강우-유출 모델링의 불확실성 고려한 다중 평가지수에 의한 확장형 모형평가 방법

An Extended Model Evaluation Method using Multiple Assessment Indices (MAIs) under Uncertainty in Rainfall-Runoff Modeling

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Abstract

Conventional methods of model evaluation usually rely only on model performance based on a comparison of simulated variables to corresponding observations. However, this type of model evaluation has been criticized because of its insufficient consideration of the various uncertainty sources involved in modeling processes. This study aims to propose an extended model evaluation method using multiple assesment indices (MAIs) that consider not only the model performance but also the model structure and parameter uncertainties in rainfall-runoff modeling. A simple reservoir model (SFM) and distributed kinematic wave models (KWMSS1 and KWMSS2 using topography from 250m, 500m, and 1km digital elevation models) were developed and assessed by three MAIs for model performance, model structural stability, and parameter identifiability. All the models provided acceptable performance in terms of a global response, but the simpler SFM and KWMSS1 could not accurately represent the local behaviors of hydrographs. In addition, SFM and KWMSS1 were structurally unstable; their performance was sensitive to the applied objective functions. On the other hand, the most sophisticated model, KWMSS2, performed well, satisfying both global and local behaviors. KMSS2 also showed good structural stability, reproducing hydrographs regardless of the applied objective functions; however, superior parameter identifiability was not guaranteed. Numerous parameter sets could lead to indistinguishable hydrographs. This result supports that while making a model complex increases its performance accuracy and reduces its structural uncertainty, the model is likely to suffer from parameter uncertainty. The proposed model evaluation process can provide an effective guideline for identifying a reliable hydrologic model.

Key words: Extended model evaluation, model performance, model structural stability, parameter identifiability

1. Introduction

This paper proposes an extended model evaluation framework under uncertainty in rainfall-runoff modeling for identifying a more reliable model. The new framework follows the basic concepts of

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uncertainty proposed by Beven (2002) and Wagener and Gupta (2005). It admits numerous plausible representations providing identically good model performance measures, while newly developed criteria are used to assess other inherent model characteristics related to structural and parameter uncertainties. We prepared seven different rainfall-runoff models ranging from a simple lumped model to sophisticated distributed models and then evaluated the models with respect to model performance, model structural stability, and parameter identifiability. A highly ranked model by these criteria is structurally stable, shows less parameter uncertainty, and ensures accurate prediction results. This evaluation process may provide a more useful guideline for selecting a suitable model for various rainfall-runoff model applications. Section 2 introduces the concept underlying the new method of model identification under uncertainty, and Section 3 describes the models used in this study. Section 4 introduces the new evaluative criteria in detail and addresses the comparative results. Finally, we summarize our major conclusions in Section 5.

2. Concept of extended model evaluation under uncertainty

Figure 1 illustrates the extended model evaluation under uncertainty. Initially, a set of rainfall-runoff models, with different representations of rainfall-runoff processes and spatial topography, is prepared for model evaluation. Here, all the models are assumed to be potentially available simulators, unless obvious evidence indicates that a model should be rejected. Three different evaluative criteria are then applied to the competing models. The first (or the most fundamental) measure of model evaluation is the model performance index (MPI), which assesses whether the models are capable of accurately simulating the observed streamflow in terms of local response modes such as low and high flows. The second criterion is the model structural stability index (MSSI) for assessing how precisely the models can represent the local response modes regardless of given objective functions. More stable models can provide more constant and accurate simulation results with respect to various local behaviors irrespective of the applied objective functions. The last measure is the model parameter identifiability index (MPII) for evaluating whether the model parameters are well identified within a predefined feasible parameter space. The models showing higher parameter identifiability indicate less parameter uncertainty during model calibration and guarantee increased prediction accuracy. The resulting criteria values from the extended model evaluation should give some objective basis by which to search for a model that balances prediction accuracy, structural stability, and parameter uncertainty.

3. Rainfall-runoff models used in this study

In this study, three different types of rainfall-runoff models, from a simple lumped model to distributed kinematic wave models, were developed under an object-oriented hydrological modeling system. Moreover, three different spatial resolutions of a digital elevation model (DEM) were used to investigate the scale effect on both model performance and uncertainty assessment in distributed rainfall-runoff modeling.

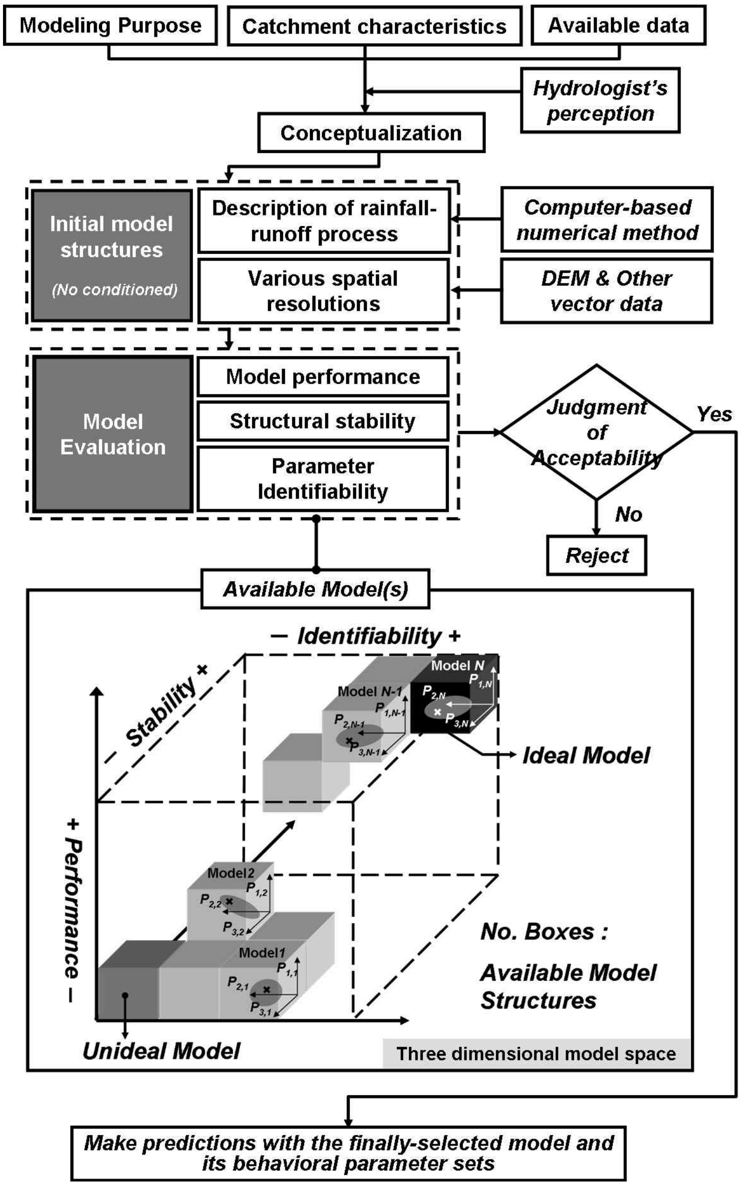

Fig. 1 Extended model evaluation under uncertainty in rainfall-runoff modeling.

4. Model evaluation with three different types of criteria

4.1 Model evaluation with the model performance index (MPI)

The performances of each model structure were assessed using the Nash-Sutcliffe coefficient (NSC) for the two periods; the two measures were then averaged to obtain the MPI.

4.2 Model evaluation with the model structural stability index (MSSI)

MSSI is formulated in the form of the RMSE between both simulated discharges based on the optimal parameter sets estimated by the SCE-UA with SLS and HMLE.

4.3 Model evaluation with the model parameter identifiability index (MPII)

For parameter identifiability assessment, we applied the SCEM-UA to estimate individual posterior parameter distributions, and then investigated the uniqueness of the calibrated parameters from the probability density functions of each model. Here, the highest density values of each distribution were used as the individual indicators of parameter identifiability, and the mean value of each maximum identifiability indicator was used for the MPII.

5. Evaluation results

Simulation results with the three criteria are summarized below tables.

Table 1 MPI values for each model structure: evaluation of global and local behaviors.

Model / No. parameter	SFM	KWMSS1			KWMSS2		
		250m	500m	1km	250m	500m	1km
NSC_{Low}	0.944	0.885	0.885	0.812	0.993	0.993	0.974
NSC_{High}	0.987	0.969	0.969	0.967	0.993	0.992	0.983
MPI	0.977	0.95	0.95	0.931	0.993	0.993	0.981

Table 2 MSSI values for each model structure: evaluation of the influence of the objective function on the model performance.

Model	MSSI	Objective Function	Best-performing Parameter				
SFM	92.21		k	p	f	R_{SA}	-
		SLS	49.61	0.52	0.63	201.21	-
		HMLE	49.64	0.64	0.57	118.94	-
KWMSS1 (250m)	3.63		N	k_d	d	-	-
		SLS	0.50	0.010	0.389	-	-
		HMLE	0.49	0.014	0.399	-	-
KWMSS1 (500m)	49.46	SLS	0.50	0.016	0.313	-	-
		HMLE	0.50	0.013	0.282	-	-
KWMSS1 (1km)	86.59	SLS	0.50	0.031	0.322	-	-
		HMLE	0.49	0.029	0.259	-	-
KWMSS2 (250m)	9.97		N	k_a	d_s	d_c	β
		SLS	0.498	0.034	0.601	0.478	5.528
		HMLE	0.497	0.050	0.682	0.600	6.368
KWMSS2 (500m)	12.97	SLS	0.322	0.05	0.626	0.481	5.361
		HMLE	0.453	0.05	0.755	0.600	7.602
KWMSS2 (1km)	31.47	SLS	0.497	0.05	0.738	0.6	7.596
		HMLE	0.500	0.05	0.696	0.6	6.980

Table 3 MPII values for each model structure: average maximum values of the marginal posterior parameter distributions of each parameter.

No. parameter \ Model	SFM		KWMSS1				KWMSS2			
				250m	**500m**	**1km**		**250m**	**500m**	**1km**
1	k	0.076	n	0.205	0.45	0.251	n	0.122	0.059	0.24
2	p	0.188	k_d	0.679	0.36	0.155	k_a	0.343	0.115	0.883
3	f	0.068	d	0.532	0.804	0.8	d_s	0.094	0.121	0.359
4	R_{SA}	0.078	-	-	-	-	d_c	0.085	0.107	0.324
5	-	-	-	-	-	-	β	0.11	0.157	0.339
MPII		**0.103**		**0.472**	**0.538**	**0.402**		**0.151**	**0.112**	**0.429**
Ave. MPII		**0.103**			**0.471**				**0.231**	

The overall results of the model evaluation demonstrate that the ideal model structure, which guarantees the best values in terms of the three criteria, was not found in this study. The distributed model, KWMSS2, was much better than the simple models, SFM and KWMSS1, in terms of two evaluative criteria, MPI and MSSI, but KWMSS2 did not ensure the best parameter identifiability. Therefore, additional constraints that are able to reject unreliable parameter set(s) and provide reliable prediction results need to be combined in the proposed modeling framework for further model identification.

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References

1. Beven, K. (2002), Towards an alternative blueprint for a physically-based digitally simulated hydrologic response modeling system, Hydrological Processes1 6(2), pp.189-206.
2. Wagener, T. and Gupta H.V. (2005), Model identification for hydrological forecasting under uncertainty, Stochastic Environmental Research and Risk Assessment 19, pp.378-387.