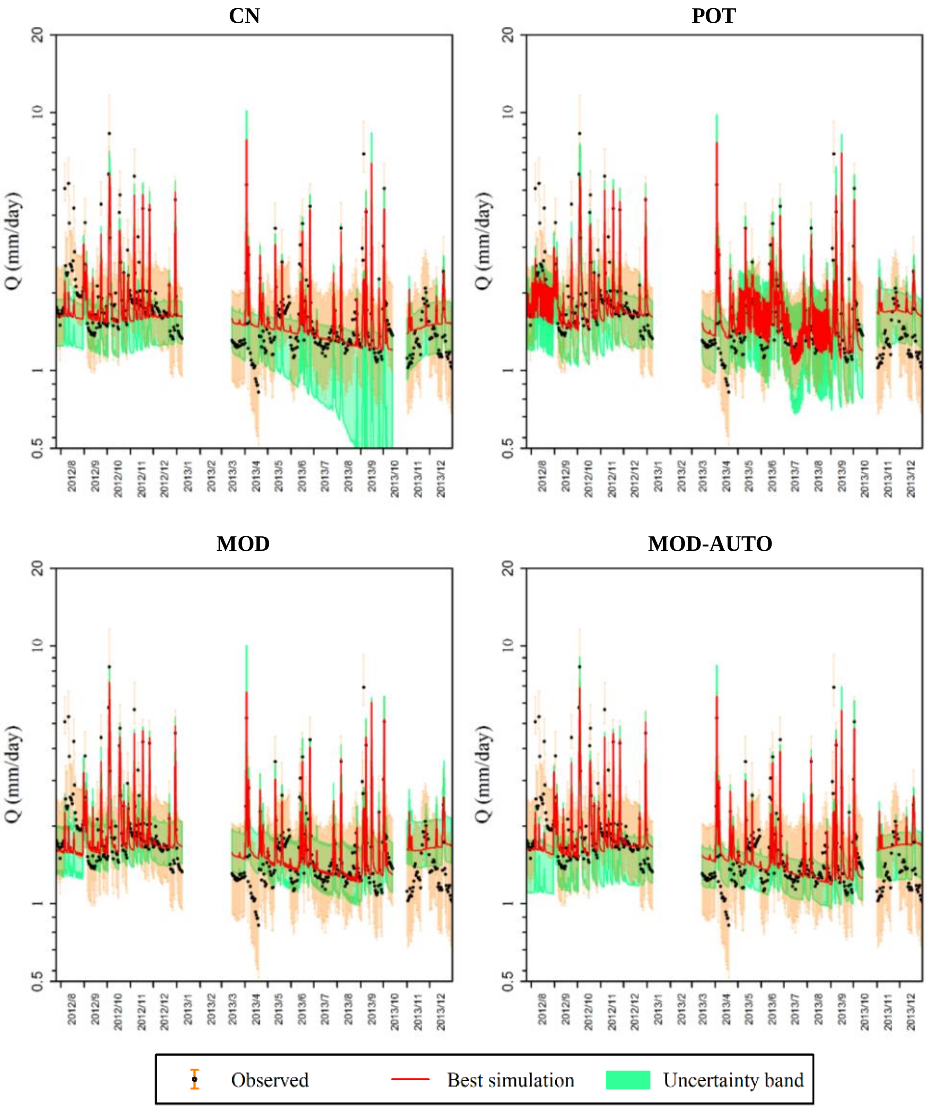


**Figure 7** Hydrograph of Best Representing Calibration Round (y Axis in Logarithmic Scale)

There are also limitations for the setting of irrigation command in the original model. Only one source of irrigation can be assigned in each day. Thus to simulate irrigation from 2 sources, the best approach is to assigned it consecutively in each day (2-day interval for each irrigation source). In the source code, there are also different time frame for execution of irrigation command from river and deep aquifer. The irrigation from river is executed after soil water simulation while the irrigation from deep aquifer is executed before soil water routing simulation. Thus, the irrigation water from the river is added to the next day. In this research with the configuratio of consecutive irrigation, this process is resulting combined irrigation amount in every 2 days. Thus in POT model, since irrigation is directly overflowed, there were fluctuation in streamflow every 2 days.

The modified model showed better result. The model could bracket the observed data at a similar percentage with narrower band. MOD could bracket 95% of the data when r-factor was 0.77 and MOD-AUTO could bracket 92% of the data when r-factor was 0.66. The resulting best simulation performance indexes were also better compared to original model. The modification of irrigation process in MOD-AUTO could give slightly better NSE. The results differences can be more clearly observed in the form of Flow Duration Curve (FDC) as in Figure 8. FDC is one of the most informative methods in water resources planning to display the complete range of streamflow from low flows to flood events. It is a relationship between any given streamflow value and the percentage of time that this streamflow is equaled or exceeded, or in other words it is the relationship between magnitude and frequency of streamflow (Smakhtin, 2001).

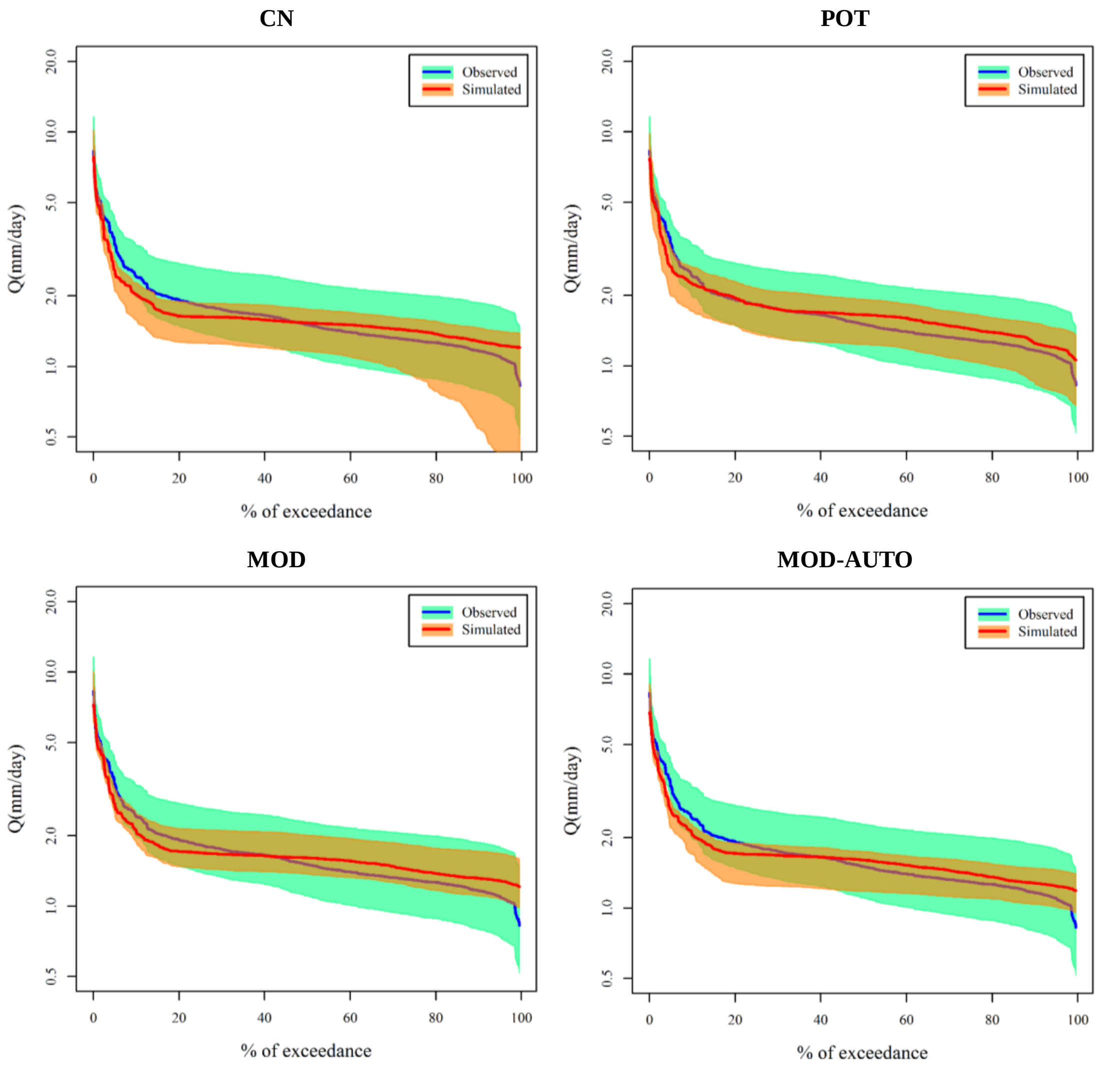


**Figure 8** Flow Duration Curve Results from Each Model (y Axis in Log Scale)

In comply with the performance results, SWAT with CN and pothole have less reliable performance in low flow period. The bands tend to be wider for those models. Modified versions have better result since it has almost similar band with in all period of exceedance. Thus, it could be concluded that modification of SWAT is necessary to develop more reliable estimates of streamflow in all flow regime.

## V. CONCLUSIONS

SWAT has different model structure to model paddy field especially in surface storage, seepage, and irrigation process. However, through calibration, it could produce satisfactory performances. These imply the capability of SUFI-2 method to calibrate SWAT model and also the equifinality characteristic of SWAT model.

Modification of SWAT model is needed to increase its reliability to estimates stremflow. Modification concepts that proposed by Sakaguchi et al. (2014b) with some additional modification could result narrower uncertainty band while bracketing enough observed data. The original SWAT model (CN and POT) has less satisfactory performance compared to the modified model (MOD and MOD-AUTO). The uncertainty band is wider and best simulation performance indexes are least satisfactory. The modified auto irrigation process gave minor change in the model performance indexes, i.e. slightly better NSE and narrower uncertainty band.

These results imply that surface storage, seepage, and irrigation are some of the most important processes in irrigated paddy field. Accommodating these processes would lead to more reliable streamflow estimates in irrigated paddy field watershed.

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