Conference Paper, Published Version

Kwak, Jaewon; Kyong, Min Soo; Hong, Il Pyo; Kim, Hung Soo

Objective Function and Parameter Calibrations of Flood Forecasting Models

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JAE WON KWAK[1], MIN SOO KYOUNG[1], IL PYO HONG[2], HUNG SOO KIM[3], BELLIE SIVAKUMAR[4]

[1]Ph. D. Student, Department of Civil Engineering, Inha University,
253 Yonghyun-dong, Nam-gu Incheon, Korea, e-mail: firstsword@naver.com
[2]Research Fellow, Water Resources Research Department, Korea Institute of Construction Technology,
2311 Daewha-dong, ilsan-gu Goyang-Si Gyeonggi-Do, Korea, e-mail: iphong@kict.re.kr
[3]Associate Professor, Department of Civil Engineering, Inha University,
253 Yonghyun-dong, Nam-gu Incheon, Korea, e-mail: sookim@inha.ac.kr
[4]Associate, Department of Land, Air and Water Resources, University of California, One Shields Avenue, Davis, California 95616, USA, e-mail: sbellie@ucdavis.edu

ABSTRACT

This study assesses and compares the performances of three rainfall-runoff models for flood forecasting in Asia: the storage function model (SFM), the TANK model, and the streamflow synthesis and reservoir regulation (SSARR) model. Particular emphasis is given to the selection of objective functions and parameter optimization techniques. Two different objective functions, namely the sum of square of residuals (SSR) and the weighted sum of square of residuals (WSSR), and two different optimization techniques, namely the pattern-search (P-S) and genetic algorithms (GA) are studied. For a more general representation, the models are applied to three different river basins in three different countries: the Miho stream basin in Korea, the Kusaki basin in Japan, and the Ta Trach basin in Vietnam.

Overall the results obtained are encouraging, including the models' ability to reliably capture the peak discharge and peak time of flood hydrographs. However, the results also indicate slight differences among the models in terms of evaluation measures as well as in their stability. The results also imply that the characteristics of the basin and the flood events may provide vital clues to the selection of a proper model, calibration method and objective function.

Keywords: rainfall-runoff models, parameter estimation, optimization, objective function

1. INTRODUCTION

There exist numerous rainfall-runoff (and other) models for flood forecasting. Various factors influence the selection of a model for a given region, and different models may be popular in different countries; for example, the storage function model is widely used as a flood forecasting model in Korea. For both scientific and practical purposes, however, it is important to assess and compare the performances of different rainfall-runoff models for flood forecasting in a region, so that the 'most appropriate' model may be chosen. To this end, three different rainfall-runoff models, namely the Storage Function Model (SFM), the TANK model, and the Streamflow Synthesis and Reservoir Regulation (SSARR) model, are studied. To make the study more general, the three models are applied to three different basins in three different countries in Asia: the Miho stream basin in Korea, the Kusaki basin in Japan, and the Ta Trach basin in Vietnam.A particular focus of this study is the investigation of the selection of appropriate objective functions and optimization techniques for the parameters involved in the models. On the basis of past studies (e.g. Kim et al. 2006, 2007) that compared the performances of various optimization techniques, it is decided to employ the pattern search

(P-S) method and the genetic algorithms (GA) for optimization. The sum of square of residuals (SSR) and the weighted sum of square of residuals (WSRR) are considered for obtaining the accurate peak discharge and peak time as the objective functions.

2. BACKGROUND

The organization of this paper is as follows. Section 2 presents a brief description of the rainfall-runoff models, optimization techniques and objective functions considered in this study. Section 3 reports some details of the three study areas and also the application of the models and the results obtained. Conclusions drawn from the present analysis are presented in Section 4.

2.1 Rainfall-runoff models

In this study, three rainfall-runoff models are chosen for application for flood forecasting in the three basins: the Storage Function Model (SFM), the TANK model and the Streamflow Synthesis and Reservoir Regulation (SSARR) model. In the SFM, surface runoff is assumed as the flood runoff and the storages in a watershed and a channel can be expressed as a function of the runoff with a power *P*. In the TANK model, proposed by Sugawara, is the rainfall-runoff process is simulated using several storage tanks. The SSARR model considers continuously-connected multiple reservoirs for a watershed, and thus represents the situation that flood wave is moved and delayed through continuous reservoirs.

2.2 Calibration

Among the many optimization techniques currently available, this study employs pattern search (P-S) and genetic algorithm (GA) techniques for parameter estimation. These techniques are chosen based on our previous knowledge of their better performances over some others, especially for the Korean conditions. For example, Kim et al.(2006) compared the random search, Rosenbrock, simulated annealing (SA), GA, P-S, and shuffled complex evolution - University of Arizona (SCE-UA) techniques for calibration of the SFM parameters, and Kim et al. (2007) applied the P-S, GA and SCE-UA techniques for calibration of the parameters of SFM for application for the Miho stream basin.

The pattern search technique is a direct search method, and has been shown to be more efficient and powerful than many other direct search methods. It is a dynamic and systematic method that creates search directions with various dimensions to improve the value of the objective function. Genetic Algorithms are adaptive heuristic search algorithms, premised on the evolutionary ideas of natural selection and genetics. The basic concept of GA is designed to simulate processes in a natural system necessary for evolution, specifically those that follow the principles first laid down.

2.3 Objective functions

The objective function acts as a measure value of model behavior and displays approximation degree of estimation of real values. Parameter automatic revision needs choice of suitable function objective according to parameters of model. In this study, the Sum of Square of Residuals (SSR) and the Weighted Sum of Square of Residuals (WSSR) (between observed and simulated values) are used as objective functions for obtaining the accurate peak discharge and peak time [see also Song et al. (2006) and Kim et al. (2008) for further details].

The expression for SSR is presented in Eq. (1), which is an objective function widely used in parameter optimization:

$$SSR = \sum_{i=1}^{n} [Q_0(i) - Q_s(i)]^2$$

where n is the number of discharge values considered, Q_o is the observed discharge, and Q_s is the simulated discharge.

The Weighted Sum of Square of Residuals (WSSR) is the added weighted factor of peak discharge and peak time. The expression for WSSR is given by:

$$WSSR = \sum_{i=1}^{n} [Q_0(i) - Q_s(i)]^2 \times W_1 \times W_2$$

$$W_1 = 1 + \frac{|Q_{op} - Q_{sp}|}{Q_{op}}$$

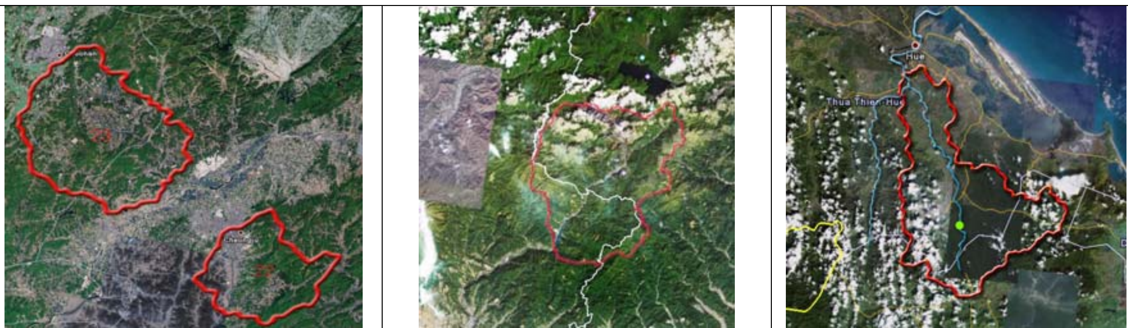
$$W_2 = 1 + \frac{|T_{op} - T_{sp}|}{T_{op}}$$

where n is the number of discharge values, Q_{op} is the observed peak discharge, Q_{sp} is the simulated peak discharge, T_{op} is the observed peak discharge time, and T_{sp} is the simulated peak discharge time.

3. APPLICATION

3.1 Study areas and data

This study considers three river basins for application,of the above rainfall-runoff models: Miho stream basin in Korea, the Kusaki dam basin in Japan, and the Ta trach river basin in Vietnam. The Miho stream basin is a tributary of the Kum River located in the western part of the middle of Korea. The Miho basin has an area of 1850 Km^2, which is 18.8% of the Kum river basin, and has a stream length of 87.3 km. The Kusaki dam basin is in the middle of Japan located between Gunma-hyun and Tochigi-huyn. It has a basin area of 254 Km^2 and the climate is similar to the southern part of Korea. The Ta Trach river basin is in the middle of Vietnam located in the Thuong Nhat region in Ta Trach river, and its basin area is 3760 Km^2. This river basin is in the tropical region and thus generally has high precipitation levels during the rainy season. Figure 1 shows the locations of these three basins.



Miho stream	Kusaki basin	Ta Trach basin

Fig. 1 Study Areas

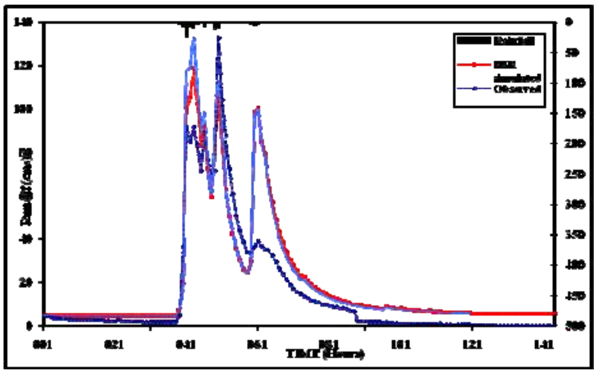
The periods of data (corresponding to flood events) used for calibration and verification in this study are presented in Table 1. For each of the three basins, four flood events are used for calibration, while two events are used for verification.

Table 1. Data periods of flood events

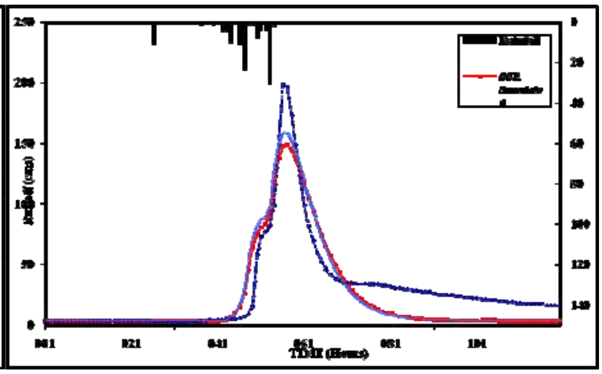
	Data Period		
	Miho stream	Kusaki basin	Ta Trach basin
Calibration Data	1997. 06. 30 ~ 1997. 07. 10	1998. 09. 12 ~ 1998. 09. 29	2000. 10. 06 ~ 2000. 10. 15
	1999. 08. 01 ~ 1999. 08. 06	1999. 08. 10 ~ 1999. 08. 28	2001. 10. 18 ~ 2001. 10. 28
	2002. 08. 04 ~ 2002. 08. 12	2000. 09. 07 ~ 2000. 09. 22	2002. 09. 20 ~ 2002. 09. 28
	2003. 07. 20 ~ 2003. 07. 27	2001. 08. 20 ~ 2001. 08. 29	2003. 10. 14 ~ 2003. 10. 22
Verification Data	2004. 06. 18 ~ 2004. 06. 24	2002. 07. 10 ~ 2002. 07. 21	2004. 09. 30 ~ 2004. 10. 09
	2006. 07. 09 ~ 2006. 07. 25	2003. 08. 10 ~ 2003. 08. 19	2005. 10. 04 ~ 2005. 10. 16

3.2 Parameter calibration

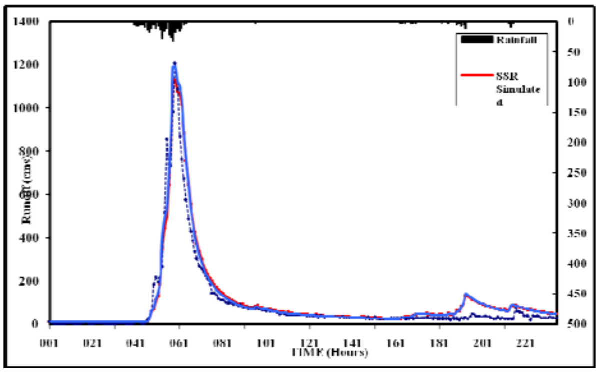
The P-S and GA techniques are used now for calibration of parameters of the three models for the above basins, with the sum of the square residuals (SSR) and the weighted sum of the square residuals (WSSR) serving as objective functions for the simulation of flood hydrograph. Figure 2 shows the flood hydrographs for some selected cases among the various combinations (i.e. four flood events and two optimization methods for each basin), while Table 2 presents the results obtained for all the cases.



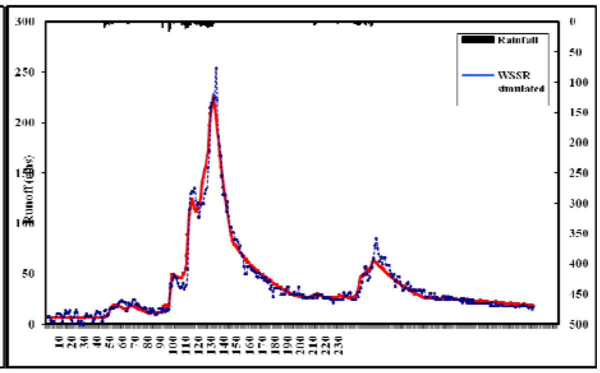
(a) Miho 22 (1999/SFM/P-S)



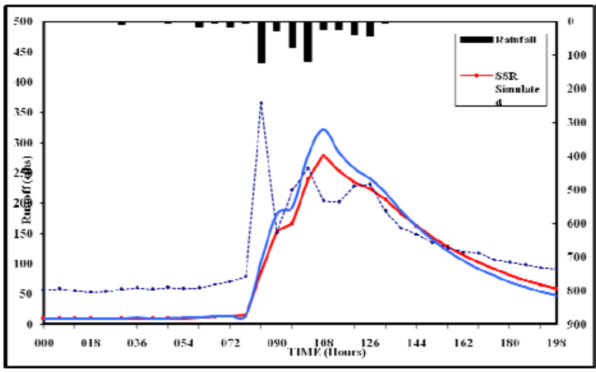
(b) Miho 23 (2001/SSARR/GA)



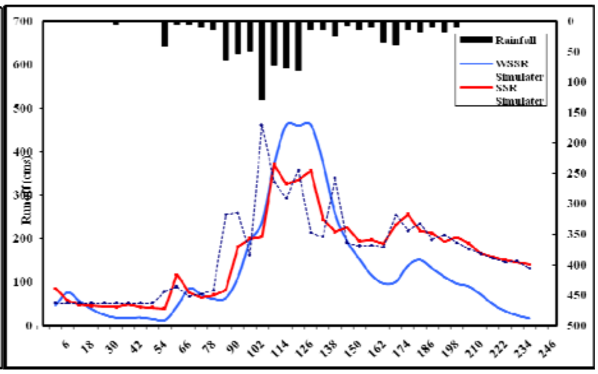
(c) Kusaki (2001/SFM/GA)



(d) Kusaki (2000/TANK/P-S)



(e) Ta Trach (2001/SSARR/P-S)



(f) Ta Trach (2000/TANK/P-S)

Fig. 2 Flood hydrograph for each basin

Table 2. Evaluation of models, calibration, and objective functions

Obj. func.	Flood Event	Calibration	Evolutuon func. (SFM)		
			NRMSE	R^2	RE
SSR	97	Pattern Search	0.0326	0.9591	0.1465
		GA	0.0517	0.9635	0.1630
	99	Pattern Search	0.0640	0.9233	0.0622
		GA	0.0798	0.9273	0.0325
	02	Pattern Search	0.0563	0.9432	0.0563
		GA	0.0647	0.9141	0.0397
	03	Pattern Search	0.0365	0.9647	0.0802
		GA	0.0326	0.9683	0.0681

(a) Miho 22 basin

Obj. func.	Flood Event	Calibration	Evolutuon func. (SFM)		
			NRMSE	R^2	RE
WSSR	97	Pattern Search	0.0982	0.8386	0.0000
		GA	0.1039	0.7398	0.0215
	99	Pattern Search	0.0798	0.9310	0.0245
		GA	0.0652	0.9516	0.0385
	02	Pattern Search	0.0710	0.9473	0.0036
		GA	0.0561	0.9468	0.0358
	03	Pattern Search	0.1210	0.8510	0.2126
		GA	0.1459	0.8567	0.3240

(b) Miho 23 basin

Obj. func.	Flood Event	Calibration	Evolutuon func. (TANK)		
			NRMSE	R^2	RE
SSR	98	Pattern Search	0.0121	0.9865	0.0052
		GA	0.0160	0.9817	0.0296
	99	Pattern Search	0.0229	0.9830	0.0794
		GA	0.0399	0.9493	0.0851
	00	Pattern Search	0.0321	0.9675	0.1232
		GA	0.0974	0.7326	0.1439
	01	Pattern Search	0.0330	0.9572	0.0595
		GA	0.0276	0.9687	0.0052

(c) Kusaki basin

Obj. func.	Flood Event	Calibration	Evolutuon func. (TANK)		
			NRMSE	R^2	RE
WSSR	98	Pattern Search	0.0264	0.9384	0.0013
		GA	0.0642	0.7758	0.0295
	99	Pattern Search	0.0220	0.9834	0.0607
		GA	0.0572	0.9279	0.1611
	00	Pattern Search	0.0324	0.9647	0.0947
		GA	0.0663	0.8584	0.1860
	01	Pattern Search	0.0319	0.9568	0.0077
		GA	0.0376	0.9440	0.0298

(d) Kusaki Basin

Obj. func.	Flood Event	Calibration	Evolutuon func. (SSARR)		
			NRMSE	R^2	RE
SSR	00	Pattern Search	0.2207	0.6053	0.1457
		GA	0.2339	0.5766	0.2506
	01	Pattern Search	0.2558	0.5403	0.3664
		GA	0.2501	0.4985	0.4041
	02	Pattern Search	0.2138	0.6318	0.2057
		GA	0.2204	0.6139	0.2341
	03	Pattern Search	0.3146	0.2585	0.1080
		GA	0.2314	0.4867	0.1148

(e) Ta Trach basin

Obj. func.	Flood Event	Calibration	Evolutuon func. (SSARR)		
			NRMSE	R^2	RE
WSSR	00	Pattern Search	0.2202	0.6053	0.1440
		GA	0.2310	0.5825	0.2410
	01	Pattern Search	0.2555	0.5403	0.3656
		GA	0.2546	0.4896	0.4149
	02	Pattern Search	0.2135	0.6318	0.2046
		GA	0.2211	0.6128	0.2370
	03	Pattern Search	0.3145	0.2587	0.1078
		GA	0.2192	0.5697	0.0338

(f) Ta Trach Basin

As the results in Figure 2 and Table 2 indicate, in general, the SFM yields similar results to those obtained from the SSARR model, while the TANK model provides slightly different results when compared to these two. The flood hydrograph resulted from the TANK model is sharper in shape when compared to that resulted from the SFM and SSARR model, but the TANK model also shows more instability in results for the Ta Trach basin.

Although there exist small differences in the results from the three models and the two calibration techniques, the simulated flood hydrograps show good results in every case. Between the two objective functions (SSR and WSSR), the results for WSSR are better than those for SSR, especially in the peak discharge and peak time of flood hydrographs; however, the SSR yields better results in other evaluation measures, including discharge volume and low flow part of flood hydrographs. With these issues raising difficulties in selecting the better model and calibration technique, one way to address the problem is to consider the basin and flood event characteristics in the first place.

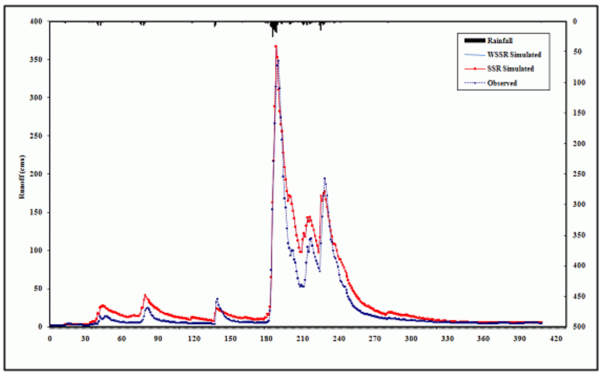
3.3 Parameter verification

In order to assess the 'practical' utility of models, it is vital to evaluate their performance on data that have not been studied as part of the calibration procedure. To achieve this, data corresponding to two flood events from each of the three basins are considered for verification or validation [see Table 1].

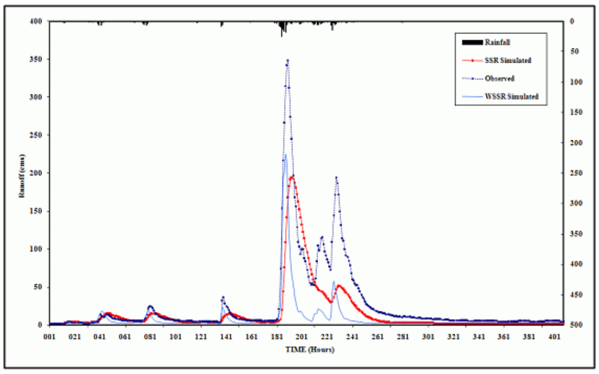
Based on the above calibration procedure, representative parameters for flood forecasting using the rainfall-runoff models are obtained. With the four flood events already studied, the representative parameters may be chosen by focusing on the flood hydrograph simulation, for example, and using the SSR and WSSR as the objective functions, as follows:

$$Min(\frac{obj_1}{w_1} + \frac{obj_2}{w_2}, \cdots\cdots, \frac{obj_n}{w_n}) \quad (3)$$

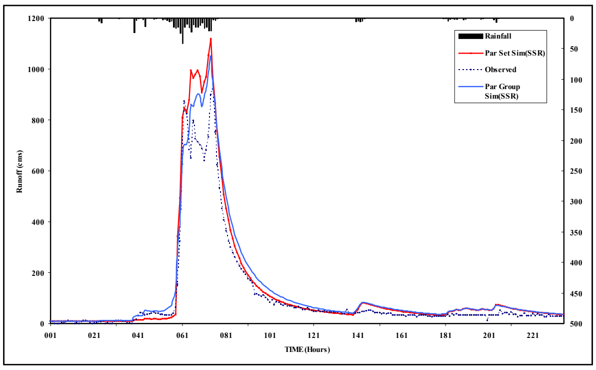
where obj is the objective function value for a flood event, w is the weight, and n is the number of the flood events used. After estimation of the representative parameters for four flood events studied during the calibration stage, their verification is made on two flood events chosen for such a purpose. The P-S and GA methods are again employed. The resulting flood hydrographs for the verification events are presented in Figure 5 for the three basins.



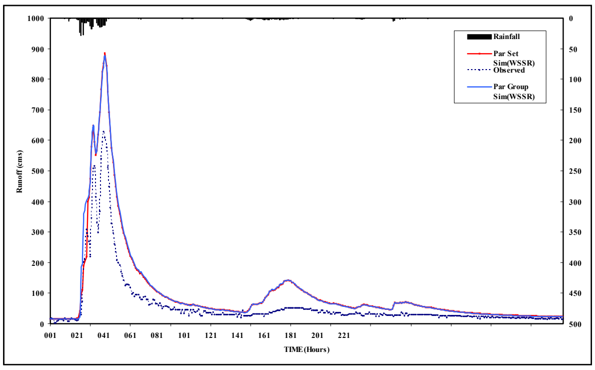
(a) Miho 22 (2006/SFM/P-S)



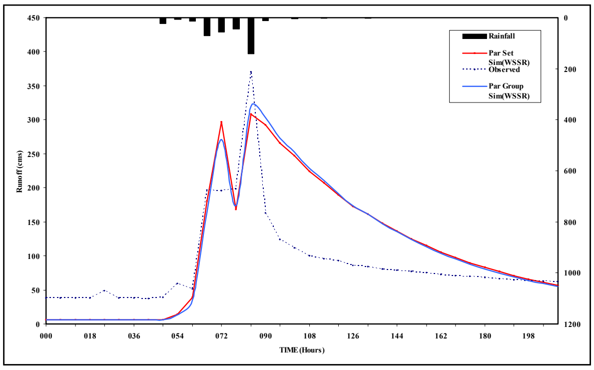
(b) Miho 23 (2003/TANK/P-S)



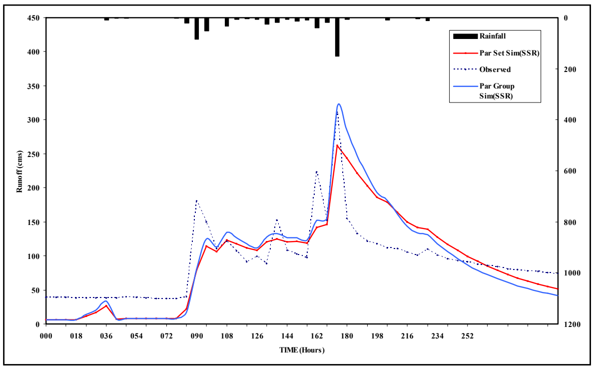
(c) Kusaki (2002/SSARR/GA)



(d) Kusaki(2003/TANK/P-S)



(e) Ta Trach (2004/TANK/GA)



(f) Ta Trach (2005/SFM/P-S)

Fig. 3 Verification Flood hydrograph at each basin

4. CONCLUSION

The performance of three rainfall-runoff models (SFM, TANK, and SSARR) for flood forecasting was assessed and compared through their applications to three different river basins in three different countries in Asia: Miho stream basin in Korea, Ta Trach basin in Vietnam, Kusaki basin in Japan. Pattern search and genetic algorithm techniques were employed for parameter optimization, with the sum of square residuals (SSR) and the weighted sum of square residuals (WSSR) serving as objective functions for obtaining peak discharge and peak time in the flood hydrograph. Four flood events from each of the three basins were used for calibration and two events from each were used for verification. Representative parameters for flood forecasting were also obtained based on each flood event.

Overall, all the three models provide reasonably good results in hydrograph simulation, regardless of the optimization technique and objective function adopted. The results also generally indicate that WSSR is more accurate for peak discharge flow and time than SSR. However, the outcomes are mixed, depending upon the case studied, with minor differences observed among the model performances and also with other issues like stability in the results.

In view of these mixed results, it is difficult to make general interpretations and conclusions on, for example, which model or optimization technique is the most appropriate or which one is better than the others. The appropriate model or optimization technique essentially depends on the basin characteristics and flood events, not to mention the objectives at hand. However, assessment and comparison of the performance of different models and techniques, such as the one carried out in the present study, could provide clues towards better forecasting and decision making ability.

ACKNOWLEDGMENTS

This study was supported by the 2005 SOC Project (05-GIBANGUCHUK-D03-01) through the Design Criteria Research Center for Abnormal Weather-Disaster Prevention (DCRC-AWDP) in KICTTEP of MOCT, KOREA.

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