New Approach for Determination of Model Parameters of a Rainfall-Runoff Model for Ungauged Catchments

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Abstract

This research concerns the determination of model parameters of a rainfall-runoff model for ungauged catchments. The main idea is to use the minimal number of measured flows in order to estimate model parameters. The approach proposed to optimize the parameters based on the use of a “a priori” knowledge of these parameters. The “a priori” information is made of an “a priori” ensemble of parameter sets, and the optimal parameter set is chosen in order to minimise the deviations when comparing some specific measurements of flow to the flows computed with individual parameter sets. In this case, two different methods are evaluated: one consists of seeking the optimum set among 3^p sets of parameters for a model having p parameters in its structure. The other method chooses the parameter set among those of selected gauged catchments on the basis of similarity of physical and climatic characteristics.

This work concerns also the research of the best strategy of acquisition of flow measurements. The objective is to plan these measurements during the days when the potential of information is the best to discriminate, among the sets of parameters candidates, the one which has the most chances to be effective. The main result of this research is that the measurements should be done on the days when the flow takes his highest possible values.

Introduction

The implementation of a rainfall-runoff model to an ungauged basin requires the relationship of the parameters of the model to the characteristics of said basin. The conventional methods use two general strategies for relating the parameters of a model with the characteristics of an ungauged basin:

- The use of simple and multiple regressions among the values of the parameters and descriptors of the basins
- The use of similitude among basins for identifying a group of basins from which it is possible to exploit the calibrated parameters of the model.

In this work we use the above second strategy.
On the other hand, it is important to remember, the studies which have been supported by such second strategy have used basins located in relative homogeneous regions and the results have been wide-ranging. Mainly, the level of the obtained results by these studies is limited over ungauged basins, generally, because the used model calibration is effected with a series of available expenditure.

In this article we propose two methods wherein the set of parameters of the model can be found in a discrete set of set of parameters previously obtained with regard to the gauged basins. In the first method, we use a set of type-basins based on the distributions a priori of the parameters values of the model. In the second method, a set of parameters is available and said set is decomposed in subsets which are formed of the set of parameters which correspond to the basins in which the physical and climatic features are “similar” to those of the study ungauged basin .

The article has three sections: a) the used basins are mentioned and the used model GR4J is disclosed; b) the two methods which are developed are described in order to obtained the parameters of the model and apply it to the ungauged basins; c) the obtained results are analyzed and discussed with regard to the efficiency of the model and the values of its parameters, finally the conclusions and prospects of the work are stated.

Data and Model

Test data

This study have required the compilation of daily data from a great number of catchments spread over four continents (1111 catchments), and without any “a priori” selection since it is not possible to do a selection for an ungauged basin.

The large sample of catchments assembled for this study is comprised of catchments, with areas from 0.1 to 50600 km^2, located in the United States (500 catchments), France (305 catchments), Mexico (260 catchments), Australia (32 catchments), the Ivory Coast (10 catchments) and Brazil (4 catchments).

Model GR4J

The GR4J model which we will use throughout this paper is described in detail by Edijatno *et al.* (1999) and Perrin *et al.* (2003). GR4J has four parameters to be calibrated. A sketch of the model structures is shown in Figure 1 (PE: potential evapotranspiration; P: precipitation; Q: streamflow; Xi: model parameter i; other letters are internal state variables) The meaning of the parameters is given in Table 1.

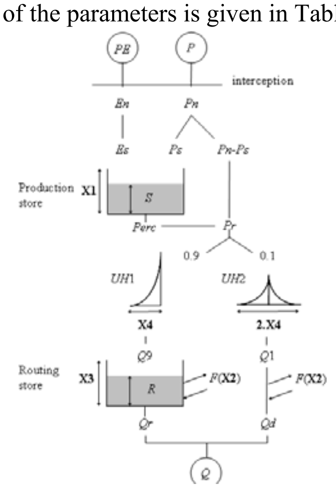

Figure 1: Scheme of the GR4J rainfall-runoff model.

Table 1: List of parameters of the GR4J model

Parameter	Meaning
X1	Capacity of the production store (mm)
X2	Water exchange coefficient (mm)
X3	Capacity of the nonlinear routing store (mm)
X4	Unit hydrograph time base (day; ≥0.5)

Proposed methods for obtaining the parameters of the model

Specific streamflow data

The idea of both proposed methods in this work, for obtaining the parameters of a model, is to use the information which corresponds to the specific measures of streamflow data. If we denote as N to the number of specific measures of streamflow, then we can denote with the small cap i the day in which a specific streamflow measure is available, this way, we can write:

$$i = 1,2,3,\ldots,N \tag{1}$$

Therefore, the model calibration for each one of the basins of the sample – which have been considered as ungauged and for which it is available only certain number of N measures of daily streamflow -; is done considering and varying N.

On the other hand, the analysis of a sampling strategy has been interesting for considering the values of the available N streamflow data. In other words, having the knowledge of what characteristics of these specific measures contribute greater information for estimating the streamflow in an ungauged basin. It has been done analysis for selecting the N streamflow data in this work. This analysis consists in applying both methods below for determining the parameters of the model, according to the next gauging conditions for the specific N streamflow data:

- In high rainfall season
- In low rainfall season
- The days when the lowest streamflow has been recorded
- The days when the highest streamflow has been recorded

To assess the impact of limited streamflow knowledge on model results, we simulated different levels of streamflow data availability for model calibration.

The model was calibrated on each catchment using the optimization algorithm applied by Edijatno et al. [1999]. The objective function used during optimization is the Nash and Sutcliffe [1970] criterion calculated on root square transformed flows as recommended by Oudin et al. [2006].

For model evaluation, we adopted the split sample test advised by Klemesˇ [1986]. For each catchment, the entire data record was split into two periods (P1 and P2). In the tests, we first calibrated the models on period P1 and tested them in validation mode on period P2. Then the role of the periods was reversed (calibration on P2 and validation on P1).

Methods of the type-basins

The distributions of the cumulative frequencies which correspond to the set of obtained parameters in the GR4J model calibration stage in the sample of 1111 basins, are used for defining “small”, “medium” and “large” values. This size definition assigned to the values of the calibrated parameters is performed with the aid of the quantiles 0.333 and 0.667. Figure 2 shows the distribution considered for the X4 parameters of the GR4J model.

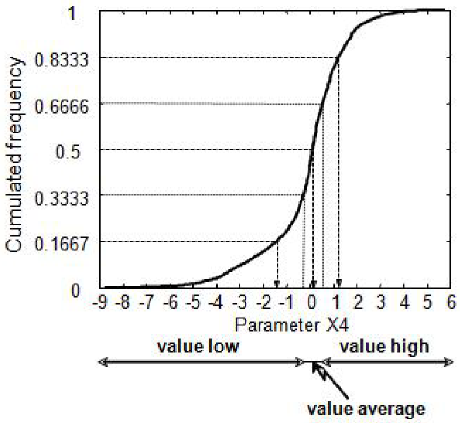

Figure 2: Identification of the values of the parameters in function of the quantiles.

According to these quantiles 0.333 and 0.667 and the number of parameters of the model it is possible to define 3^4 basin classes. The type-basin of a class has been defined by the set of parameters which is located at the center of the defined interval in Figure 2. In other words, the quantiles 0.167, 0.500 and 0.833 define the type-basin for each one of the three classes. In this way, getting each of 3 class for each one of the four parameters of the model GR4J, there are obtained 3^4 set of parameters (having 3 classes for each one of p parameters; $\text{classes}^{\text{parameters}} = 3^p = 3^4 = 81$ set of parameters).

The retained parameters of the model for an ungauged basin are those that better reproduce the possible N streamflow data. The aforementioned is validated with the CRIT criterion showed in equation 2; in this equation N corresponds to the number of specific available streamflow data; Q is the specific streamflow data of the day i (i = 1, … N) and Q corresponds to the calculated streamflow of day i with the set of parameters of the selected type-basin . Moreover, each one of the 3^4 set of parameters corresponding to the above mentioned type-basin is used.

$$\mathrm{CRIT} = \frac{1}{N}\sum_{i=1}^{N}\left(\sqrt{Q} - \sqrt{\hat{Q}}\right)^2 \qquad (2)$$

Method of the similar basins

The method of the similar basins uses the set of a priori available parameters of the 1111 basins of the sample. Nevertheless, for calibrating the model only the parameters corresponding to the basins having the same physical and climatic features of the study ungauged basin are used. The available physical and climatic features are as follows:

Table 2: Available physical and climatic features for each one of the 1111 basins of the sample -characteristics used for the modeling-.

	Characteristics used for the modeling
A	Area (km^2)
ETP	Potential evapotranspiration mean (mm)
P	P(Rainfall>0.1mm); Probability that the daily rainfall will be higher than 0.1 mm

For each one of these characteristics, their distribution of cumulative frequency was obtained considering the 1111 basins of the sample. The distributions reached from basin characteristics, are used to define categories between quantiles 0.333 and 0.667. Figure 3 shows the distribution of area cumulative frequency of basins of the sample, in the graphic showed in this Figure 3 it is considered the distribution of logarithms of said characteristic.

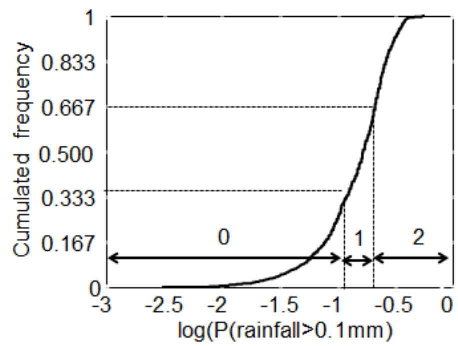

Figure 3: Identification of values of the characteristic in function of the quantiles.

The graphic in Figure 3 shows the following three ranges defined by quantiles 0.333 and 0.667; in range with value equal to 0 small area basins are considered, the range defined for value equal to 1 medium area basins are considered, and the range with value equal to 2 considers large area basins.

In this way, getting each of three ranges for each one of the four characteristics of the basins, there are obtained 3^4 categories of the basins, having 3 classes for each one of four c characteristics ($\text{classes}^{\text{characteristics}} = 3^c = 3^4 = 81$ categories).

This method of similar basins consists in retaining all the basins of the sample that belong to same category of basin in study which is considered as ungauged basin. If we denote like m the number of basin into the same category, the parameters of these basins make a set of parameters belonging to m number of basins.

The model calibration is made using the available N streamflow data. The model parameters that are used for ungauged basin are those that calculate the more proximal streamflow to each one of the N streamflow data, and besides obtain minimal values for equation 1. The mean value of parameters of each one of m basins is the assigned value to each model parameters for applying it to ungauged basin.

Results, Conclusions and Prospects

Discussion of results

Figure 4 presents the mean results of the use of GR4J model in each one of 1111 basins that have been considered like ungauged, and for which it has been considered that only a number of N streamflow data for calibrating the model is known. Figure 5 shows mean results, but using the method of similar basins (also results correspond to use of GR4J model in each one of basins of the sample, and considering N streamflow data).

On the other hand, using the similar basin method, we considered the N streamflow data according to the aforementioned gauge conditions in the section of specific streamflow data. Figure 6 shows the results considering the days, in which the N streamflow data have the highest values.

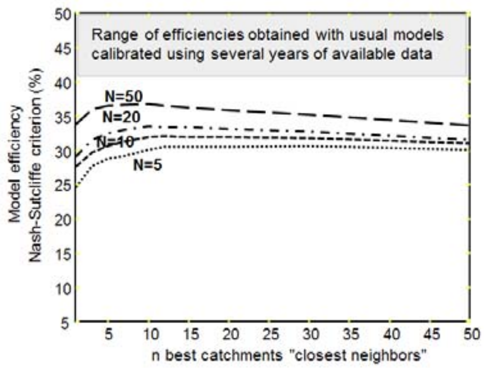

Figure 4: Parameter estimation using N point measurements in ***n*** hydrologic "closest neighbors" catchments.

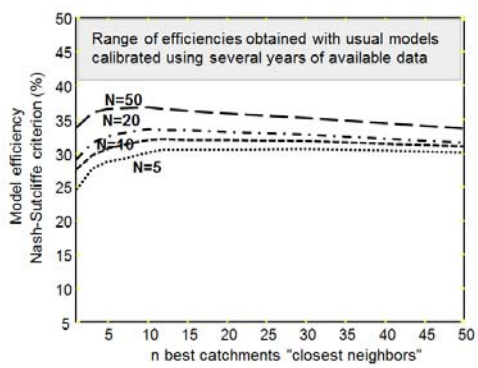

Figure 5: Parameter estimation using N point measurements in ***n*** hydrologic "closest neighbors" catchments.

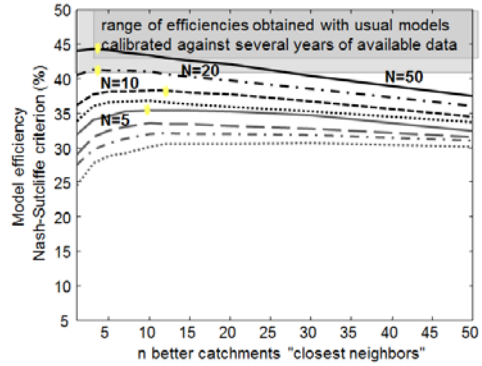

Figure 6: Sampling strategy using parameter estimation using N point measurements in ***n*** catchments hydrologic "closest neighbors".

Conclusions and future work

- In this paper, a combined approach was devised to simultaneously exploit regional information and local measurements.
- Interest on utilization of locally measured hydrometric data.
- The season of high waters is the best season of the year when it is more interesting to know the N streamflow data.
- The strong values of streamflow provide significant information on simulations.
- To define a sampling strategy considering the best climatic and season conditions.

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References

Edijatno, Nascimento, N. O., Yang, X., Makhlouf, Z. & Michel, C. (1999) GR3J a daily watershed model with three free parameters. Hydrol. Sci. J. 44(2), 263–277.

Klemeš, V. (1986), Operational testing of hydrological simulation models, Hydrol. Sci. J., 31, 13-24.

Nash, J. E. & J. V. Sutcliffe (1970) River flow forecasting through conceptual models. Part I - A discussion of principles., J. Hydrol., 27, 282-290.

Oudin, L., V. Andréassian, T. Mathevet, C. Perrin, & C. Michel (2006), Dynamic averaging of rainfall-runoff model simulations from complementary model parameterizations, Water Resour. Res., 42, W07410, doi: 07410.01029/02005WR004636.

Perrin, C., Michel, C. & Andréassian, V. (2003) Improvement of a parsimonious model for streamflow simulation. J. Hydrol. 279(1–4), 275–289.