THE RUNOFF PREDICTION USING THE STORAGE FUNCTION MODELS WITH LOSS MECHANISMS

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1. Introduction

The storage function model has been widely used for the rainfall-runoff analysis in Japan due to the ease of expressing the nonlinear relationship of rainfall-runoff events with simple equations and its ability to provide relatively easy computation. However, there are some difficulties to apply this model to the actual catchments such as a requirement of the estimation of the effective rainfall. The storage function model with loss mechanisms is proposed by Hoshi et al. (1999). This model overcomes such problems occurred when the conventionally used storage function model is applied to the actual river basin involving the direct rainfall as an input to obtain the runoff as an output and requires no pretreatment.

In this study, to examine the performance and the characteristics of the runoff prediction by the storage function models with loss mechanisms, the original version of storage function model with loss mechanisms and three other models are selected and the comparison of the results of the runoff prediction by those models is provided. Moreover, the shuffled complex evolution (SCE-UA) method that is proposed by Duan et al. (1992) as a new global optimization strategy is applied to the parameter optimization for all four models.

2. Studied area and data used

Studied river basin is the Koishiwara River basin mainly located in Amagi city with a catchment area of 85.9km^2 and a mean annual rainfall of 2247.6mm. The Koishiwara River is the tributary of the Chikugo River. Before the crop of dams located at the upper reaches of the Chikugo River were built, this area had often been affected by droughts and floods that inflict large damage to the surrounding area occur with an average frequency of three times every ten years. A large deluge that occurred in 1953 caused the levee to collapse and, hence, extensive damage occurred.

Six data sets of event 1 to event 6 that contain hourly rainfall and runoff data recorded at the Egawa dam during the period for 1993 to 1997 are used in this study.

3. The storage function model with loss mechanisms

The storage function model coupled with loss mechanisms, as proposed by Baba et al. (1999), is given by the following equations

$$s(t) = k_1 q^{p1}(t) + k_2 \frac{d}{dt} q^{p2}(t) \qquad (1)$$

$$\frac{ds(t)}{dt} = r(t) - q(t) - p(t) \qquad (2)$$

$$p(t) = aq(t) \qquad (3)$$

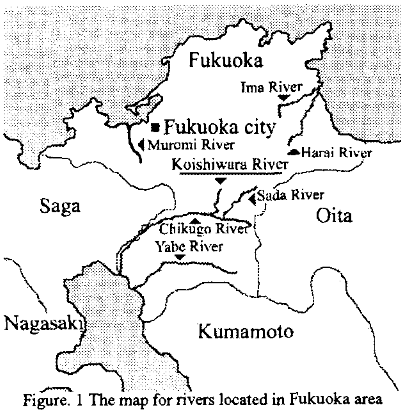

Figure. 1 The map for rivers located in Fukuoka area

where s: storage (mm), q: observed runoff (mm/h), r: observed rainfall (mm/h), p: loss (mm/h), t: time (hours), k_1, k_2, p_1, p_2, a: model parameters. By equation (1), (2), and (3) with equation (4) employed, the runoff is finally obtained by equation (5).

$$x_1(t) = q^{p_2}(t) \quad ; \; x_2(t) = \frac{dq^{p2}(t)}{dt} \qquad (4)$$

$$y(k) = q(k) = x_1^{\frac{1}{p_2}} \qquad (5)$$

The detailed solution for this transforming has been described by authors (2002).

4. Three simplified versions of the storage function models

In addition to the original version of the storage function model with loss mechanisms as above, three other versions are obtained as special cases of the storage function model with loss mechanisms. Some simplifications are implemented to the equation (1) as follows. Firstly, if we set p_2=1 in Equation (1), we obtain following equation which is known as Prasad's model.

$$s(t) = k_1 q^{p1}(t) + k_2 \frac{d}{dt} q(t) \qquad (6)$$

Secondly, if we set k_2=0 in equation (1), we obtain equation (7) which is known as Kimura's model.

$$s(t) = k_1 q^{p_1}(t) \qquad (7)$$

For a further simplification, equation (8) is obtained by setting p_1=1 in equation (7).

$$s(t) = k_1 q(t) \qquad (8)$$

For each of three special cases of the storage function model with loss mechanisms, each of equation (6), (7) and (8) is adopted instead of equation (1).

In this study, the original version of the storage function model is named the five-parameter model, the storage function model with p_2=1 is named the four-parameter model, the model with $k_2=0$ is named the three-parameter model, and the model with $k_2=0$ and $p_1=1$ is named the two-parameter model for convenience.

5. Parameter optimization

In this study, the model parameters in all versions of the storage function models with loss mechanisms are optimized using the SCE-UA method. The SCE-UA method is a new global optimization strategy designed to be effective and efficient for a broad class of parameter estimation problems occurred in the calibration of nonlinear simulation models, proposed by Duan et al. (1992). For the algorithmic parameters of the SCE-UA method such as m of the number of points in each complex and q of the number of points in each sub-complex, the values recommended by Duan et al. (1992) of $m=2n+1$ and $q=n+1$ where n is the number of parameters to be optimized are used and the number of complexes of p is set equal to 10. As a result, the optimized parameter values for all of four models are shown in Table 1.

6. Runoff prediction

The runoff predictions are conducted for six flood events occurred in the Koishiwara River basin using three storage function models with loss mechanisms. Hourly runoff of $q(t)$ is forecasted by each model with hourly rainfall of $r(t)$ as an input involving the optimized parameter values mentioned as above. The runoff predicted using the optimized parameter values in Table1 for event 1 is shown in Figure 2 and the resulting values of the root mean square error (RMSE) computed between the observed and predicted runoff and the peak % error for each event are shown in Table 2.

From Figure 2, there are broadly two peaks for the flood event 1. The five-parameter and the three-parameter model provided approximately same prediction with slight differences through the prediction and they generally gave good prediction for the first and second peak. On the other hand, the four-parameter and two-parameter model overestimated the first peak and underestimated the second peak.

From Table 2 for event 1, the smallest RMSE is given by the five-parameter model and the smallest peak % error is provided by the four-parameter model and it is slightly better than the value by the five-parameter model. Moreover, from table 2, the five-parameter model gave the smallest RMSE for all of six events and the smallest peak % error for three out of six flood events. The two-parameter model provided the worst results for the RMSE in all six predictions and the peak % error for five events out of six.

Table 1. The optimized parameter values for each model for event1

	5-parameter model	*4-parameter model*	*3-parameter model*	*2-parameter model*
k1	96.5820	100.0000	134.0332	19.4775
k2	16.3408	5.9672		
p1	0.2585	0.2666	0.1948	[1.0000]
p2	0.3550	[1.0000]		
a	0.4416	0.4726	0.3981	0.4815

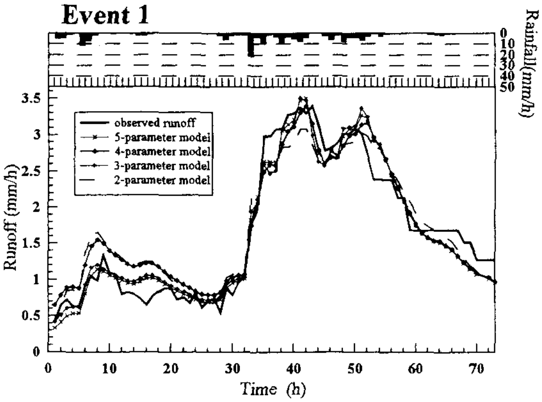

Figure 2. The observed rainfall and the runoff predicted using three versions of the storage function model with loss mechanisms

7. Conclusion

It was indicated that the five-parameter model is the most appropriate model to predict the runoff for the Koishiwara River basin of all four models.

On the other hand, the two-parameter model could not provide the reasonable results in terms of both of the RMSE and the peak % error compared with other models.

No advantages by using the three-parameter and the four-parameter model in the runoff estimation for the studied river basin were shown in this study.

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Table 2. The RMSE and peak % error for each simulation of runoff prediction with optimized parameter set applied

used parameters and models	Event 1		Event 2		Event 3		Event 4		Event 5		Event 6	
	RMSE	peak error	RMSE	peak error	RMSE	peak error	RMSE	peak error	RMSE	peak error	RMSE	peak error
The storage function model with loss mechanisms	0.2153	7.8771	0.4140	4.2978	0.5123	6.3202	0.3811	32.0839	0.1990	13.1674	0.2450	17.5791
The storage function model with loss mechanisms with p2=1	0.2765	7.0766	0.5667	4.9682	0.6808	20.1708	0.4044	33.0230	0.2694	24.7342	0.3378	24.6437
The storage function model with loss mechanisms with k2=0	0.2329	11.9344	0.4561	3.2092	0.8353	14.4269	0.4075	35.8780	0.2596	22.6009	0.2609	17.0872
The storage function model with loss emchanisms with k2=0, p1=1	0.3027	16.2150	0.6335	19.4960	1.0679	30.7432	0.4933	37.9287	0.2610	25.2829	0.3154	32.0528