Research on Parameter Sensitivity Analysis of Distributed Hydrological Model in Karst Watershed

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ABSTRACT: Irrational use of water resources in Karst regions, resulting in the fragile environment for further deterioration, native vegetation degradation, soil erosion, desertification intensified, frequent occurrence of floods, therefore, it is import to explore the methodologies to accurately simulate the water cycle process in Karst river basin. The paper applies local sensitivity analysis method and LH-OAT algorithm to distributed hydrological simulation of Karst river basin, finds out the most sensitive parameters, simulation results has improved significantly, the Nash efficient coefficient increases from 0.3 to 0.7, and the difference of annual runoff in each year is less than 15%, provides a good suggestion for the future construction and application of distributed hydrological model in typical Karst watershed, which has significant scientific meaning.

KEYWORDS: parameter sensitivity analysis; LH-OAT algorithm; distributed hydrological model; Karst watershed;

I. INTRODUCTION

With the proposal and development of distributed hydrological model, high-strength computing needs and space complexity of hydrological model restricts the understanding the relationship between model parameters and parameter sensitivity analysis to a large extent. Parameter sensitivity analysis is to study model response by parameter changing, is the important mean of model parameter uncertainty analysis, and also is an indispensable part of model development and evaluation. Over-parameterization is a well-known and often described problem in hydrological models [1], especially for distributed models. The purpose of sensitivity analysis is to minimize the number of parameters need to be adjusted when calibration, as well as help understand model structure, then to find out model defects, makes it possible to improve model structure.

Based on Monte Carlo simulation, McKay[2] (1979) proposed Latin Hypercube sampling(LH) sampling. K. Holvoet and A. van Griensven etc [3] (2005) made sensitivity analysis and parameter calibration of SWAT model parameters in southeastern mountainous region of Brussels with LH-OAT algorithm, and they put forward that reasonable parameter input is the premise of exact result output. A. van Griensven and T. Meixner etc[4] (2006) made parameter calibration of SWAT model in upper and northern runoff region of Texas River and Sandusky runoff area in Ohio, which shows that LH-OAT method is feasible. A. van Griensven etc（2006）selected two areas to make sensitivity evaluation of different parameters during the simulation process in the way of LH-OAT when SWAT model was respectively applied in runoff, silt and pollutant simulation processes.

Karst river basin is a material and energy flow open system with dual three-dimensional spatial structure consisted by a dual aquifer layer[5]. Therefore, it is not only demonstrating unique landscape and process of geological-geomorphologic characteristic, but also has its own hydrological features and processes. Because of the highly complex nature of the basin, it is more important to focus on the parameter sensitivity analysis. The paper applies local sensitivity analysis method and LH-OAT algorithm to distributed hydrological simulation of Karst river basin, finds out the most sensitive parameters, simulation results has improved significantly, provides a good suggestion for the further research.

II. LOCAL SENSITIVITY ANALYSIS METHOD AND LH-OAT ALGORITH

A. Local method of parameter analysis

A local sensitivity analysis evaluates sensitivity at one point in the parameter hyperspace. This point may be defined by default values or a crude manual model calibration. Sensitivities are usually defined by computing partial derivatives of the output functions with respect to parameters. A sensitivity index S can be calculated for a small change Δe_i, while the other input parameters are held constant，the formula is as follows[6]:

$$S = \frac{\dfrac{M(e_1,\ldots,+\Delta e_i,\ldots,e_p) - M(e_1,\ldots,+e_i,\ldots,e_p)}{M(e_1,\ldots,+e_i,\ldots,e_p)}}{\dfrac{\Delta e_i}{e_i}}$$

Where M is the model output, e_i refers to the different model parameters, and Δe_i is the perturbation in a single model parameter.

As the distributed hydrological model with a complex spatial degrees require intensive computing power, while the karst river basin with a variety of landscape forms, for a typical karst watershed to build a distributed hydrological model requires that the model can reflect the characteristics

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of runoff, groundwater regulation, and long-lasting slow decay characteristics. The local method of parameter sensitivity analysis requires the model run time is not very much, which can reduce the power of a distributed hydrological model calculation pressure, as a alternative method.

B. Sensitivity analysis based on LH-OAT algorithm

LH-OAT is a kind of new method integrating LH（Latin-Hypercube）sampling and OAT（One-factor-At-a-Time）sensitivity analysis, so it has advantages of LH sampling and OAT sensitivity analysis.

Although global sampling can provide useful information on model input, the calculation of distributed hydrological model in some complicated basins is too huge. The Karst watershed with binary flow patterns, have two underground water net, two river basins, which show a complex relationship between the incoincide borders, but constitute an inseparable whole through the hydraulic connection, therefore exist an imbalance water exchange amount[7]. As the complexity of specific Karst topography, global sampling method does not apply. Hydrological model usually has a lot of parameters [8], but the important parameters of calibration and model output in specific basin is limited, and one method is needed to classify importance of these parameters. OAT method can meet the requirement, but Monte Carlo sampling based on OAT needs a lot of sampling data to cover parameter zone while this results in huge calculation. To substitute Monte Carlo sampling with LH sampling is an important improvement. When the parameter zone is fixed, users are allowed to control the whole simulation process of the parameters.

In terms of disadvantages above, LH sampling is introduced into LH-OAT on the basis of OAT sampling. First divide the whole parameter space into N layers, then sample in every layer separately for one time, namely one LH sampling point (including parameter set of P parameters), finally change parameters for P times in every LH sampling point, and only one parameter is changed every time. LH-OAT method can be fulfilled with several circulations. Starting point of every circulation is LH sampling point, and partial influence value $S_{i,j}$ of every parameter e_i can be calculated on the basis of formula：

$$S_{i,j}=\left|\frac{100*\left(\dfrac{M\left(e_1,\ldots,e_i*(1+f_i),\ldots,e_p\right)-M\left(e_1,\ldots,e_i,\ldots,e_p\right)}{\left[M\left(e_1,\ldots,e_i*(1+f_i),\ldots,e_p\right)+M\left(e_1,\ldots,e_i,\ldots,e_p\right)\right]/2}\right)}{f_i}\right|$$

Where M is model objective function, f_i is slight disturbance incurred by parameter change e_i , j is a sampling point of LH. Formula shows that f_i change can result in increasing or decreasing parameters. The circulation shall be carried out for P+1 times. Final influence value is calculated from average partial influence of every circulation of all LH sampling points. LH method has N intervals, so the model has to be operated for N*（P+1）times and this method is highly efficient.

III. CASE STUDY

A. General Description of Research Region and Model Development

PingHu river basin is located in the southern Guizhou Province, belongs to XiJiang river of ZhuJiang river basin, in the region of E107°03′～107°37′and N25°51′～26°06′, covers an area of 1418 km^2. The exposed strata are mainly Carboniferous, Permian and Triassic. The watershed have a lot of underground water, depression and water elimination holes, with a typical Karst area features of dual water system, such as KaiKou river, LiMuSai river and HaiMa river in the northwest watershed conflux together to underground river, and finally into ShaLa river, while KaLuo river in the southwest watershed confluxes into underground water, and finally into TuChang river. Whenever in the flood period, due to the size of water elimination holes too small, resulting in floods of varying degrees every year.

The paper adopts daily precipitation data of five precipitation stations and daily runoff data of PingHu hydrological station, land use information uses 2000 year with 1:100000 land use map, land DEM information, and soil characteristics, to establish the distributed hydrological model of typical Karst watershed.

B. Parameter Sensitivity Analysis

a Define Optimization Space

The distributed hydrological model includes a lot of parameters, the paper picks out 21 parameters to sensitivity analysis and parameter optimization according to the characteristic of Karst River Basin, shows in table 1. The parameter optimization space is composited by the corresponding upper and lower boundaries, determined by recommended range of parameters, or according to the physical meaning of parameters.

TABLE I. PARAMETER SAMPLING RANGE OF SENSITIVITY ANALYSIS TABLE TYPE STYLES

Type	No	Name	Lower limit	Upper limit
Global Parameter	1	ki_sub	0.5	2
	2	kg_tot	0.001	0.05
	3	T0	0.1	0.9
	4	k_snow	0.1	2
	5	k_rain	0.0001	0.001
	6	k_run	0.5	3
	7	p_max	100	500
Runoff Parameter	8	UnitSlopeM	0.5	1.5
	9	RunOffCoeM	0.5	1.5
	10	ConductM	0.5	1.5
	11	PorosityM	0.5	1.5
	12	FieldCapM	0.5	1.5
	13	PoreIndexM	0.5	1.5
	14	LaiMaxM	0.5	1.5
	15	DepressM	0.5	1.5
	16	RootDpthM	0.5	1.5
	17	ItcmaxM	0.5	1.5
Conflux Parameter	18	CH_S2	0.5	1.5
	19	CH_L2	0.5	1.5
	20	CH_N2	0.5	1.5
	21	CH_K2	0.5	1.5

b *Parameter Sensitivity Analysis in Karst River Basin*

After the results analysis and statistical comparison, water cycle simulation with LH-OAT sensitivity analysis method is much better than local sensitivity analysis algorithm. The paper elaborates the process of LH-OAT algorithm in the distributed hydrological model of Karst River Basin, and makes the following discussion.

The paper uses day average runoff of PingHu Hydrostation from 2004 to 2006 to do sensitivity analysis, picks out two index to judge the result, including residual sum of squares $SSQ = \sum_{i=1}^{n} \left(X_{sim,i} - X_{obs,i} \right)^2$ of simulation flow and daily average runoff $Q_{avg} = \sum_{i=1}^{n} X_{sim,i} / n$. Please refer the results to figure 2 and figure 3.

Fig.1 shows the result of LH sampling of 21 key parameters of distributed hydrological model. The sampling divides the whole parameter space into ten layers and 21 parameter sets are obtained through sampling. Make OAT sampling of each parameter set in each parameter space after LH sampling. Since each OAT sampling only changes one parameter value and there are 21parameters in each group, it will make 10 samplings if all OAT samplings of LH parameter set in the group are made. Therefore, LH-OAT sampling number is 220=10*(1+21).

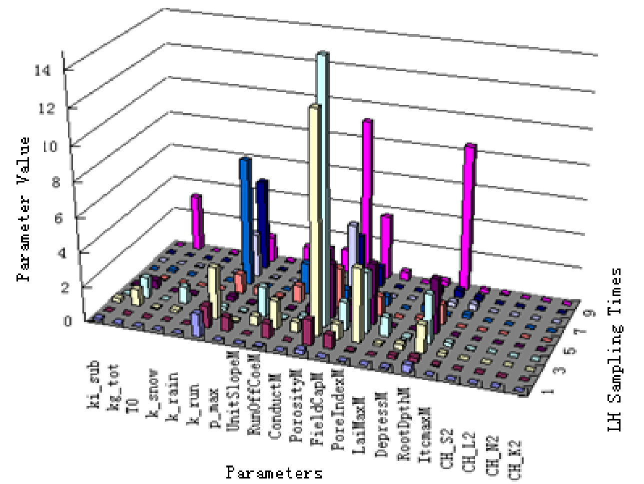

Fig.1 LH sampling of PingHu station

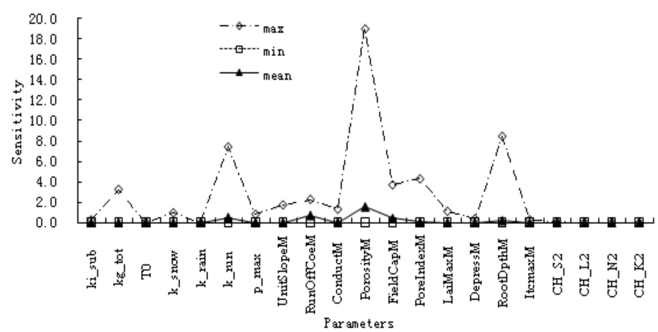

Fig. 2 Oavg sensitivity results at PingHu Station

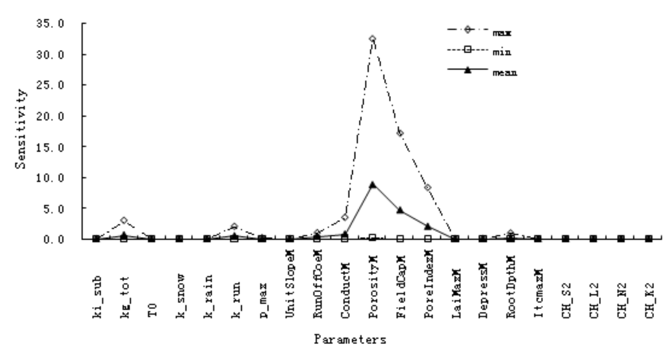

Fig.3 SQQ sensitivity results at Pinghu Station

According to the results of LH-OAT, continue to compute 220 times, and calculate the sensitivity of each parameter. Fig.2 and Fig.3 respectively show sensitivity results of the two indexes at PingHu Station. According to Qavg, the parameter PorosityM with 19.6 is the highest sensitivity, the following is k_run and RootDpthM. While according to SSQ, the parameter PorosityM is also the highest with 34.8 , the following is FieldCapM.

C. Model parameter calibration and verification

Because the data are limited, the paper selects the data from 2004 to 2006, using day time step to do model calibration, then using the data from 2007 to 2008 to do model verification. Nash efficiency coefficient of daily runoff is above 0.7, the relative error is about 10%. Figure 4 and figure 5 respectively show comparison of simulation of result of monthly runoff process and actual measurement result during calibration period and verification period at PingHu station. Table 3 shows runoff simulation calibration and verification result.

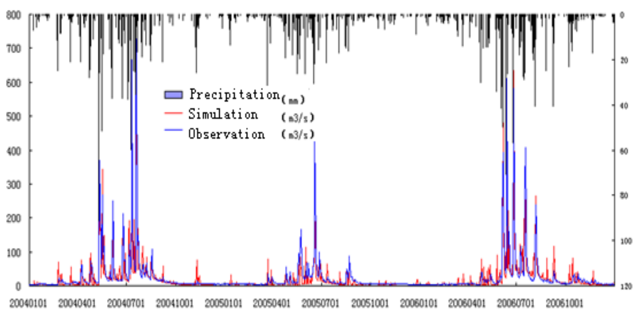

Fig.4 Comparison between runoff simulation process and actual measurement runoff process during calibration term at PingHu Station

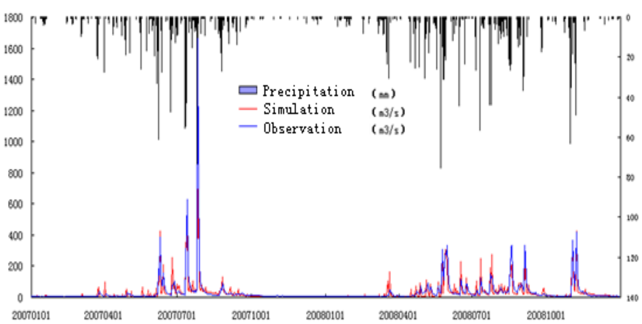

Fig.5 Comparison between runoff simulation process and actual measurement runoff process during verification period at PingHu Station

TABLE II. RUNOFF SIMULATION CALIBRATION AND VERIFICATION RESULT AT PINGHU STATION

Year	Difference of average annual runoff（%）	Nash efficiency coefficient of runoff process
2004	10.5	0.823
2005	15.2	0.694
2006	4.5	0.781
2007	11.7	0.734
2008	13.8	0.749

IV. CONCLUSIONS AND PROSPECT

Irrational use of water resources in Karst regions, resulting in the fragile environment for further deterioration, native vegetation degradation, soil erosion, desertification intensified, frequent occurrence of floods, therefore, it is import to explore the methodologies to accurately simulate the water cycle process in Karst river basin. The paper applies local sensitivity analysis method and LH-OAT algorithm to distributed hydrological simulation of Karst river basin, finds out the most sensitive parameters, simulation results has improved significantly, the Nash efficient coefficient increases from 0.3 to 0.7.

Karst river basin as a special kind of watershed has its own structural characteristics and evolution. On the basis of continuous improve model, if water to simulate the real process of water cycle in Karst basins, need to renew understand the viewpoint of water balance, through distributed hydrological simulation can given the real process.

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