Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

Article

Development of SWAT-PADDY for Simulating Lowland Paddy Fields

Ryota Tsuchiya [1,2,*], Tasuku Kato [3] and Jaehak Jeong [4]

[1] The Graduate School of Agriculture, Tokyo University of Agriculture and Technology, 3-5-8 Saiwaicho, Fuchu 183-8509, Tokyo
[2] Present affiliation: Institute for Rural Engineering, NARO, 2-1-6 Kannondai, Tsukuba 305-8609, Ibaraki
[3] Institute of Agriculture, Tokyo University of Agriculture and Technology, 3-5-8 Saiwaicho, Fuchu 183-8509, Tokyo; taskkato@cc.tuat.ac.jp
[4] Blackland Research and Extension Center, Texas A&M AgriLife Research, 720 East Blackland Road, Temple, TX 76502, USA; jjeong@brc.tamus.edu
* Correspondence: r.tsuchiya@affrc.go.jp; Tel.: +81-29-838-7594

Abstract: The consumption of rice, which recently increases globally, leads to requirement for planning sustainable water management for paddy cultivation. In this research, SWAT model was modified to evaluate sustainability of paddy cultivation. Modifications to simulate paddy cultivation are 1) to equip with a new water balance model of impounded fields, 2) to add an irrigation management option for paddy fields, which is characterized by flood irrigation managed by farmers on a daily basis, 3) to consider puddling operation that influences water quality and infiltration rate of soil. The enhanced model, named SWAT-PADDY, was applied to an agricultural watershed in Japan as a case study. The modified model succeeded in representing paddy cultivation in the study area. However, SWAT-PADDY underestimated base flow in irrigation period. The cause of this is inferred that the modified model doesn't represent return flow of excess withdrawal of river water. In conclusion, addition of the models of impoundment and management practices in paddy fields to SWAT improved field scale simulation of water balance and irrigation in paddy fields. However, further improvement of the model on irrigation return flow process is needed to better predict hydrology of watersheds dominated by paddy irrigation.

Keywords: SWAT; model development; paddy fields; irrigation; return flow

---

1. Introduction

Rice is said to be a staple food for more than half of the world's population and supplies more dietary energy than the other crops [1]. A consumption of rice is increasing because of the population increasing in South, Southeast and East Asian countries and the area expanding of rice consumption to Africa [2, 3]. Increasing demand of rice requires the land productivity in paddy fields to be globally increased by 0.6 ton/ha during the next 10 years [4]. To increase land productivity, several ways are generally conducted; increasing harvesting times, improving crop yield potential by genetic modification, and applying more agrochemical, fertilizer and irrigation water. In addition, saving soil and cropland is also important to improve and sustain land productivity for future [5]. Most of paddy fields are cultivated under inundated condition by irrigation. To keep field inundated, paddy cultivation consumes and discharges much water. Therefore, paddy cultivation sometimes affects water resource sustainability through large amount of water use for irrigation and pollutant discharge from paddy fields [6-8]. To mitigate impact on water environment in a watershed containing paddy fields, a management plan of land use, irrigation and drainage should be programmed with considering their sustainability. In order to assess the sustainability of natural resources including land and surface or ground water, several hydrological models have been used including MIKE SHE [9, 10], HSPF [11, 12] and the other hydrological models [13, 14]. Soil and Water Assessment Tool (SWAT) is one of hydrological models to assess sustainability of land and water

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

resources in watershed scale with considering agricultural production [15, 16]. SWAT has been globally used for many objectives [17-19], including to make or evaluate irrigation plan [20, 21] and land management plan [22, 23] and to evaluate impacts of climate change on hydrological cycle [24, 25]. Because several kinds of application software are available to prepare input data (ArcSWAT, http://swat.tamu.edu/software/arcswat/), check errors in a simulation (SWAT-Check, http://swat.tamu.edu/software/swat-check/), and calibrate parameters (SWAT-CUP, http://swat.tamu.edu/software/swat-cup/) for SWAT model simulation, the users of SWAT can easily apply the model. Therefore, it has a significant potential to help administrators to make sustainable management plans for watersheds with paddy fields. However, SWAT is not designed to model such an extraordinarily wet condition as seen in paddy fields [26, 27]. To represent impounded environment in paddy fields in SWAT simulation, the pothole model has been recommended to be used [28, 29]. However, the pothole model is originally developed to model the hydrologic characteristic of pothole landscapes that are common in the Corn Belt and Great Lakes in U.S. Sakaguchi et al. [30] pointed out unsuitability of the pothole model to simulate water balance in paddy fields. In order to model paddy fields in a SWAT simulation, the several researches were conducted. Xie and Cui [31] modified the existing pothole algorithm to simulate hydrological processes in paddy fields. Boulange et al. [32] developed PCPF-1@SWAT by combining a field scale model for estimating pesticide concentration in paddy water and surface soil (PCPF-1 [33]) with the modified pothole model to evaluate an impact of pesticide use in paddy fields in watershed scale. In the water balance computation, lateral seepage through embankment was considered in this model. Sakaguchi et al. [30] developed a paddy model based on the modified pothole. In this model, a new parameter, potential percolation rate of paddy fields, was added. This parameter was defined as a parameter which is determined through calibration process and includes lateral seepage and vertical percolation from paddy impoundment in one term. Therefore, the strong point in Sakaguchi's model compared to PCPF-1@SWAT, which requires users to define two parameters to represent water loss from impoundment through paddy soil, is the less number of fitting parameters for paddy fields. Though those models showed acceptable simulation result in their research, the structures of those models are still based on the pothole model. However, the characteristics of potholes are conceptually different from paddy fields in aspects of hydrology and agricultural management. At first, a depth of impoundment in a paddy field is controlled by each farmer every day, considering growth of paddy crop and climate condition on that time. Next, a difference exists in the way to control soil water condition. Soil in pothole region is completely drained with tile drainage when a field is used for crop production [34]. However, soil is kept to be wet under paddy impoundment to stabilize water supply to paddy plants, to control dynamics of organic matter, to supply inorganic mineral salts contained in irrigation water, to control weed, to prevent damages by blight and harmful animals, insects, and other living things, and to maintain temperature [35]. For those reasons, hydrological characteristics in paddy fields are conceptually different from potholes. In addition, previous researches revealed that paddy fields sometimes discharge nutrient with a large amount of water [6, 36], and on the other hand, polluted irrigation water is purified in paddy fields as the effect of plant uptake, denitrification and cyclic water use in paddy fields district [37, 38]. Therefore, water management in paddy fields is significantly important to be considered when watershed management is planned in an area containing paddy fields [39]. For those reasons, paddy fields should be modelled in SWAT based on its own hydrological process. As objectives in this research, modification of SWAT2012 was conducted to simulate paddy fields water management, that are 1) to equip with a new water balance model including water impoundments in paddy fields, 2) to add an irrigation management option for paddy fields, which is characterized by flood irrigation with target ponding depths managed on a daily basis, 3) to consider puddling operation that influences discharge water quality and infiltration rate during growing periods. The modified model was named SWAT-PADDY. To examine the model performance, SWAT-PADDY was applied to an actual watershed containing paddy fields in Japan.

2. Materials and method

2.1 Overview of SWAT model simulation

SWAT is a semi-distributed and process-oriented ecohydrological model which computes water, nutrients and pesticide discharge from a watershed on a daily time step [15]. In the simulation, water and material balance, plant growth, and management practices are simulated in each hydrological response unit (HRU), which is generated by overlying maps of land use, soil, and slope. Then, outputs from HRUs are aggregated at each subbasin level and routed to downstream. This enables the model to represent hydrological characteristics of watershed efficiently with reasonable approximation. For the simulation, SWAT requires input data of weather, maps and schedule of management practices. Detailed description of the model is available in SWAT2009 theoretical documentation [29].

2.2 Development of SWAT-PADDY

In previous researches, the pothole module was used to model impoundment in paddy fields [30-32]. However, computational algorithm of the pothole model is not targeted on hydrological process in paddy fields (Figure 1). This makes structure of the model complicated in SWAT, because the model has to represent two conceptually different processes in one module. This is not appropriate when considering the further model development for future. Therefore, the authors decided to developed more simple simulation scheme to model paddy fields in SWAT, which is suitable as a basis of the paddy-fields-directed model development in SWAT. A terrestrial process is modified as shown in Figure 2 for this purpose. Besides, agricultural management practices in paddy fields are different from the other farm land assumed in SWAT. Thus, new management options for paddy management are added to the scheduled management scheme in SWAT.

2.2.1 Development of paddy impoundment module

Hydrological process in paddy fields is different from processes in other land uses because rainfall on paddy fields and irrigation water are stored above the land surface as an impoundment during a paddy growing season [35]. In order to represent paddy impoundment in SWAT, new module for impoundment was developed based on the modified pothole model [30]. This module computes water storage in the form of depth though the modified pothole model computes water storage in volume. Water balance is calculated using equation (1).

$$\Delta DEP_{impnd} = IR + R_{day} - Q_{surf} - EV_{impnd} - PERC_{day}, \quad (1)$$

where ΔDEP_{impnd} is daily change of impounded depth (mmH_2O), IR is daily irrigated water depth (mmH2O), R_{day} is daily precipitation (mmH_2O), Q_{surf} is daily surface discharge (i.e. overflow from outlet weir) from paddy fields (mmH_2O), EV_{impnd} is daily evaporation from water surface (mmH_2O), and $PERC_{day}$ is daily water percolation to soil surface layer (mmH_2O). Evaporation from water surface is calculated using equation (2) and (3).

$$\text{If } LAI > LAI_{ev},\ EV_{impnd} = \eta E_0 (1 - LAI / LAI_{ev}), \quad (2)$$

$$\text{If } LAI \le LAI_{ev},\ EV_{impnd} = 0, \quad (3)$$

where η is the evaporation coefficient, E_0 is potential evapotranspiration for a given day (PET; mmH_2O), LAI is leaf area index of a crop grown in flooding, LAI_{ev} is the leaf area index at which evaporation from water surface does not occur. For the parameters of η and LAI_{ev}, the values of 0.6

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

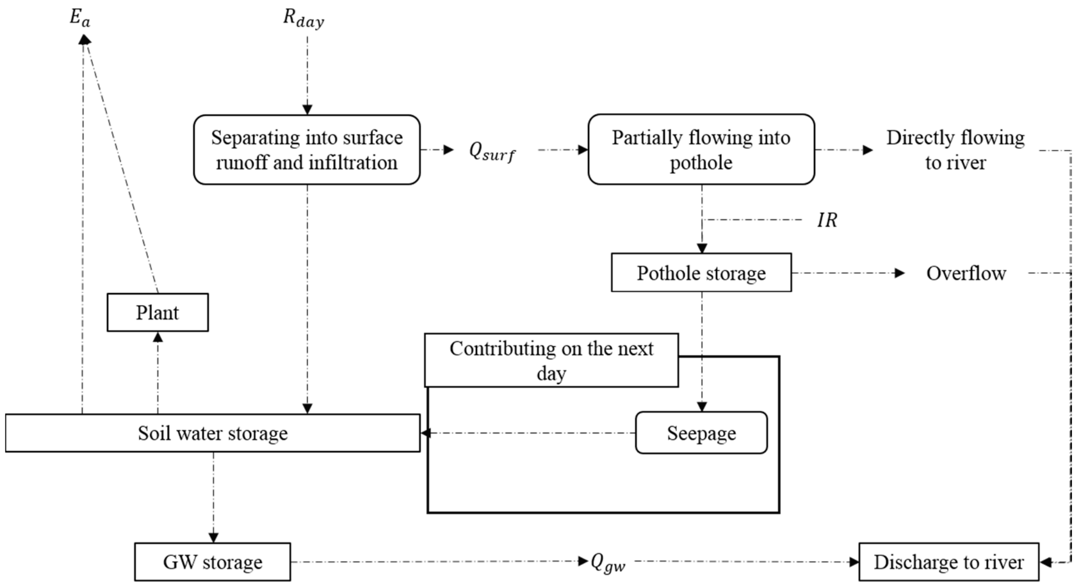

Figure 1. Schematic chart of pothole procedure in SWAT2012

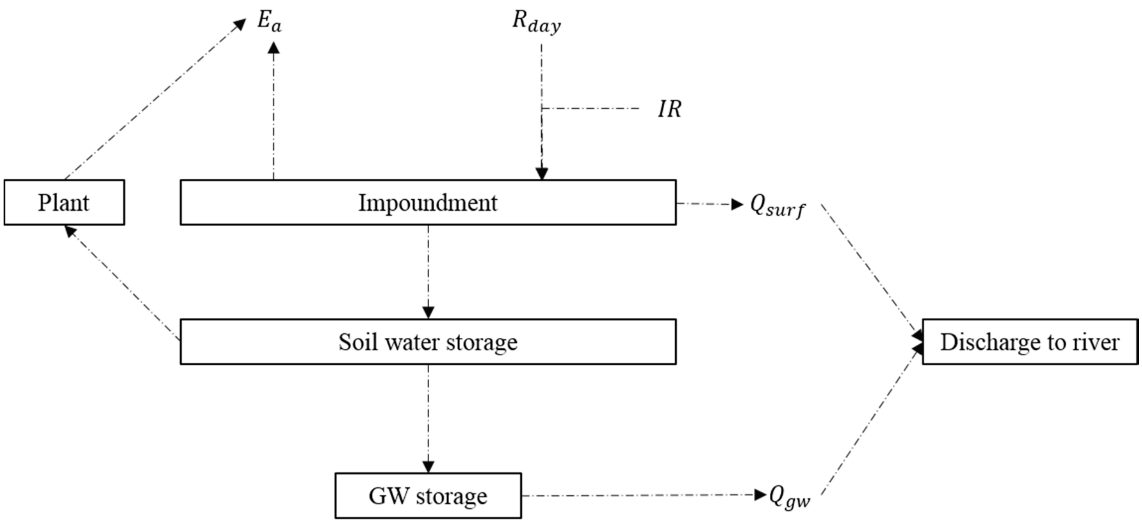

Figure 2. Schematic chart of the paddy model developed in SWAT-PADDY

and 4.0 were adopted respectively based on the previous research [30]. Computation techniques for Q_{surf} and IR are described in the following sections. In SWAT-PADDY, the method to compute percolation of water from impoundment to soil which is used in the original or modified pothole [28, 31] was not adopted, because soil water content and saturated hydraulic conductivity of surface soil layers are only the elements to determine the percolation rate and this leads to much underestimation of percolation in paddy fields [27]. In actual paddy fields, there is a constant water loss as a seepage through bund of paddy field and vertical percolation even though surface soils are saturated and hydraulic conductivity is very low because of puddling operation. Thus, potential percolation rate ($PERC_0$) from impoundment to soil layers is defined as the constant value as modeled in the previous research [30].

2.2.2 Modification of the operation scheme of irrigation and drainage for paddy fields district

In paddy fields, impounded water depth is controlled by farmers based on a growth stage of paddy and a climate condition. Controlling impounded water depth is quite important for rice production [40]. In SWAT-PADDY, the water depth control method used in the past research [31]

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

was adopted. Three critical water depths, which are maximum flooding depth for surface discharge computation (DEP_{max}), irrigation trigger depth ($DEP_{trigger}$), and irrigation target depth (DEP_{target}), were introduced in this method. Values of the critical water depths are variable and determined in the scheduled management on each day. Surface discharge is calculated using equation (4) and (5).

$$\text{If } DEP_{impnd} > DEP_{max},\ Q_{surf} = DEP_{impnd} - DEP_{max}, \quad (4)$$

$$\text{If } DEP_{impnd} \leq DEP_{max},\ Q_{surf} = 0, \quad (5)$$

where DEP_{impnd} is depth of impoundment on a given day (mmH_2O), and DEP_{max} is maximum depth of impoundment (mmH_2O). Demanded irrigation depth on a given day (IR_{demand}, mmH_2O) is calculated using equation (6) and (7).

$$\text{If } DEP_{impnd} < DEP_{trigger},\ IR_{demand} = DEP_{target} - DEP_{impnd}, \quad (6)$$

$$\text{If } DEP_{impnd} \geq DEP_{trigger},\ IR_{demand} = 0, \quad (7)$$

During rice cultivation, the value of IR_{demand} becomes large and one water resource is sometimes not enough to satisfy the demand. So, multiple kinds of water resources are used in paddy fields districts when the amount of available water from a resource is not enough [8, 41]. In a paddy fields district with well-developed irrigation system, including water withdrawal facilities and irrigation canals, a ratio of irrigation water amount from each resource can be assumed to be the same as the area of paddy fields and the ratio doesn't fluctuate day by day. Therefore, we introduced a parameter of the main resource ratio, r_{main} with assuming double water resources for one district as shown in equation (8) and (9).

$$IR_{demand,main} = r_{main} \times IR_{demand}, \quad (8)$$

$$IR_{demand,sub} = (\ 1 - r_{main}\ ) \times IR_{demand}, \quad (9)$$

where $IR_{demand,main}$ is irrigation demand for main water resource (mmH_2O), and $IR_{demand,sub}$ is irrigation water demand for sub water resource (mmH_2O).

2.2.3 Adding puddling operation to scheduled management

To keep water above land surface, farmer has to manage the hydraulic conductivity in paddy soil to be low. An operation of puddling, which means mixing soil and impounded water before transplanting, is conducted for this purpose [42-44]. In puddling operation, farmers break soil aggregations and fill crack in plow sole with small soil particles, and this leads to low conductivity of plow sole. Therefore, hydraulic conductivity of surface soil in a paddy field is low in rice growing season. In addition, this makes surface soil saturated with water, and leads to reduced condition in paddy soil. Reduced soil environment promotes denitrification, which is related to nitrogen loss in paddy soil. In this sense, modelling puddling operation in SWAT is important when the model is used in a paddy fields watershed. In SWAT-PADDY, equation (10), originally from the previous work in APEX modification for paddy fields [45], is computed when puddling is operated.

$$K_{sat,wet} = coeff_{pudd} \times K_{sat,dry} \quad (8)$$

where $K_{sat,wet}$ is saturated hydraulic conductivity after puddling (mm/hr), $coeff_{pudd}$ is puddling coefficient less than 1, and $K_{sat,dry}$ is an original value of hydraulic conductivity (mm/hr). Users can set

 doi:10.20944/preprints201611.0024.v1

the depth of plow sole and this equation is applied to the layer including plow sole and the overlying layers. After paddy cultivation finishes, users can operate "break puddle" to return the value of hydraulic conductivity to the original ($K_{sat,dry}$). In addition to changing soil physical property, puddling often causes water pollution when farmers drain water just after the management is operated, which contains much sediments and nutrients resuspended by mixing surface soil and impounded water. To represent this, the resuspension after puddling is also modeled in this puddling scheme based on the tillage algorithm existing in SWAT2012. The basic idea of this is conceptually the same as the modification in APEX [45].

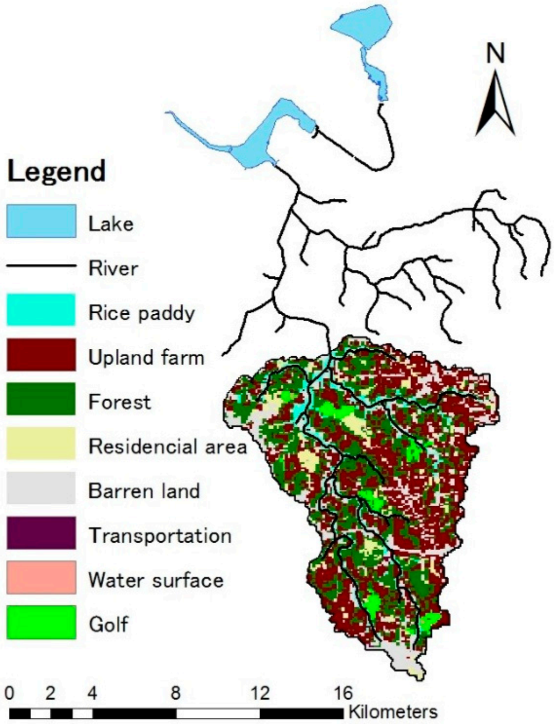

Figure 3. Land use distribution in the study area

2.3 Study area for evaluation

The SWAT-PADDY is tested in the Upper Kashima River watershed in Imbanuma Lake basin, Chiba Prefecture, Japan. The area of research site is 117 km^2. The watershed is covered mainly by andosol soil, which is made from volcanic ash and is very permeable [46]. Therefore, surface runoff is not significant in this area, and groundwater discharge is dominant for river flow. In this watershed, lowland area is used for paddy fields and it occupies 9% of the watershed. The largest land use in this watershed is farmland excluding paddy fields and it is located on the hill area (Figure 3; Table 1). This number shows that the portion of paddy fields is not so high, but it has a large impact on the watershed hydrology because paddy fields are located along the river. In addition, 2000~3000 mmH_2O water is withdrawn from using pump facilities. This value is much larger than average annual precipitation (approximately 1400 mmH_2O) and the main source of irrigation water, which accounts for 80 % of total irrigation water use, is Kashima River itself. Therefore, paddy irrigation has an impact on water environment through both irrigation and drainage practices. Thus, considering paddy fields in hydrological simulation is much important for the management of this watershed. We set a hydrologic investigation point in the middle of Kashima River and observed river flow rate in the period of 2012 ~ 2014 though we stopped monitoring in January ~ March because paddy fields are not cultivated in that period, and the data in October ~ December 2013 is lost because of a big typhoon event happening in October 13th 2013. In addition, we observed irrigated water amount and water flow in paddy drainage channel in the period of June 4th ~ August 31st in 2015, and estimated actual ET by the FAO56 method [47], whose ability is confirmed

Table 1. Land classification in the study area

Land use	Area (%)
Rice	8.98
Farm land (excl. rice)	38.08
Forest	28.61
Barren land	5.79
Residential area	15.24
Others	0.09
Water surface	0.16
Golf field	3.05

in the similar environment [48]. The source of weather data used to estimate water balance in paddy fields was the same as that used in the simulation.

2.4 The application and calibration of SWAT2012

Model input files were generated using ArcSWAT 2012 with following data:

1. Digital Elevation Model (10 m mesh, [49])
2. Land use (100 m mesh [50])
3. Soil map by Japan Soil Association [51] with vertical data from SolphyJ [52]
4. Weather data gained at the weather station in Sakura, Chiba, and Tsukuba [53]

With these data, 227 HRUs are defined in 11 subbasins. A management schedule in paddy fields is determined based on the local standard of fertilizing [54], the guideline for paddy management [55] and the field scale monitoring conducted at an actual field located near the outlet of watershed in 2015. In addition, both river and deep aquifer are used as irrigation sources in this region. However, the number of available sources for SWAT2012 is only one. Groundwater is chosen for the irrigation water source in the calibration of SWAT2012 because water withdrawal from deep aquifer is income for the watershed in water balance aspect though river water use is cyclic use of water within a watershed. To widen the model capability globally, SWAT allows users to choose several methods to compute each hydrological process. In this research, the authors chose plant-evapotranspiration-related estimation method of retention parameter used for surface runoff computation [56] and Priestley-Taylor method [57] to compute potential ET to represent hydrological characteristics of the watershed. Though Penman-Monteith method [58] is widely used in SWAT application, Priestley-Taylor method can also be used when the model is applied in wet condition, as seen in rice cultivated region, and it requires less climatic data input [29]. Thus, this method is more suitable than another when considering SWAT-PADDY application to the

Table 2. Inputted schedule of paddy management

Date	Management
Apr. 24th	Basal fertilizer
Apr. 28th	Puddling
May 1st	Trans-planting
Jun. 9th	Mid-summer drainage
Jun. 23rd	Start impounded
Jul. 1st	Ear manuring
Jul. 31st	Intermittent irrigation
Aug. 25th	Drained
Sep. 10th	Harvest/Break Puddle

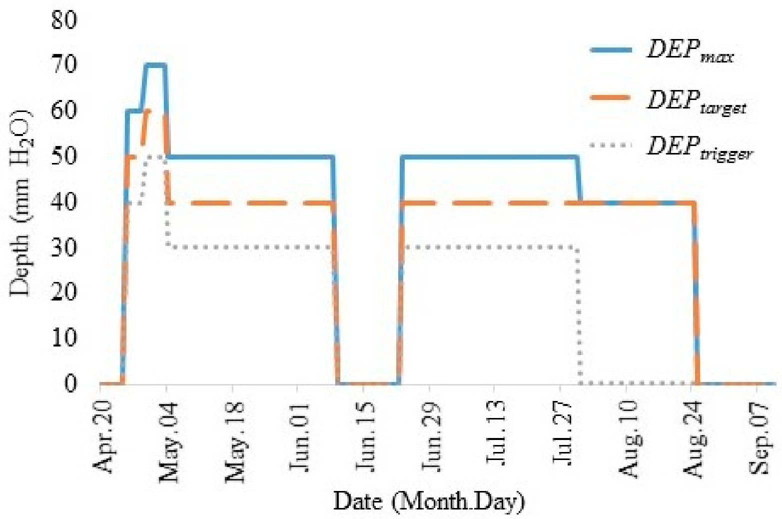

Figure 4. Water depth management schedule used in the simulation

southeast and south Asian countries where data availability is comparably poor and demand for hydrological models increase rapidly these days. For this reason, Priestley-Taylor method was chosen for the model evaluation in this research. To evaluate performance of the model, the hydrological parameters were calibrated in watershed scale using SWAT-CUP with the original SWAT2012 at first and then SWAT-PADDY was applied with the parameters gained in calibration.

2.5 The setting and evaluation of SWAT-PADDY

In the application of SWAT-PADDY, the water depth and agricultural management were defined as shown in Figure 4 and Table 2, respectively. The value of $PERC_0$ was set to 10 as recommended and observed in the same region [59, 60]. To examine the performance of puddling model introduced in SWAT-PADDY, five values were inputted to the parameter, $coeff_{pudd}$; 1, 0.1, 0.01, 0.001, and 0.0001. For the evaluation, we chose a paddy HRU which is defined as the combination of paddy field, gleysol, and gentle slope in the lowest subbasin. In the HRU scale, simulated ET was compared with ET value estimated by FAO56 method. The simulated values of surface runoff using SWAT and SWAT-PADDY were compared each other. And then, performance of the two models were compared by the simulation result of river flow and water balance in the paddy HRU.

3. Results

3.1 The calibration of SWAT2012

The parameters to compute hydrologic cycle in this watershed were calibrated using observed river flow data in daily time step by SUFI-2 [61] method in SWAT-CUP. After 7 iterations (1 iteration equals 1500 times simulations), we got the best parameter set. Table 3 shows the calibrated values of hydrological parameters and the rank of sensitivity. In SUFI-2 method, parameter sensitivity is determined by computing multiple regression system [62]. In this process, we got the rank of parameter sensitivity in the final iteration as shown in Table 3. When seeing the P-Value of each parameter gained from t-test, the sensitivity of ALPHA_BF is considerably significant. This means groundwater process in this watershed gives a large impact on river flow compared to the other processes. In addition, the value of ALPHA_BF is calibrated to the significantly low value to represent much stable baseflow in Kashima River. Based on the result of calibration, the watershed was characterized as very flat and groundwater discharge takes a very long time to reach river flow. With

Table 3. The list of calibrated parameters and sensitivity

Parameters	Type	Original	Range min.	Range max.	Best	Rank	P-Value
CN2.mgt	R	36 ~ 86	1.04	1.07	38.12 ~ 91.05	2	0.17
SOL_AWC.sol	R	0.09 ~ 0.25	1.35	1.43	0.13 ~ 0.35	7	0.55
ALPHA_BF.gw	V	0.005	0.00	0.02	0.08×10^{-2}	1	0.00
GW_DELAY.gw	V	5	36.83	39.39	38.22	10	0.91
ESCO.hru	V	0.95	0.98	1.00	1.00	6	0.29
EPCO.hru	V	1.00	0.71	0.76	0.73	8	0.74
SURLAG.bsn	V	4	14.77	16.75	16.67	5	0.23
RCHRG_DP.gw	V	0.02	0.10	0.12	0.11	9	0.88
ALPHA_BF_D.gw	V	0.9	0.12	0.19	0.15	4	0.22
CNCOEF.bsn	V	0.5	0.52	0.55	0.52	3	0.19

Further information about each parameter can be found in the theoretical documentation (Neitsch et al., 2011). The column "Type" shows whether the value was replaced (V) or multiplied (R) to the original value. The values stored in the column "Range min. (max.)" is replaced or multiplied to the values stored in "Original". The column "Best" stores the best parameter set used in the model evaluation described in the following part. The column “Rank” shows rank of parameter sensitivity.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

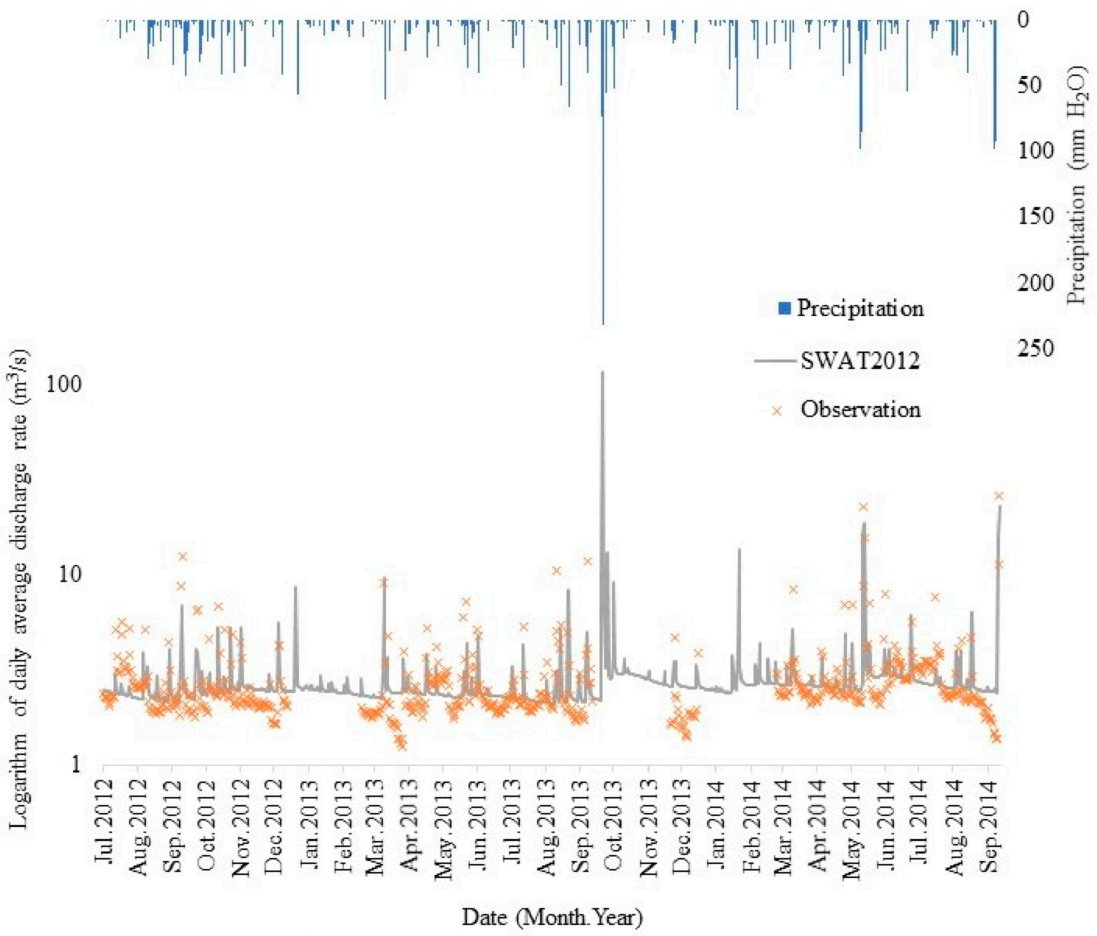

Figure 5. Daily hydrograph simulated with SWAT2012 model compared with the observed river flow

the best parameter set gained in calibration process, Nash Sutcliffe model efficiency (NSE) [63] of the river flow simulation (Figure 5) was 0.63, which means "satisfactory" for hydrological simulation [64]. Therefore, this parameter set was chosen to be used for the test of SWAT-PADDY.

3.2 Test of soil moisture simulation with puddling operation

In order to represent a saturated soil condition in paddy soil, puddling management was added in SWAT-PADDY. To check the model performance and to identify the value of $coeff_{pudd}$, the different values were inputted to the model. Figure 6 shows the soil water content simulated with each coefficient value. In this graph, soil water content in irrigation periods increases as the coefficient becomes lower and there was not so much difference between the simulation results with $coeff_{pudd}$ = 0.001 and $coeff_{pudd}$ = 0.0001. Therefore, the value of 0.0001 is considered to be extraordinarily low for the model and the value of 0.001 was adopted for the case study. Figure 7 shows the fluctuation of degree of saturation in each layer of the soil in the paddy HRU with $coeff_{pudd}$ = 0.001. In this research, plow sole was set in the second layer. Thus, the first and second layers got saturated after puddling operation. This graph suggested the puddling was operated successfully in SWAT-PADDY.

3.3 Evaluation of ET simulated in SWAT-PADDY

The ET estimated with FAO56 is compared to the ET simulated with SWAT2012 and SWAT-PADDY (Figure 8). The slope of regression line of SWAT-PADDY is apparently closer to 1 than that of SWAT2012. This means ET is estimated better with SWAT-PADDY. In addition, the data were separated into two parts based on the cumulative simulated ET; i.e. the former part (less than 300

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

mmH_2O) and the latter part (more than 300 mmH_2O). Comparing the regression lines, the slope of latter part was 0.9358 and was closer to 1 than the former part, whose slope was 0.6013. This suggests that the ET was better estimated after rice growing up.

3.4 Test of irrigation component

Figure 9 shows the monthly irrigated water amount of the observation and the simulation results with SWAT2012 and SWAT-PADDY. The graph suggested irrigation management simulated with SWAT-PADDY represent the better simulation than SWAT2012. The reasons of this are considered

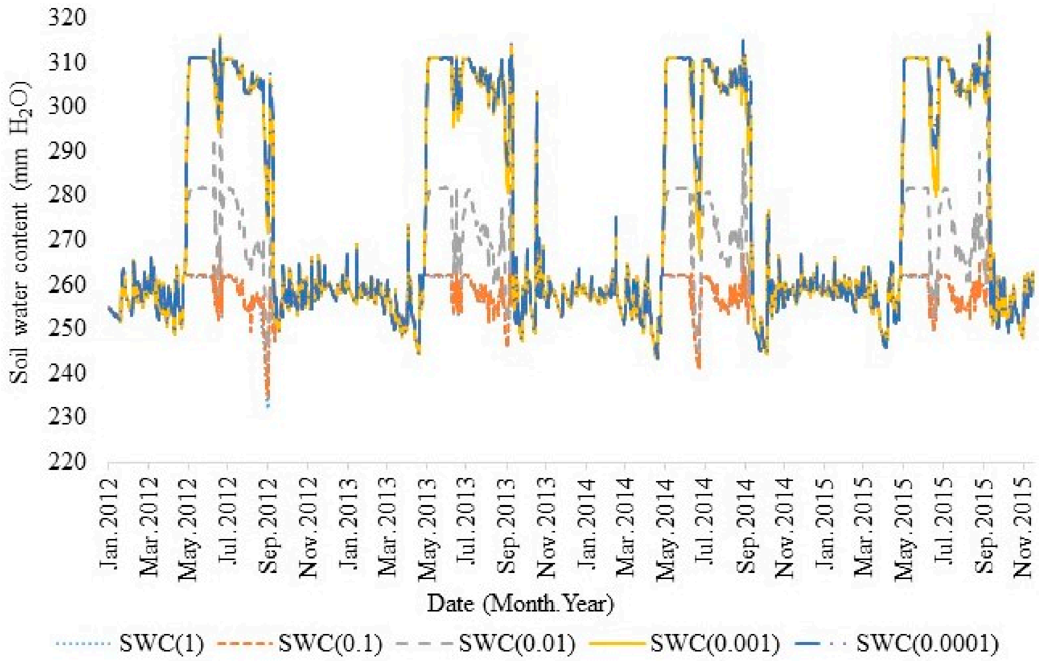

Figure 6. Daily soil water content in a paddy field HRU with different $coeff_{pudd}$ value

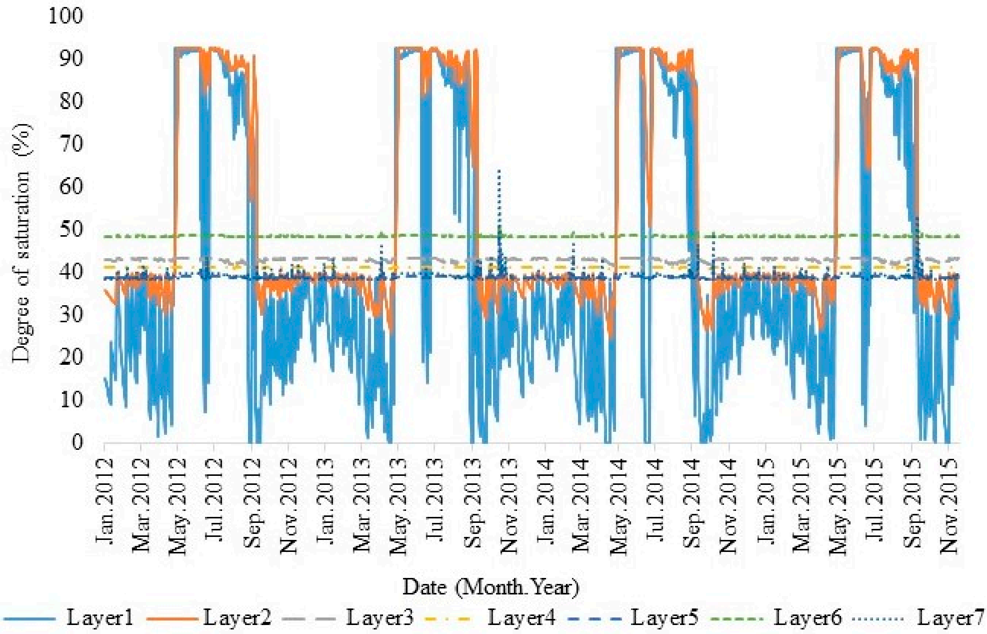

Figure 7. Daily fluctuation of degree of saturation of soil layers in a paddy HRU simulated with SWAT-PADDY

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

to be improvement of water balance calculation and ET estimation, and that SWAT-PADDY can operate irrigation using both river and deep aquifer though only one source, i.e. deep aquifer in the case study, can be used in the simulation of SWAT2012. In this graph, the simulation error exists especially in June. The cause of this is considered to be that we inputted general management schedule in this area, not the local and observed management data. Therefore, field observation should be continued to make more accurate management input data.

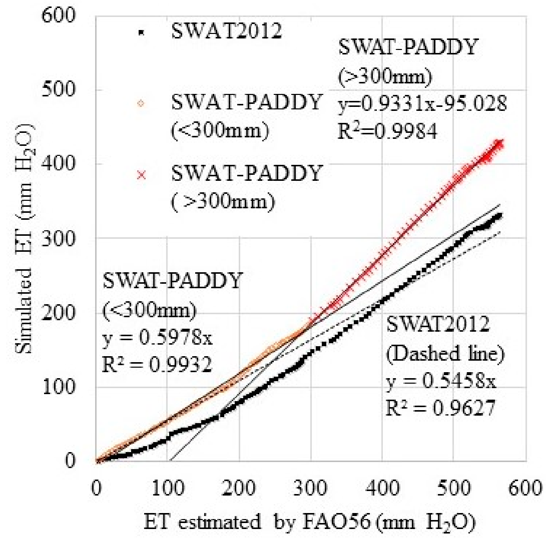

Figure 8. Comparison of ET simulated using SWAT2012 / SWAT-PADDY with ET estimated by FAO56

3.5 Evaluation of water balance simulated by SWAT-PADDY

Figure 10 shows the water balance of surface impoundment of paddy fields simulated with SWAT-PADDY in 2015. The graph showed that the ground surface of paddy field was kept to be impounded, surface discharge occurred only when it had much precipitation, percolation rate was constant as the value of *PERC*$_0$ (= 10), and evaporation stopped after LAI grew up in middle July. Those tendencies are reasonable as a model of paddy fields. In addition, Figure 11 shows the comparison of water balances of a paddy HRU in 2015 simulated with SWAT2012 and SWAT-PADDY, respectively. When comparing the graphs in Figure 11, there is an apparent difference in surface discharge. In the SWAT2012 simulation, surface discharge occurred only when precipitation more than 80 mmH_2O was observed. However, surface discharge occurred more frequently in the simulation of SWAT-PADDY and this is more reasonable as the simulation result. In addition, the simulated value of ET is underestimated by SWAT2012 because SWAT2012 cannot represent an extraordinary wet condition of paddy surface soil. Those results suggested that SWAT-PADDY better represents the hydrological characteristic of paddy field than SWAT2012.

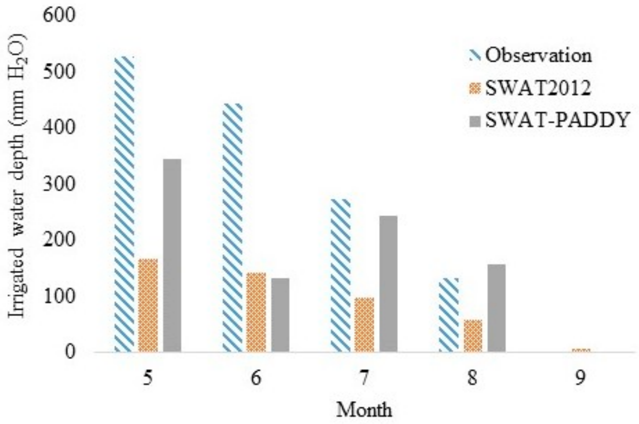

Figure 9. Monthly irrigated water depth for a paddy district in the observation and simulation with SWAT2012 and SWAT-PADDY

The observed and simulated water balance in the Upper Kashima River Basin is summarized in Table 4. This table shows simulated and observed water balance in paddy fields in daily average. As explained in 2.3, the period of observation is different from the simulation period. This causes the difference of precipitation between the observation and the simulation though using the same data source. In Table 4, the observed data shows extraordinarily high values for irrigation and water yield. This suggests that paddy cultivation consumes much more water than the crop requires. The values of every water balance element simulated with SWAT-PADDY increased because of modified irrigation method and paddy module introduced to SWAT-PADDY. Comparing the ratio of output/input (i.e. c / (a + b) in Table 4), the ratios were 0.74, 0.27, and 0.47 for the observation, the SWAT2012 simulation, and the SWAT-PADDY simulation, respectively. Thus, the ratio of return flow of irrigation is underestimated in the simulation.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

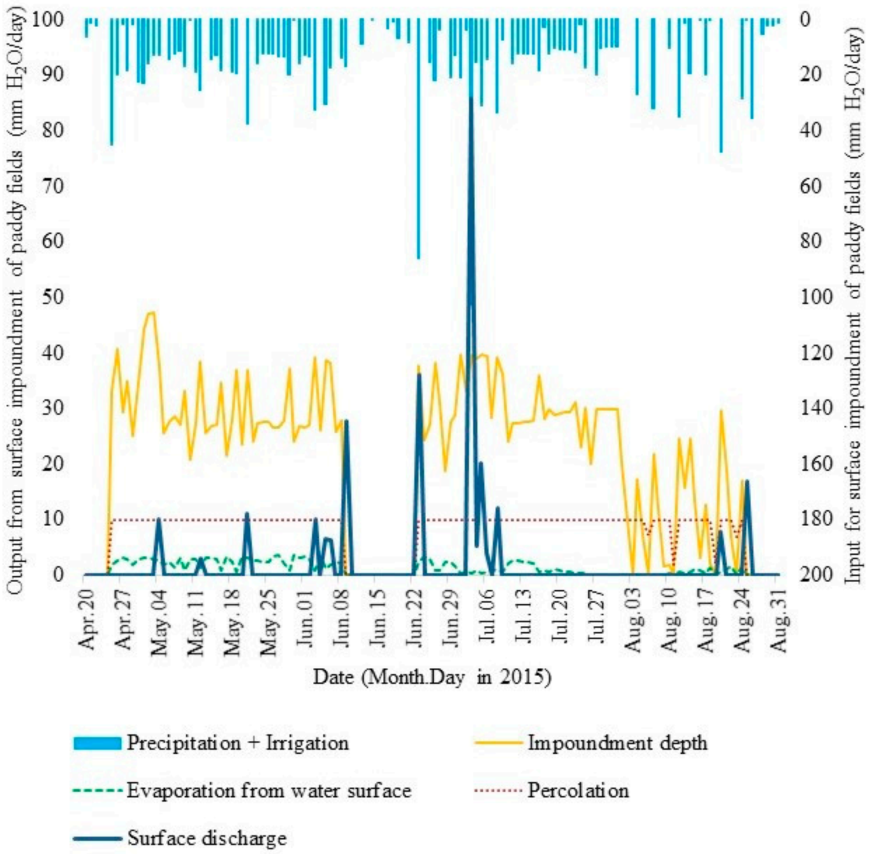

Figure 10. Daily water balance of surface impoundment in paddy fields simulated with SWAT-PADDY

3.6 Comparison of river flow simulated with SWAT2012 and SWAT-PADDY

Figure 12 shows the hydrograph simulated with SWAT-PADDY comparing with SWAT2012. NSE of the simulation was 0.40, which is lower than that of the original model (0.63). This means the applicability of SWAT-PADDY is less than SWAT2012. When the hydrograph of SWAT-PADDY is compared with SWAT2012, base flow in irrigation period is significantly underestimated in SWAT-PADDY simulation.

4 Discussion

4.1 Water balance model for paddy impoundment

The result shows that the water balance model for paddy impoundment developed in SWAT-PADDY succeeded in combining hydrological processes in paddy fields with SWAT hydrological simulation though some inconsistencies were found between the modified and the original algorithms. However, the authors found that SWAT-PADDY cannot represent the return flow of excess irrigation water withdrawal which is significant in irrigation and drainage system of the well-modernized paddy district. The cause of this is that lateral flow was scarcely occurred in the simulation and most of percolated water was discharged through groundwater process, which is hydrologically characterized as "very slow" to represent much stable flow rate in Kashima River. In addition, surface flow was occurred only when it rained much. Therefore, water discharge from the paddy HRU was mostly estimated to be in slow speed through a groundwater process in the simulation. However, drainage system is well developed in modernized paddy district, which increases water discharge through lateral flow process and seepage through a ridge of paddy field, and quickly transfers discharged water to river [42]. Thus, river flow is kept in high rate though large

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

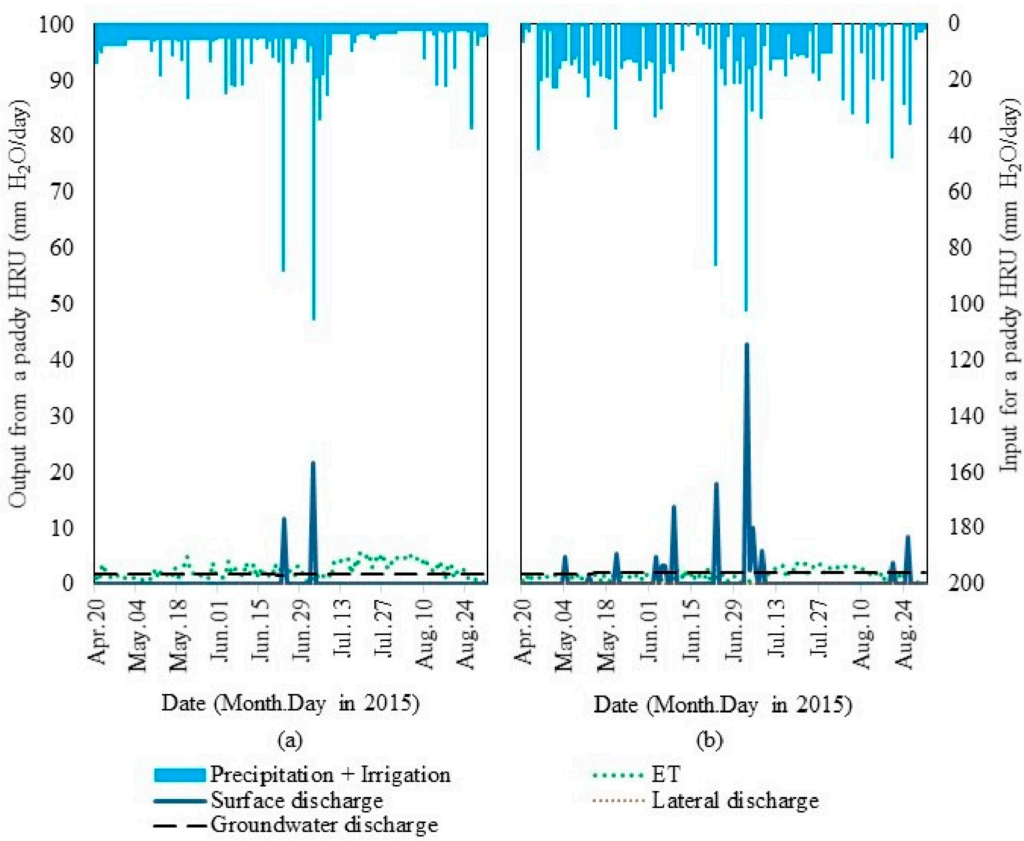

Figure 11. Daily water balances in a paddy HRU simulated with SWAT2012 (a) and SWAT-PADDY (b)

Table 4. Daily average values of water balance elements observed or simulated in paddy fields (mm/day)

Elements	Observation	SWAT2012	SWAT-PADDY
Precipitation (a)	4.68	5.82	5.82
Irrigation (b)	23.03	3.84	6.85
ET	4.61	2.42	3.12
Water yield (discharged water amount in drainage channel in observation) (c)	20.52	2.63	5.96
Surface and lateral discharge		0.46	1.88
Groundwater recharge		2.43	5.41
Groundwater discharge		1.90	4.09

amount of water is withdrawn for irrigation. Base flow in irrigation period was apparently underestimated by SWAT-PADDY because the model couldn't have simulated the quick return flow process through drainage system though large amount of water was withdrawn for paddy irrigation. Therefore, this should be solved by modelling drainage system in paddy fields district in SWAT.

4.2 Management operation for paddy cultivation

In SWAT-PADDY, there are two modification points to model paddy cultivation in SWAT; 1) irrigation scheme was modified to model paddy water management and 2) puddling operation was added to the options of agricultural management. Modified irrigation function enables the model to simulate irrigation water use more accurately than the original. Puddling operation reduced the

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

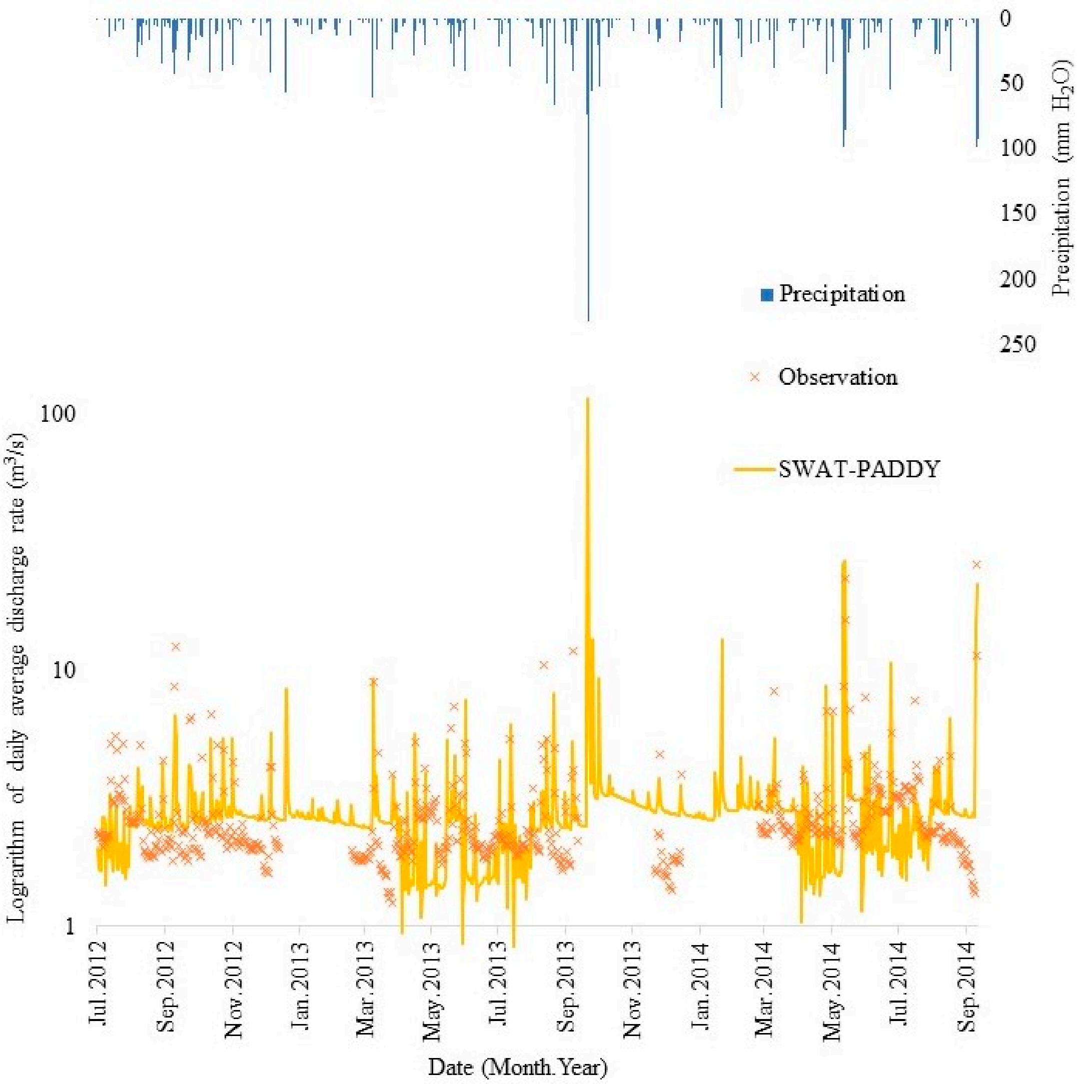

Figure 12. Daily hydrograph simulated with SWAT-PADDY

hydraulic conductivity of paddy soil and it allows the model to reduce vertical water flow in the surface soil layers and then to represent saturated soil condition under impoundment. This is much important when SWAT-PADDY is used to evaluate water pollution in the watershed including irrigated paddy fields district because nitrate in irrigation water decreases through denitrification in reduced conditions [38]. However, there is a requirement for further effort to model paddy cultivation in SWAT. In an actual paddy cultivation, puddling changes hydraulic conductivity of surface soil and it contributes to improve ability of paddy soil to retain water above ground surface. In SWAT-PADDY, percolation rate is defined as the constant value and soil hydraulic conductivity doesn't effect it. Thus, percolation and puddling operation is not correlated in the current simulation scheme. To simulate the impact of land management on water requirement for paddy cultivation, the way to determine percolation rate should be formulated considering hydraulic of the soil and hydraulic condition of paddy soil.

4.3 Contribution of SWAT-PADDY on sustainable water use in paddy cultivation

Irrigation is one of the most important factors for paddy cultivation as water scarcity affects the production of rice largely. Farmers irrigate much more water than the crop requires because it takes much labor to manage water depth strictly and this sometimes leads to water scarcity in the paddy field region. In addition, irrigation requires energy input in lowland area where large scale paddy fields are located. Therefore, to increase rice productivity in whole region scale with saving water

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

and energy consumption, irrigation should be planned with considering various aspects of crop production, including productivity, lower input, and sustainability of water resources and environment. SWAT-PADDY will help decision makers to plan irrigation based on hydrological condition of their region and to clarify the effect of changing management practices to water consumers, i.e. farmers.

5 Conclusion

In this research, discharge processes and management practices in a paddy field were newly modeled in SWAT (SWAT-PADDY). As the result, the authors succeeded in developing reasonable paddy model in SWAT and combining paddy cultivation with SWAT simulation. As a case study, SWAT-PADDY was applied to an actual watershed containing paddy fields. The authors found that SWAT-PADDY succeeded in representing the hydrological characteristics of an irrigated and impounded paddy field. However, the further improvement is required for watershed scale simulation, which is that quick return flow of irrigated river water through modernized irrigation and drainage system is not well modeled in SWAT-PADDY and this caused apparently low base flow in the river in irrigation period. Thus, this research succeeded in making a progress in paddy modeling using SWAT and clarify the further improvement point for paddy modeling.

Acknowledgement: This research was partly supported by the academic fund of the Japan Society of Irrigation, Drainage and Rural Engineering. Japan Public-Private Partnership Student Study Abroad Program "TOBITATE! Young Ambassador Program" supported making a communication between the researchers of Tokyo University of Agriculture and Technology and Blackland Research and Extension Center, Texas. The authors express our gratitude to Dr. Jeffrey G. Arnold and Dr. Raghavan Srinivasan for the kind advice about the modification and calibration of SWAT model. The authors would like to thank Enago (www.enago.jp) for the English language review.

Author Contributions: Tasuku Kato and Ryota Tsuchiya designed this research. Jaehak Jeong and Ryota Tsuchiya designed and developed the model. Ryota Tsuchiya applied the model and analyzed the result of simulation in the case study. Ryota Tsuchiya drafted the manuscript, which was revised by all authors.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. FAO Food and Nutrition Division Rice and human nutrition. Available online: http://www.fao.org/rice2004/en/f-sheet/factsheet3.pdf (accessed on 9 August 2016).
2. Hossain, M.; Fischer, K. S., Rice Research for Food Security and Sustainable Agricultural Development in Asia: Achievements and Future Challenges. *GeoJournal* **1995,** *35* (3), 286-298.
3. Nwanze, K. F.; Mohapatra, S.; Kormawa, P.; Keya, S.; Bruce-Oliver, S., Rice development in sub-Saharan Africa. *Journal of the Science of Food and Agriculture* **2006,** *86* (5), 675-677.
4. Global Rice Science Partnership (GRiSP), *Rice Almanac*. 4th Edition ed.; IRRI: Los Baños, Philippines, 2013.
5. Brown, L. R., Raising Land Productivity. In *Plan B: Rescuing a Planet Under Stress and a Civilization in Trouble*, Earth Policy Institute: New Jersey, 2003; pp 131-150.
6. Maruyama, T.; Hashimoto, I.; Murashima, K.; Takimoto, H., Evaluation of N and P mass balance in paddy rice culture along Kahokugata Lake, Japan, to assess potential lake pollution. *Paddy and Water Environment* **2008,** *6* (4), 355-362.
7. Phong, T. K.; Yoshino, K.; Hiramatsu, K.; Harada, M.; Inoue, T., Pesticide discharge and water management in a paddy catchment in Japan. *Paddy and Water Environment* **2010,** *8* (4), 361-369.
8. Liyantono; Kato, T.; Kuroda, H.; Yoshida, K., GIS analysis of conjunctive water resource use in Nganjuk district, east Java, Indonesia. *Paddy and Water Environment* **2013,** *11* (1-4), 193-205.
9. Singh, R.; Subramanian, K.; Refsgaard, J. C., Hydrological modelling of a small watershed using MIKE SHE for irrigation planning. *Agricultural Water Management* **1999,** *41* (3), 149-166.
10. Hughes, J. D.; Liu, J., MIKE SHE: Software for Integrated Surface Water/Ground Water Modeling. *Ground Water* **2008,** *46* (6), 797-802.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

11. Bicknell, B. R.; Imhoff, J. C.; Kittle, J. L.; Donigian, A. S.; Johanson, R. C., Hydrological Simulation Program-Fortran, User's manual for version 11. U.S. Environmental Protection Agency, National Exposure Research Laboratory: Athens, Georgia., 1997.
12. Jeon, J. H.; Yoon, C. G.; Donigian, A. S.; Jung, K. W., Development of the HSPF-Paddy model to estimate watershed pollutant loads in paddy farming regions. *Agricultural Water Management* **2007,** *90* (1-2), 75-86.
13. Kato, T., Development of a water quality tank model classified by land use for nitrogen load reduction scenarios. *Paddy and Water Environment* **2005,** *3* (1), 21-27.
14. Van Chinh, L.; Iseri, H.; Hiramatsu, K.; Harada, M.; Mori, M., Simulation of rainfall runoff and pollutant load for Chikugo River basin in Japan using a GIS-based distributed parameter model. *Paddy and Water Environment* **2013,** *11* (1-4), 97-112.
15. Arnold, J. G.; Srinivasan, R.; Muttiah, R. S.; Williams, J. R., Large area hydrologic modeling and assessment - Part 1: Model development. *Journal of the American Water Resources Association* **1998,** *34* (1), 73-89.
16. Srinivasan, R.; Ramanarayanan, T. S.; Arnold, J. G.; Bednarz, S. T., Large area hydrologic modeling and assessment - Part II: Model application. *Journal of the American Water Resources Association* **1998,** *34* (1), 91-101.
17. Gassman, P. W.; Reyes, M. R.; Green, C. H.; Arnold, J. G., The soil and water assessment tool: Historical development, applications, and future research directions. *Transactions of the Asabe* **2007,** *50* (4), 1211-1250.
18. Douglas-Mankin, K. R.; Srinivasan, R.; Arnold, J. G., SOIL AND WATER ASSESSMENT TOOL (SWAT) MODEL: CURRENT DEVELOPMENTS AND APPLICATIONS. *Transactions of the Asabe* **2010,** *53* (5), 1423-1431.
19. Tuppad, P.; Douglas-Mankin, K. R.; Lee, T.; Srinivasan, R.; Arnold, J. G., SOIL AND WATER ASSESSMENT TOOL (SWAT) HYDROLOGIC/WATER QUALITY MODEL: EXTENDED CAPABILITY AND WIDER ADOPTION. *Transactions of the Asabe* **2011,** *54* (5), 1677-1684.
20. Santhi, C.; Muttiah, R. S.; Arnold, J. G.; Srinivasan, R., A GIS-based regional planning tool for irrigation demand assessment and savings using SWAT. *Transactions of the Asae* **2005,** *48* (1), 137-147.
21. Ahmadzadeh, H.; Morida, S.; Delavara, M.; Srinivasan, R., Using the SWAT model to assess the impacts of changing irrigation from surface to pressurized systems on water productivity and water saving in the Zarrineh Rud catchment. *Agricultural Water Management* **2016,** *175*, 15–28.
22. Baker, T. J.; Miller, S. N., Using the Soil and Water Assessment Tool (SWAT) to assess land use impact on water resources in an East African watershed. *Journal of Hydrology* **2013,** *486*, 100-111.
23. Tao, C.; Chen, X. L.; Lu, J. Z.; Gassman, P. W.; Sabine, S.; Jose-Miguel, S. P., Assessing impacts of different land use scenarios on water budget of Fuhe River, China using SWAT model. *International Journal of Agricultural and Biological Engineering* **2015,** *8* (3), 95-109.
24. Somura, H.; Arnold, J.; Hoffman, D.; Takeda, I.; Mori, Y.; Di Luzio, M., Impact of climate change on the Hii River basin and salinity in Lake Shinji: a case study using the SWAT model and a regression curve. *Hydrological Processes* **2009,** *23* (13), 1887-1900.
25. Mehta, V. M.; Mendoza, K.; Daggupati, P.; Srinivasan, R.; Rosenberg, N. J.; Deb, D., High-resolution Simulations of Decadal Climate Variability Impacts on Water Yield in the Missouri River Basin with the Soil and Water Assessment Tool (SWAT). *Journal of Hydrometeorology* **2015**.
26. Kato, T.; Somura, H.; Kuroda; H.; Nakasone, H., Simulation of nutrients from an agricultural watershed in Japan using the SWAT model. *International Agricultural Engineering Journal* **2011,** *20* (3), 40-49.
27. Sakaguchi, A.; Eguchi, S.; Kasuya, M., Examination of the water balance of irrigated paddy fields in SWAT 2009 using the curve number procedure and the pothole module. *Soil Science and Plant Nutrition* **2014,** *60* (4), 551-564.
28. Du, B.; Arnold, J. G.; Saleh, A.; Jaynes, D. B., Development and application of SWAT to landscapes with tiles and potholes. *Transactions of the Asae* **2005,** *48* (3), 1121-1133.
29. Neitsch, S. L.; Arnold, J. G.; Kiniry, J. R.; Williams, J. R., Soil and water assessment tool theoretical documentation. Texas, U.S., 2011.
30. Sakaguchi, A.; Eguchi, S.; Kato, T.; Kasuya, M.; Ono, K.; Miyata, A.; Tase, N., Development and evaluation of a paddy module for improving hydrological simulation in SWAT. *Agricultural Water Management* **2014,** *137*, 116-122.
31. Xie, X. H.; Cui, Y. L., Development and test of SWAT for modeling hydrological processes in irrigation districts with paddy rice. *Journal of Hydrology* **2011,** *396* (1-2), 61-71.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

32. Boulange, J.; Watanabe, H.; Inao, K.; Iwafune, T.; Zhang, M. H.; Luo, Y. Z.; Arnold, J., Development and validation of a basin scale model PCPF-1@SWAT for simulating fate and transport of rice pesticides. *Journal of Hydrology* **2014,** *517*, 146-156.
33. Watanabe, H.; Takagi, K., A simulation model for predicting pesticide concentrations in paddy water and surface soil. I. Model development. *Environmental Technology* **2000,** *21* (12), 1379-1391.
34. Dahl, T. E., Wetlands Losses in the United States 1780's to 1980's. U.S. Department of the Interior, Fish and Wildlife Service: Washington, D.C., 1990.
35. Watanabe, T., Irrigation Water Requirement. In *Advanced paddy field engineering*, The Japanese Society of Irrigation, Drainage and Reclamation Engineering, Ed. Shinzan-sha Sci. & Tech.: Tokyo, 1999; pp 31-50.
36. Chen, S. K.; Jang, C. S.; Chen, S. M.; Chen, K. H., Effect of N-fertilizer application on return flow water quality from a terraced paddy field in Northern Taiwan. *Paddy and Water Environment* **2013,** *11* (1-4), 123-133.
37. Tabuchi, T.; Takamura, Y., *Nitrogen and Phosphorus Outflow from Catchment Area*. University of Tokyo Press: Tokyo, 1985 (in Japanese).
38. Takeda, I.; Fukushima, A.; Tanaka, R., Non-point pollutant reduction in a paddy-field watershed using a circular irrigation system. *Water Research* **1997,** *31* (11), 2685-2692.
39. Matsuno, Y.; Nakamura, K.; Masumoto, T.; Matsui, H.; Kato, T.; Sato, Y., Prospects for multifunctionality of paddy rice cultivation in Japan and other countries in monsoon Asia. *Paddy and Water Environment* **2006,** *4* (4), 189-197.
40. Anbumozhi, V.; Yamaji, E.; Tabuchi, T., Rice crop growth and yield as influenced by changes in ponding water depth, water regime and fertigation level. *Agricultural Water Management* **1998,** *37* (3), 241-253.
41. Elhassan, A. M.; Goto, A.; Mizutani, M., Effect of Conjunctive Use of Water for Paddy Field Irrigation on Groundwater Budget in an Alluvial Fan. *Agricultural Engineering International: the CIGR Journal of Scientific Research and Development* **2003,** *5*.
42. Adachi, K.; Sasaki, C., Percolation and seepage. In *Advanced paddy field engineering*, The Japanese Society of Irrigation, Drainage and Reclamation Engineering, Ed. Shinzan-sha Sci. & Tech.: Tokyo, Japan, 1999; pp 71-88.
43. Garg, K. K.; Das, B. S.; Safeeq, M.; Bhadoria, P. B. S., Measurement and modeling of soil water regime in a lowland paddy field showing preferential transport. *Agricultural Water Management* **2009,** *96* (12), 1705-1714.
44. Mousavi, S. F.; Yousefi-Moghadam, S.; Mostafazadeh-Fard, B.; Hemmat, A.; Yazdani, M. R., Effect of puddling intensity on physical properties of a silty clay soil under laboratory and field conditions. *Paddy and Water Environment* **2009,** *7* (1), 45-54.
45. Choi, S.; Kim, M.; Jeong, J., Simulating the Effects of Agricultural Management on Water Quality Dynamics in Rice Paddies for Sustainable Rice Production. *Agricultural Water Management* (Under review).
46. Wada, K., The distinctive properties of Andosols. *Advances in Soil Science, USA* **1985,** *2*, 173-229.
47. Allen, R. G.; Pereira, L. S.; Raes, D.; Smith, M., *Crop evapotranspiration - Guidelines for computing crop water requirements*. FAO: Rome, Italy, 1998; Vol. 56.
48. Vu, S. H.; Watanabe, H.; Takagi, K., Application of FAO-56 for evaluating evapotranspiration in simulation of pollutant runoff from paddy rice field in Japan. *Agricultural Water Management* **2005,** *76* (3), 195-210.
49. Geographical Survay Institute basic geographic data of Japan. Available online: http://www.gsi.go.jp/kiban/ (available in Japanese; accessed on 26 January 2016).
50. Ministry of Land, Infrastructure and Transport, National Land Numerical Information download service. Available online http://nlftp.mlit.go.jp/ksj/ (in Japanese; accessed on 12 January 2016).
51. Japan Soil Association, The database of soil information based on basical investigation for soil fertility conservation - Soil map data CD-ROM. 2009 (in Japanese).
52. Eguchi, S.; Aoki, K.; Kohyama, K. Development of agricultural soil-profile physical properties database, Japan: SolphyJ, Proceedings of ASA-CSSA-SSSA International Annual Meetings, San Antonio, Texas, San Antonio, Texas, 17 October 2011.
53. Japan Meteorological Agency Data download service of past meteorological information. Available online: http://www.data.jma.go.jp/gmd/risk/obsdl/index.php (in Japanese; accessed on 1 December 2015).
54. Chiba Prefecture Standard of fertilizing for main crops. Available online: http://www.pref.chiba.lg.jp/annou/sehikijun.html (in Japanese; 1 August 2014).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 3 November 2016 doi:10.20944/preprints201611.0024.v1

55. Chiba Prefectural Committee on Agriculture, Forestry & Fishery, Standard Guideline for Rice Cultivation. Chiba Prefecture: 1-1 Ichiba-cho, Chiba, Japan, 2014.
56. Kannan, N.; Santhi, C.; Williams, J. R.; Arnold, J. G., Development of a continuous soil moisture accounting procedure for curve number methodology and its behaviour with different evapotranspiration methods. *Hydrological Processes* **2008,** *22* (13), 2114-2121.
57. Priestley, C. H. B.; Taylor; R.J., On the assessment of surface heat flux and evaporation using large-scale parameters. *Monthly Weather Review* **1972,** *100* (2), 81-92.
58. Monteith, J. L., Evaporation and the environment. *Symposia of the Society for Experimental Biology* **1965,** *19*, 224.
59. Hitomi, T.; Yoshinaga, I.; Miura, A.; Hamada, K.; Shiratani, E.; Takaki, K., Research for Effluent of DOM and Hydrophobic Acids from a Paddy Field. *Journal of the Agricultural Engineering Society, Japan* **2007,** (250), 419-427 (in Japanese).
60. Kitagawa, I., Planning paddy fields consolidation. In *Handbook of Irrigation, Drainage and Rural Engineering*, 7 ed.; The Japanese Society of Irrigation, Drainage and Rural Engineering,, Ed. The Japanese Society of Irrigation, Drainage, and Rural Engineering: Tokyo, 2010; pp 77-90.
61. Abbaspour, K. C.; Yang, J.; Maximov, I.; Siber, R.; Bogner, K.; Mieleitner, J.; Zobrist, J.; Srinivasan, R., Modelling hydrology and water quality in the pre-ailpine/alpine Thur watershed using SWAT. *Journal of Hydrology* **2007,** *333* (2-4), 413-430.
62. Abbaspour, K. C., *SWAT-CUP: SWAT Calibration and Uncertainty Programs – A User Manual*. Eawag: Dübendorf, Switzerland, 2015.
63. Nash, J. E.; Sutcliffe, J. V., River flow forecasting through conceptual models part I - A discussion of principles. *Journal of Hydrology* **1970,** *10* (3), 282-290.
64. Moriasi, D. N.; Arnold, J. G.; Van Liew, M. W.; Bingner, R. L.; Harmel, R. D.; Veith, T. L., Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the Asabe* **2007,** *50* (3), 885-900.

© 2016 by the authors; licensee *Preprints*, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons by Attribution (CC-BY) license (http://creativecommons.org/licenses/by/4.0/).