CALIBRATION APPROACHES FOR A DISTRIBUTED HYDROLOGICAL MODEL'S PARAMETERS USING SOIL MOISTURE IN CAMBODIA

R. Gomaibashi[1], S. Oliver[2], Z. Suif[3] and S.Ly[4]

[1] *Tokyo Institute of Technology, gomaibashi.r.ab@m.titech.ac.jp*
[2] *Tokyo Institute of Technology, saavedra.o.aa@m.titech.ac.jp*
[3] *Tokyo Institute of Technology, suif.z.aa@m.titech.ac.jp*
[4] *Institute of Technology of Cambodia, ly.sarann@gmail.com*

ABSTRACT

In recent years, global warming and population growth are one of the biggest issues facing the world today. Hydrological model is useful for water resource management. The usability of the hydrological model depends on the accurate calibration. However, equifinality problem is one of the most critical problem of calibration of hydrological model's parameters. This study attempt to reduce equifinality problem draw calibration of distributed hydrological model's parameters. We tested the different calibration approach; first use only discharge, second use soil moisture and discharge in small basin of Cambodia. The calibrated hydrological parameter sets shows similar simulated discharge and different simulated soil moisture. Calibration with observed soil moisture has a potential to define the hydrological parameters which cannot be defined in the conventional way. In addition, weight of the calibration to soil moisture has a potential to define the accuracy of soil moisture simulation. Continuous soil moisture observation is recommended to improve calibration of hydrological parameters.

Keywords: Simulated discharge, Soil moisture, Hydrological model Calibration, Equifinality

1 INTRODUCTION

In recent years, global warming and population growth are one of the biggest issues facing the world today. Large population leads to water stress (Vorosmarty et al. 2000) and the heavy precipitation is one of the problems of global warming (Fowler & Hennessy 1995). Heavy precipitation has the potential to lead severe flooding (Nijssen et al. 2001). The potential of hydrological simulation for flood forecasting system and planning of water management was already found (Winz et al. 2008). Dams were constructed for managing water resource. Their location and size of dams should be planned in advance. Hydrological simulation can be used for this planning.

The usability of hydrological model depends on the suitability of simulated discharge. To get best fitted simulated discharge, hydrological model's parameter calibration were improved (Gupta et al. 2002). Usually, the range of hydrological model is defied by sensitivity analysis, and then, 'best fitting' hydrological model's parameters are defined by manually or automatically based calibration method. In recent research, satellite soil moisture data can be used to improve hydrological model's parameters calibration (Sutanudjaja et al. 2014; Wanders et al. 2014).

Hydrological calibration has the equifinality problem (Todini 2007). The simulated result only focused for simulation calibration and each hydrological model has best fitting parameters. However, it cannot be said which hydrological parameter sets are the most realistic. Equifinality problem is caused by the lack of consistent monitoring of hydrological processes. Calibration with only discharge data cannot be considered hydrological process because it focuses on only the discharge output. This equifinality problem has a potential to mislead the hydrological simulation.

The Cambodian population is expected to increase 1.5 times from the current population until 2050 and the economy grew rapidly from 1998 to 2008 (ADB 2010b; ADB 2010a; UNPD. 2007). The resulting

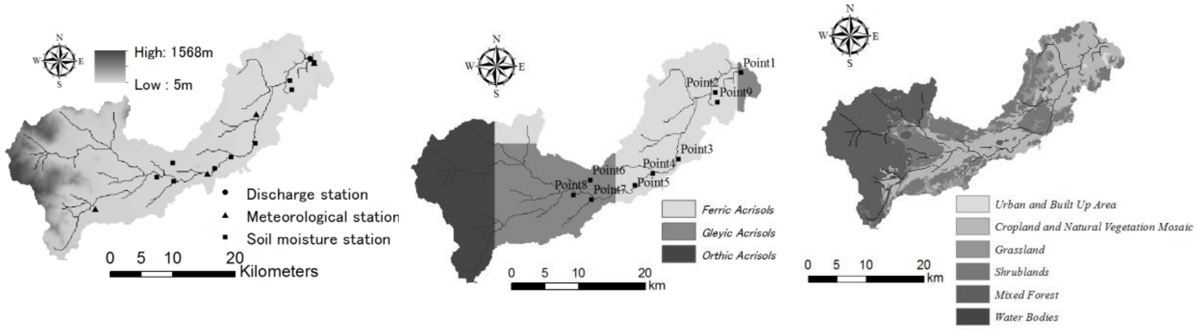

Figure 1. CBB; left panel is elevation, middle panel is soil type and right panel is land use

increase in the demand for food is estimated to become between 109% and 206% from the level of 2000 (Hoanh et al. 2003; UNDP 2008). The domestic production of food will increase because of increasing in demand and water demand for agriculture will increase. In addition, water resource management will become more important because of climate change (Dore 2003). Temperature and precipitation in Cambodia will become higher, and therefore, the irrigation system becomes more important to agriculture (Keskinen et al. 2009).

The objective of this study is to reveal the equifinality problem from hydrological model's parameters calibration with observed soil moisture and discharge. The hypothesis of this study is that alternative calibration with observed soil moisture and discharge data has a potential to get the hydrological model's parameters which are ignored in calibration method with only discharge. At first, hydrological parameters were calibrated tentatively to define the hydrological parameters which are less influential to simulated discharge. Then, the influence of these parameters to soil moisture was checked by sensitivity analysis. At last, calibration with soil moisture and discharge data was tested.

2 TARGET AREA

Figure 1 shows Chrey Bak Basin (CBB) in Cambodia and observation stations Cambodia. The area of CBB is about 663 km^2, the length of the river is about 80 km and the annual discharge is about 289 million m^3 (Phalla et al. 2011). Discharge, precipitation and temperature data were observed from 1st, Jan to 3rd, Oct in 2014. Soil moisture data were observed from 3rd, Oct to 9th, Oct in 2014. This data set is obtained from the Institute of Technology of Cambodia (ITC). Global soil type data is downloaded from Food and Agricultural Organization (FAO; http://www.fao.org/home/en/) and Normalized Difference Vegetation Index (NDVI) data is downloaded from Japan Aerospace Exploration Agency (JAXA; http://kuroshio.eorc.jaxa.jp/JASMES/index_j.html). The global soil and NDVI data are converted to 100 m resolution and delineate to shape of CBB. Evaporation data were calculated by Thornthwaite method (Thornthwaite 1948) from observed temperature and sunlight time. Thiessen method is used to convert point precipitation and evaporation data to raster data (Thiessen 1911).

3 METHOD

3.1 Gbhm

Geomorphology-Based Hydrological Model (GBHM) will be used in this research (Yang et al. 2000; Yang et al. 2002). Simulation of the hydrological processes in GBHM includes two components, hillslope and river routing in the river. The whole CBB will be decided into 9 sub-basins by the Pfafstetter coding system (Yang & Musiake 2003). Then, each sub-basin will be divided into flow intervals according to the flow distance from each grid to the mouth of the river in that sub-basin. The runoff in the grids will be added together to obtain the total runoff in each flow interval.

Hydrological parameters are used for simulate the hydrological process in GBHM. **Table 1** shows the hydrological parameters and symbol. At first, all parameters were calibrated to reveal the hydrological parameters which are influential to soil moisture simulation and less influential to discharge simulation.

Table 1. Hydrological parameters

α	Surface roughness	Saturated hydraulic conductivity (mm/hour)	Saturated hydraulic conductivity at the bottom of soil layer (mm/hour)	Hydraulic conductivity of ground water (mm/hour)	Ground water storage coefficient	Saturated soil water contents (m^3/m^3)
α	n	k_{sat1}	k_{sat2}	k_{sg}	G_{wsc}	W_{sat}

3.2 Sensitivity analysis

GBHM has several parameters which influence to discharge and soil moisture output. To define the influence of these parameters, GBHM ran with manually changed hydrological parameters which is defied by Trial calibration.

3.3 Calibration method

The Shuffled Complex Evolution Method Developed at the University of Arizona (SCE-UA) method which is one of the genetic algorithms was used as calibration method on soil moisture and discharge data (Chu et al. 2010; Eckhardt & Arnold 2001). The hydrological parameters are changed by SCE-UA automatically to get best objective function.

At first GBHM simulation, initial hydrological water parameters were decided from experiment or literature and these hydrological parameters have to be adjusted to get best results of the simulated discharge by calibration. In this study, following equation was used as the objective functions of SCE-UA method.

$$z = 1 - A\frac{\sum (Q_{obs} - Q_{sim})^2}{\sum (Q_{obs} - \overline{Q_{obs}})^2} - (1-A)\frac{\sum (SOM_{obs} - SOM_{sim})^2}{\sum (SOM_{obs} - \overline{SOM_{obs}})^2} \qquad (1)$$

Where, Q_{sim}, Q_{obs} and $\overline{Q_{obs}}$ are simulated, ground-based observation and average of ground-based observation discharge data, SOM_{sim}, SOM_{obs} and $\overline{SOM_{obs}}$ are simulated, ground-based observation and average of ground-based observation soil moisture data and A is the weighting parameter ($0 \le A \le 1$).

3.4 Evaluation of simulated result

Result of simulation was evaluated to define the equifinality problem and the effect of alternative calibration. Nash-Sutcliffe model Efficiency coefficient (NSE) (Nash & Sutcliffe 1970) was used for evaluation of the simulated discharge and coefficient of variation of the root-mean squared error (CV) (Reddy et al. 1997) was used for evaluation of the simulated soil moisture. CV was defined as following

$$RMSE = \sqrt{\frac{\sum (SOM_{obs} - SOM_{sim})^2}{N}} \quad (3)$$

$$CV = \frac{RMSE}{\overline{SOM_{obs}}} \quad (4)$$

Where, $RMSE$ is root mean square error and N is number of data.

4 RESULTS AND DISCUSSION

4.1 Trial calibration

Error! Reference source not found. shows the hydrological parameters calibrated tentatively in each soil type in CBB. The NSE of Trial 1 is 0.562 and that of Trial 2 is 0.532. This result shows the equifinality problem. Several hydrological parameters shows similar NSE. In this case, α, n, W_{sat} and G_{wsc} changed dramatically from Trial 1 to Trial 2. These hydrological parameters reveal the equifinality problem and the differences between calibrated hydrological parameter sets have a potential to affect the hydrological process which is ignored in the calibration with only discharge. The influential of these parameters soil moisture simulation were checked in sensitivity analysis.

4.2 Sensitivity analysis of α, n and W_{sat}

Figure 2 shows the result of sensitivity analysis with , and . Detail of the hydrological parameters are shown in **Table 3**.

Result shows that the combination of α, n and W_{sat} less influential to discharge simulation than soil moisture simulation. Soil moisture output was not sensitive to precipitation, it may cause by water storage of the ground surface and small number of precipitation stations. Moreover, this simulated soil moisture is the average of whole CBB, therefore the fluctuation of simulated soil moisture was less than the point data.

Table 2. Calibrated hydrological parameters

	Ferric Acrisols		Gleyic Acrisols		Orthic Acrisols	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
α	0.030	0.030	0.021	0.027	0.024	0.022
n	1.455	1.320	1.324	1.518	1.232	1.355
k_{sat1}	31381	30885	15721	19277	19936	20401
k_{sat2}	2360	2358	1512	1526	1818	1938
k_{sg}	992	965	565	551	687	716
G_{wsc}	0.472	0.301	0.480	0.283	0.442	0.349
W_{sat}	0.452	0.463	0.405	0.426	0.436	0.441

Table 3. Hydrological parameters in sensitivity analysis with α, n and W_{sat}

Group number	1	2	3	4	5	6	7	8
α	0.027	0.027	0.027	0.027	0.033	0.033	0.033	0.033
n	1.309	1.309	1.600	1.600	1.309	1.309	1.600	1.600
W_{sat}	0.407	0.498	0.407	0.498	0.407	0.498	0.407	0.498

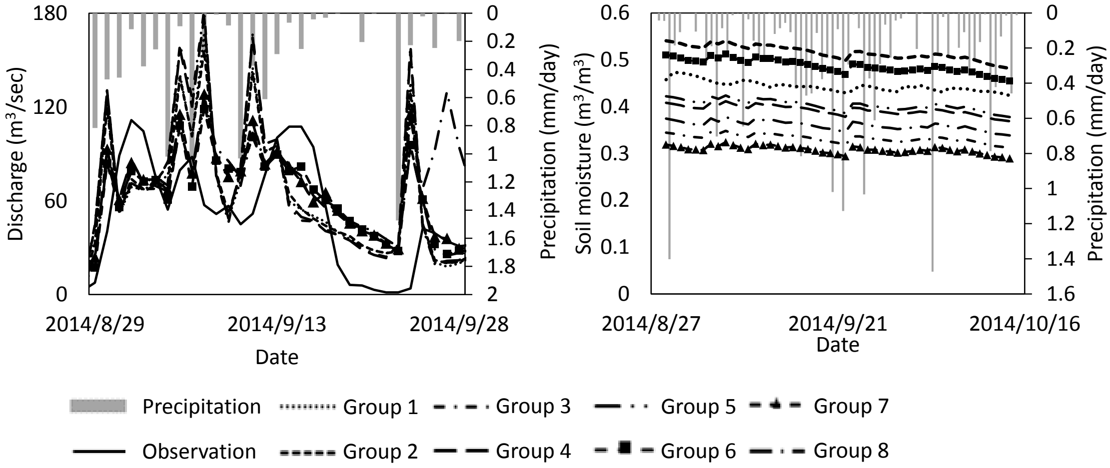

Figure 2. Result of sensitivity analysis with α, n and W_{sat}

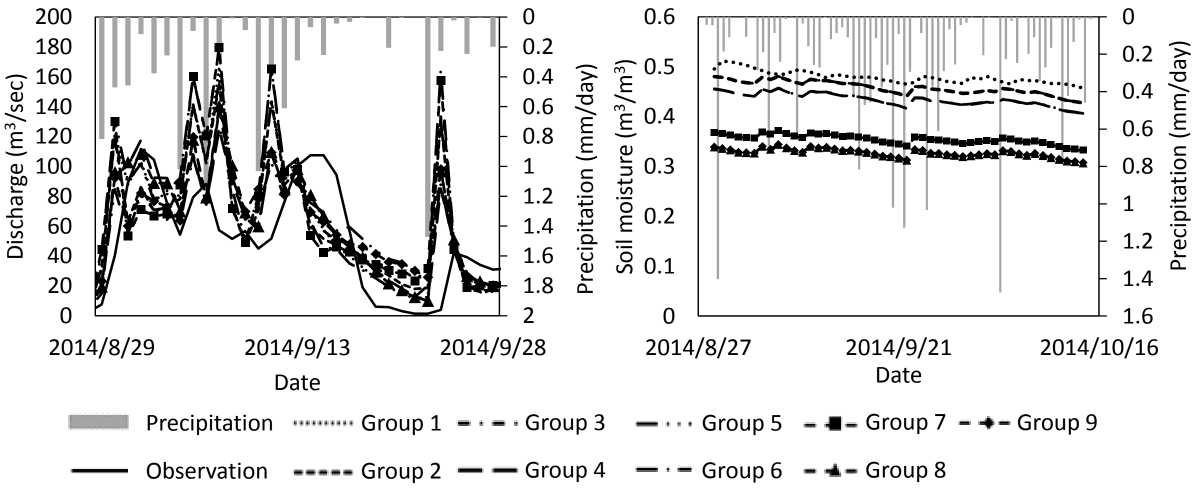

Figure 3. Result of sensitivity analysis with α, n and G_{wsc}

4.3 Sensitivity analysis of α, n and G_{wsc}

Figure 3 shows the result of sensitivity analysis with α, n and G_{wsc}. Detail of the hydrological parameters are shown in **Table 4**. Group 2 and Group 3, and Group 8 and Group 9 shows the similar simulated soil moisture. It can be said that the limitation of influential of G_{wsc} to soil moisture simulation is defined by the combination of α and n.

Table 4. Hydrological parameters in sensitivity analysis with α, n and G_{wsc}

Group number	1	2	3	4	5	6	7	8	9
α	0.027	0.027	0.027	0.033	0.033	0.027	0.027	0.033	0.033
n	1.309	1.309	1.309	1.309	1.309	1.600	1.600	1.600	1.600
G_{wsc}	0.301	0.451	0.602	0.301	0.602	0.301	0.602	0.301	0.602

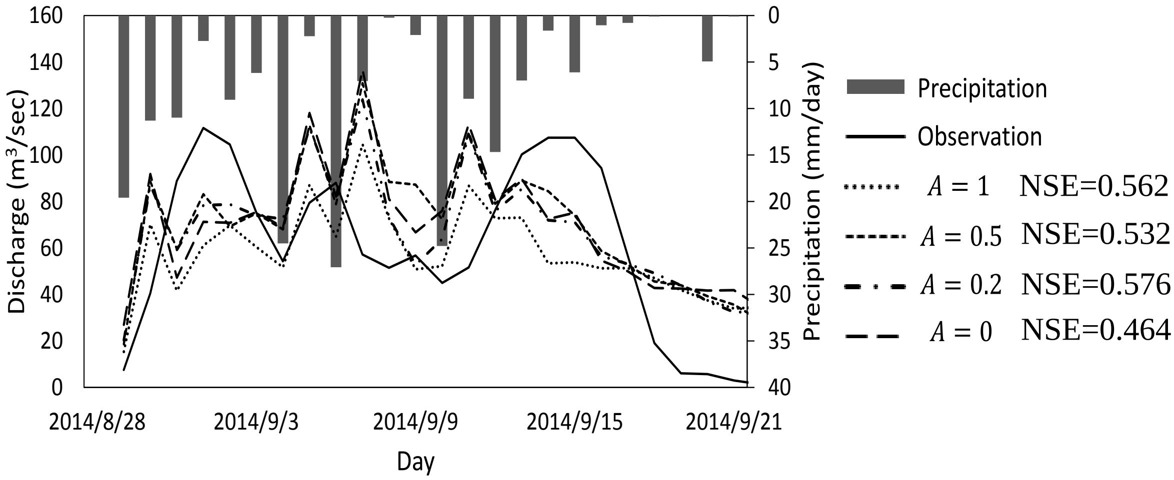

Figure 4. Simulated discharge

From the sensitivity analysis, it is defined that all of 4 parameters are influential to soil moisture simulation however, less influential to discharge simulation. These 4 parameters cannot defined from the calibration with only discharge data.

4.4 Simulated discharge

Figure 4 shows the detail of the simulated discharge. The low NSE was potentially caused by reverse flow and the water use for agriculture. In CBB, reverse flow was usually occurred and the water was stored in the crop land. The discharge simulation can be improve from the observation of reverse flow and water use. On the other hands, less differences of NSI in each weighting parameter reveal the equifinality problem. There are several parameters sets which can be said ‘better fitting parameters’. However, the realistic hydrological parameters cannot be defined by calibration with only discharge. Other data is needed to define the hydrological parameters which is similar as real.

When $A=0$, the discharge was not considered. Therefore the NSI in the case of $A=0$ was lower than the others.

4.5 Simulated soil moisture

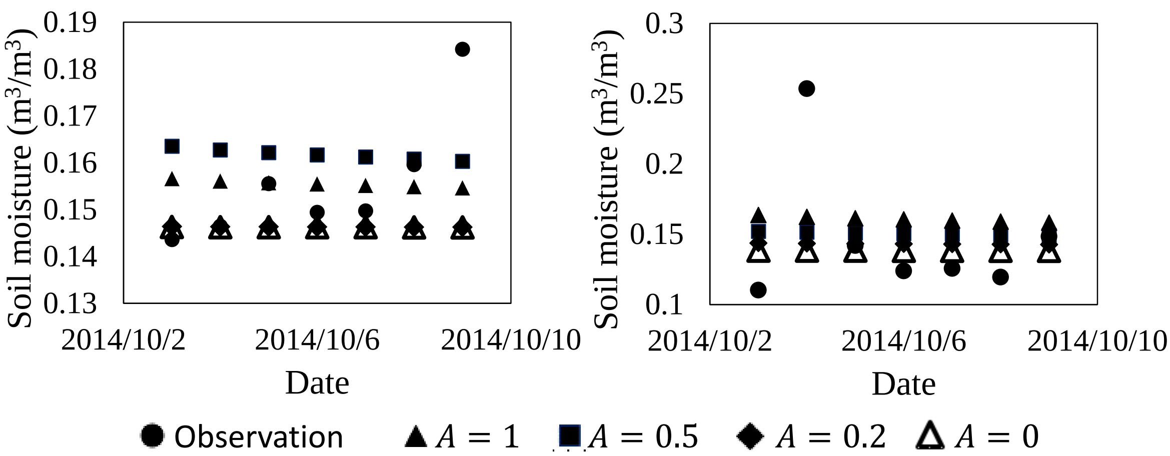

Figure 5. Simulated soil moisture

Table 5. CV **of the simulated soil moisture**

Point	1	2	3	4	5	6	7	8	9
$A=0.5$	0.275	0.338	2.773	0.167	0.268	0.712	0.753	0.873	0.823
$A=0.2$	0.277	0.315	0.836	0.227	0.173	0.619	0.660	0.890	0.837
$A=0$	0.281	0.314	0.298	0.232	0.172	0.551	0.609	0.900	0.838
$A=1$	0.273	0.327	2.106	0.180	0.217	0.853	0.867	0.850	0.829

Figure 5 shows the average simulated soil moisture in each soil type and **Table 5** shows the CV of the simulated soil moisture. In Ferric Acrisols, simulated soil moisture was underestimated when the case of $A=0$ and $A=0.2$. Moreover, the alternative calibration with lower A get better simulated soil moisture than that with higher A.

Calibration with only discharge can get the hydrological parameters set which can be said "better fitting parameters" to discharge, however it cannot be said that these hydrological parameters set is along with real, because it cannot be defined that these hydrological parameters can simulate the hydrological process similar as real or not. Soil moisture and discharge data shows the potential to calibrate hydrological parameters which cannot calibrate with only discharge data. Moreover, soil moisture has a potential to solve the one of the causes of equifinality problem of hydrological model's parameter calibration.

5 CONCLUSIONS

In this study, we tested the different calibration approach; first use only discharge, second use soil moisture and discharge. The calibrated hydrological parameters sets shows similar simulated discharge and different simulated soil moisture.

This study attempt to reduce equifinality problem draw calibration of distributed hydrological model's parameters. Usually, only discharge data were focused in calibration of hydrological model's parameters without considering the hydrological variables like soil moisture. Therefore, calibration with observed soil moisture has a potential to define the hydrological parameters which is ignored in the conventional way.

Observed soil moisture data have a potential to track the infiltration process. The alternative objective function is useful for this estimation. In addition, weighting parameter has a potential to define the accuracy of hydrological process estimation. However, the best may be changed by some factors; the period of data, temporal and spatial resolution and the geological characteristics of the basin. The best value depends on the objective of the research. For example, when soil moisture is focused, soil moisture term in objective function should be weighted than discharge term.

In this research, soil moisture was observed only one week, and the precipitation data was observed in only the 4 stations. In the future, more detailed and continuous observation will be recommended to improve calibration method with alternative objective function.

ACKNOWLEDGMENTS

This study was supported financially by the Japan Society of Science Promotion (JSPS) under Asia core program and core-to-core program (B. Asia-Africa Science platforms). We also appreciate data collection support from Ms. Pinnara Ket, Institute of Technology of Cambodia.

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