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Method Article

Estimation of nonlinear parameters of the type 5 Muskingum model using SOS algorithm



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A B S T R A C T

The Symbiotic Organisms Search Algorithm (SOS) is used as an algorithm based on the social behavior of Symbiotic Organisms in optimization of Non-linear 5 model parameters for flood routing.

The data used in this article is 4 day observations from 30 November 2008 to 3 December 2008, which is located between the Molasani, and Ahwaz station on the Karun River.

The time series data used included river inflow, storage volume, and river outflow.

The results of the developed model with the Symbiotic Organisms Search Algorithm (SOS) were compared with the other Evolutionary algorithms including Genetic Algorithm (GA), and Harmony Search Algorithm (HS).

The analysis showed that the best solutions achieved from the objective function by the SOS, GA, and HS algorithms were 143052.02, 143252.35, and 142952.45, respectively. The processes of these datasets determined that the SOS algorithm was premiere to GA, and HS algorithms on the optimal flood routing river problem.

- In this article applied the Symbiotic Organisms Search Algorithm for Estimation of nonlinear parameters of the Muskingum hydrologic model of the Karun River located in Iran.
- This method can be useful for managers of water, and wastewater companies, water resource facilities for predicting the flood process downstream of the rivers.
- The present algorithm performs better than the other algorithms in the discussion of the optimization of Nonlinear 5 parameters of Muskingum model in flood routing.

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A R T I C L E I N F O

Method name: Symbiotic Organisms Search Algorithm (SOS)

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Specifications table

Subject Area:	Engineering
More specific subject area:	Optimization of problem using Symbiotic Organisms Search Algorithm.
Name and reference of original method:	Cheng M. Y., and Prayogo D. 2014. Symbiotic Organisms Search: A new metaheuristic optimization algorithm. <i>Computers & Structures</i> 139:98-112. 10.1016/j.compstruc.2014.03.007 .
Resource availability:	<ul style="list-style-type: none"> - Computer (Intel(R)CoreTMi7-7700 3.60-GHz 32 GB) - MATLAB software - Microsoft Excel Worksheet [3]

Method details

Flood or wave motion is an example of an unstable varying flow which be changed some specifications including its location in a water stream, the flow stage, and flow depth from one section to another, and from time to time. Flood routing is the sum of the operations by which the downstream hydrograph is determined by the upstream flow hydrograph. Understanding flood routing through mathematical methods helps designing engineer understand the effects of flow on the river, and surrounding areas [2].

The Muskingum method was first developed by US Army engineers for the Muskingum River Basin Flood Control Studies in Ohio [3].

During the last years, several Meta-Heuristic Algorithms (MAs) including Symbiotic Organisms Search (SOS) algorithm [4–6], Haris Hawks Optimization Algorithm [7], Grasshopper Optimization Algorithm (GOA) [8], have been applied for solving different optimization problems [9].

Recently, in order to optimally estimate the nonlinear parameters of the Muskingum model, especially the nonlinear model of the third type, many pro-exploration algorithms have been proposed, which include:

Nord algorithm [10], bat algorithm [11], and GOA algorithm [8].

Symbiotic Organisms Search (SOS) is one of the metaheuristic algorithms proposed based on interactive behavioral simulations (Cheng and Prayogo, 2014). Due to relying on other species to survive, creatures rarely isolate themselves. This relationship, which based on trust, is known as coexistence.

In the present study, the application of the SOS, as one of the new metaheuristic methods for estimating parameters of the nonlinear Muskingum model, has been investigated. To investigate the performance of the developed algorithm, the results of its implementation have been compared with other metaheuristic methods such as genetic algorithm (GA), and Harmony Search algorithm (HS). The coding of the SOS, GA, and HS algorithms was done in the MATLAB software (R2014a).

Symbiotic Organisms Search (SOS) algorithm

The Symbiotic Organisms Search Algorithm (SOS) as a nature-inspired optimization paradigm is proposed to solve optimization problems by Cheng et al. in 2014 [1]. This algorithm is a population-based search that is implemented in three main phases.

The SOS algorithm simulates the Symbiotic interactions between two species, so that a species searches for the most suitable one. Like other population-based algorithms, the SOS repeatedly creates a population of alternatives to find the optimal answer in the overall range of responses. The SOS algorithm begins with an initial population called the ecosystem. In the initial ecosystem, a group of creatures (decision variables) are randomly generated in the search space. Each living creature as a candidate for the solution that is associated with a particular fit is indicative of the degree of compliance with the target (the value of the objective function). All of the metaheuristic algorithms apply an alternate function to solve a problem in each iteration and create a new solution for subsequent iteration. For example, a standard genetic algorithm uses two integration and mutation functions for this purpose. The Harmonic Search algorithm suggests three rules including learning memory, step-by-step, and random selection to create a new harmony. Three phases including worker bees, observer bees, and honey bee are introduced in the ABC algorithm to find the best source

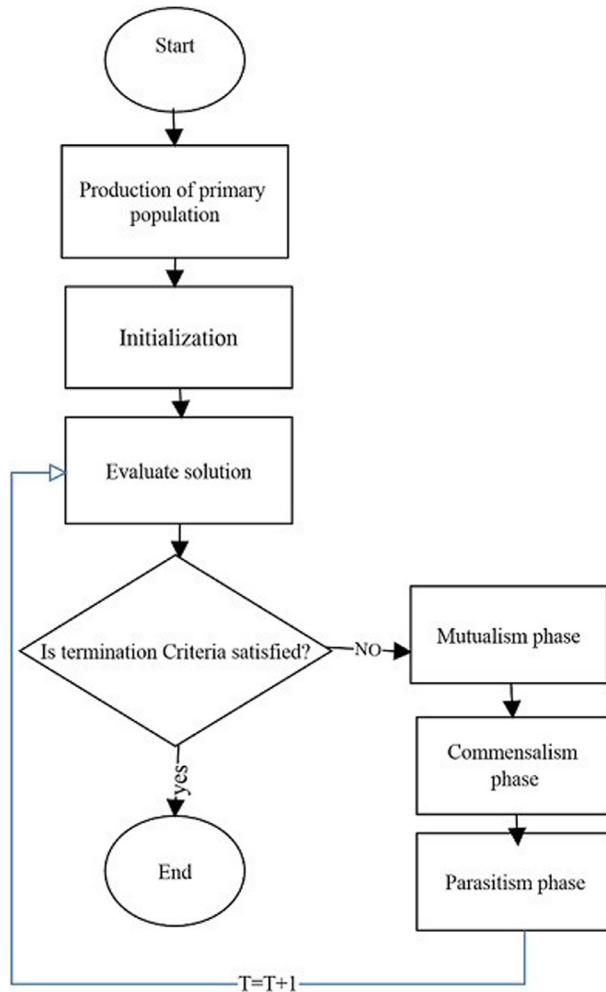


Fig. 1. Flowchart of the SOS algorithm (Cheng et al. [1]).

of food. In the SOS, the production of a new solution is governed by the recreation of biological interactions between the two existing ecosystems. Three phases of Mutualism, Commensalism and Parasitism are presented, which are similar to the biological interactive model in the real world.

The identity of each interaction is defined based on the type of interaction. Thus, the two-way interest represents the phase of mutualism, the one-sided profit shows the phase of commensalism and the disadvantage of one side and the losses of the other represent parasitism. In all phases, each entity randomly interacts with another one. This process continues until the end of the process (reaching the maximum number of repetitions). The general trend of the algorithm is as follows:

Initialization → Repetition → Mutualism → Commensalism → Parasitism → End process after reaching the maximum number of iterations

The general trend of the SOS algorithm is shown in Fig. 1.

Mutualism phase

An example for the mutualism phase is the relationship between flowers and bees, from which the two sides benefit. Bees fly among flowers, collecting nectar to make honey. This makes the bees

beneficial. This activity also benefits the flowers because bees distribute pollen during the process, which facilitates pollination. The SOS algorithm recreates this trend in the mutualism phase.

In the SOS, X_i is the creature that matches the i th member of the environment (the decision variable of the problem). The other one, which is X_j , is chosen randomly to interact with X_i . Both creatures take part in a mutual relationship with the purpose of the benefits of two-way survival in the ecosystem. New solutions for X_i , and X_j are calculated based on the mutual collaboration between X_i , and X_j using equations (1) and (2):

$$X_{i_{new}} = X_i + \text{rand}(0, 1) \times (X_{best} - \text{Mutual} - \text{Vector} \times \text{BF}_1) \quad (1)$$

$$X_{j_{new}} = X_j + \text{rand}(0, 1) \times (X_{best} - \text{Mutual} - \text{Vector} \times \text{BF}_2) \quad (2)$$

$$\text{Mutual} - \text{Vector} = \frac{X_i + X_j}{2} \quad (3)$$

In the above equations, $\text{rand}(0, 1)$ is a vector of random numbers. The role of BF_1 and BF_2 is as follows:

In nature, some interactive relationships may have more profits for one side than on the other. In other words, the creature A may receive more benefit than creature B. Meanwhile, creature B is content with its benefits or it does not make significant gains. Here, the benefit factor (BF_1 , and BF_2) are defined randomly in Eqs. (1) and (2). These factors represent the level of benefits available for each creature, whether a creature benefits fully or partly from this relationship.

Eq. (3) shows the cross vector and the communication characteristic between X_i , and X_j . A part of the relationship ($X_{best} - \text{Mutual} - \text{Vector} \times \text{BF}_1$) refers to the mutual effect; the extent to which the goal of survival will be achieved for both sides through this mutualism and collaboration. Under the mutualism phase, all creatures are faced with increasing ability and adaptability in the environment. Some use the symbiotic relationship with another to increase the survival chance. The goal here is to get X_{best} because X_{best} has the highest degree of compliance with the global optimum point. Therefore, X_{best} (global solution) is used to model the highest degree of adaptation as the final point and to increase the fit of both creatures. Ultimately, the creature will adapt when its new fitness is better than previous mutualism.

Phase of commensalism

Commensalism is the relationship between sticky fish, and shark. The sticky fish sticks to the shark and eats the remaining food, so it gains benefit. The shark does not benefit from the sticky fish's activity, or it gets the least benefit. Similar to the two-way interaction mode, creature X_j is randomly selected from the ecosystem associated with the creature X_i . In this situation, creature X_i is trying to get the most out of this relationship, while the X_j does not benefit or endure harm in this regard. The new solution X_i is calculated from (4) according to the commensalism symbiosis between creature X_i and X_j . According to the laws governing the nature, creature X_i only adapts when its new fitness is better than its fitness before the interaction.

The part ($X_{best} - X_j$) refers to the benefit of X_j to help X_i to increase its chances of surviving in the current ecosystem.

$$X_{i_{new}} = X_i + \text{rand}(-1, 1) \times (X_{best} - X_j) \quad (4)$$

Parasitic phase

An example of a parasitic phase is the Plasmodium parasite, which is used by the Anopheles mosquito in human body, and human body plays the role of a host for it. While the parasite grows, and breeds in the human body, the host may have malaria, and therefore die.

In the SOS, the creature X_i plays the role of Anopheles mosquitoes by creating an artificial parasite called "parasite vector". The parasite vector is created in the search space with the multiplication of creature X_i , and then changes are made based on a random selection using a random number.

Creature X_j is the host and is randomly selected from the ecosystem. The parasite vector attempts to move X_j in the ecosystem. Both creatures (X_i and X_jX_j) are evaluated by measuring the degree of fitness (the amount of their target function). If the parasite vector is more productive, it will kill creature X_j , and seize its position in the ecosystem, but if the fitness of X_j is greater, X_j will be immune to the parasite, and the parasite vector will not have the ability to live in that ecosystem, and it will have no place in that ecosystem.

Optimization model formulation

The improved version of this model is first proposed by Bozorg Hadad et al. (2015), which is called the Non-linear model of type 5 (NL5) [12]. The procedure of getting the NL5 model is explained below. The NL5 method was originally offered by Chow (1973) [13].

$$S_{in} = b \left(\frac{I}{a_1} \right)^{\frac{m}{n_1}} \quad (5)$$

$$S_{out} = b \left(\frac{O}{a_2} \right)^{\frac{m}{n_2}} \quad (6)$$

Where a_1 , and n_1 correspond to the depth – flow relation of the river upstream; a_2 and n_2 reveal the depth – flow specifications of the downstream part. By substitution of S_{in} , and S_{out} , from Eqs. (1), and (2) in $S = [XS_{in} + (1-X)S_{out}]^\beta$, and simplifying the conclusion of the work of Eq. (3) is produced.

$$S = K[X(C_1I^{\alpha_1}) + (1-X)(C_2O^{\alpha_2})]^\beta \quad (NL5) \quad (7)$$

$$K = b^\beta \quad (8)$$

$$\alpha_1 = \frac{m}{n_1} \quad (9)$$

$$\alpha_2 = \frac{m}{n_2} \quad (10)$$

$$C_1 = \left(\frac{1}{a_1} \right)^{\alpha_1} \quad (11)$$

$$C_2 = \left(\frac{1}{a_2} \right)^{\alpha_2} \quad (12)$$

Where I and O are the inflow and outflow rate (m^3/s), K is the reserve constant which is larger than 0. X : The dimensionless weight coefficient indicating the relative effects of the input and output flow and the value for the river is between 0 and 0.3.

α_1 , α_2 and β : The exponential parameters that are zero. C_1 , and C_2 : are fixed parameters that are zero.

The Non-Linear of type 5 model has 7 parameters X , K , α_1 , α_2 , C_1 , C_2 , β . In this sense, one of the other Non-linear models is more complex. These parameters are optimized using optimization models.

Simulation method of the suggested NL5 model

This paper utilizes Tung's (1985) [14] flood routing procedure, also employed by Geem (2006) [15], to Simulate flood routing using the NL5 model. In the NL5 model, the observed inflow, computed outflow, and computed storage at i th time period are I_i , \hat{O}_i , and S_i , respectively, Where $i=0, 1, 2, \dots, N$ denotes the simulation time periods. The steps of the proposed NL5 flood simulation model are as follows:

Step 1: Assume values for the seven hydrologic parameters (X , K , α_1 , α_2 , β , C_1 , C_2).

$$S_0 = K[X(C_1I^{\alpha_1}) + (1-X)(C_2O_0^{\alpha_2})]^\beta \quad i = 0 \quad (13)$$

Table 1
Values of used algorithms parameters for problem.

SOS (2014)	parameter	Max_iteration	Dim	SearchAgents	-	-
	Value	1000	7	100	-	-
GA (Base)	parameter	Max_iteration	Number of variables	Number of genes	Mutation rate	Crossover rate
	Value	1000	7	100	0.02	0.6
HS (2002)	parameter	Max_iteration	Number of variables	Population Size	HMCR	PAR
	Value	1000	7	100	0.2	0.2

Step 2: Compute the initial storage S_0 , letting the initial Computed outflow be equal to initial Observed inflow ($\hat{O}_0=I_0$):

$$\frac{\Delta S_i}{\Delta t} = I_i \left\{ \left[\frac{1}{C_2(1-X)} \right] \left(\frac{S_i}{K} \right)^{\frac{1}{\beta}} - \left[\frac{1}{C_2(1-X)} \right] [X(C_1 I^{\alpha_1})] \right\}^{\frac{1}{\alpha_2}} \tag{14}$$

Step 3: Compute the time rate of change of the storage volume at time period i (starting with $i=1$):

$$S_i = S_{i-1} + \Delta t \left(\frac{\Delta S_{i-1}}{\Delta t} \right) \tag{15}$$

Step 4: Compute the storage at time i :

Step 5: Compute the outflow at time period i :

$$\hat{O}_i = \left\{ \left[\frac{1}{C_2(1-X)} \right] \left(\frac{S_i}{K} \right)^{\frac{1}{\beta}} - \left[\frac{1}{C_2(1-X)} \right] [X(C_1 I_{i-1}^{\alpha_1})] \right\}^{\frac{1}{\alpha_2}} \tag{16}$$

Notice that I_{i-1} rather than I_i is used in Eq. (16).

Step 6: Increment the index i by 1 and repeat Steps (3)–(5) until the simulation has reached time N .

Objective function of the Karun River is as follows:

$$Min(SSQ) = \sum_{t=1}^N (O_t - O_{ct})^2 \tag{17}$$

In this paper, the objective function is considered as minimizing the sum of squares of residuals (SSQ) between actual, and routed outputs according to Eq. (13) to estimate the optimal values of X , K , α_1 , α_2 , β , C_1 and C_2 parameters in the Muskingum model.

Where $O_{c,t}$ is the volume of flood discharge routed (computational) at time t , and N is the number of times steps of the flood routing [10,11].

Case study

In this paper, the Karun River were investigated as the case study. The Karun River are evaluated to show the performance of modified NL5 by the SOS algorithm. The Karun River information includes a time series river outflow, storage volume, and river inflow for 4 days (30 November 2008 to 3 December 2008).

Fig. 2 shows the location of the Karun River in the geographical map and Fig. 3 displays the time series hydrological dataset consists of river inflow, river observed outflow, and river outflow routed by algorithms for the Karun River.

Table 1 displays the values of used algorithms parameters for the flood routing problem. Table 2 explains the objective value of objective functions and the average CPU run time obtained by algorithms for the Karun River problem. Fig. 4 shows the scatter of observational and simulated data in Karun River.

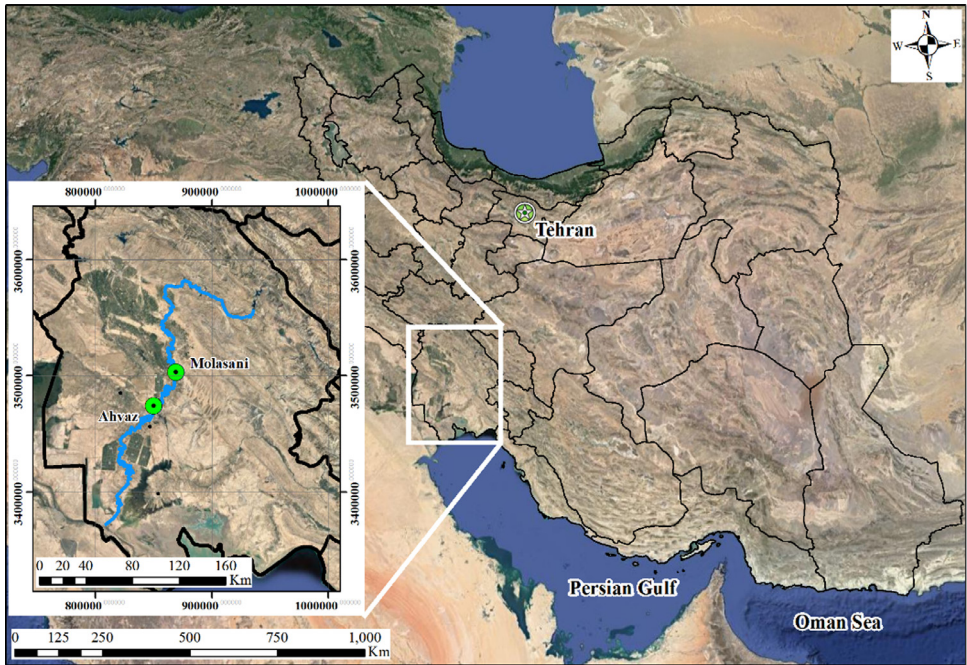


Fig. 2. Location of the Karun River in the Ahvaz Province (SouthWestern of Iran).

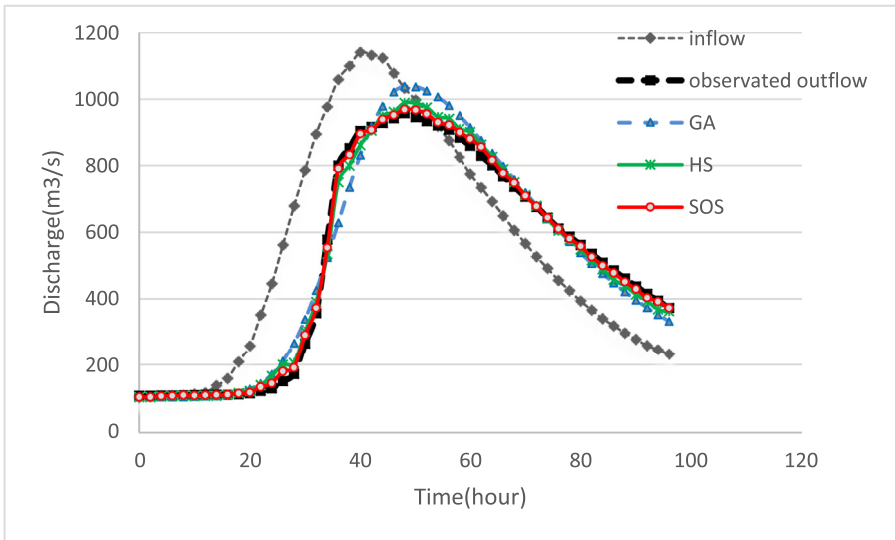
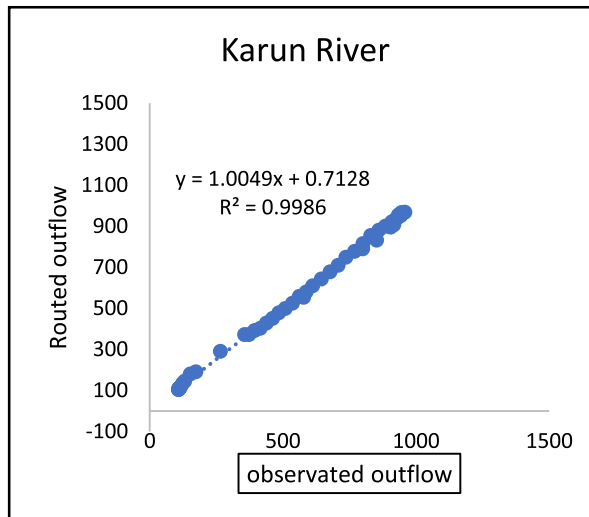


Fig. 3. Flood hydrographic diagrams, including inflow hydrographs, observational output hydrographs, and output hydrographs routed by meta-heuristic algorithms for a period of 4 days (from 30 November 2008 to 3 December 2008).

Table 2

Analysis of the objective function of the problem with meta-heuristic algorithms for the Karun River.

Number of runs	SOS (2014)		HS (2002)		GA (Base)	
	Optimal value	CPU time (s)	Optimal value	CPU time (s)	Optimal value	CPU time (s)
1	143052.02	4.17	142952.45	6.76	143252.35	11.21
2	145364.14	3.98	153299.27	6.75	143299.23	11.56
3	159842.01	3.84	162615.52	6.71	182615.36	15.47
4	193287.34	3.75	145062.25	6.62	144962.45	11.57
5	149826.79	3.65	154534.12	6.61	164534.12	11.59
6	184792.45	3.77	173764.19	6.75	143764.18	12.28
7	144561.33	3.82	173240.36	6.73	163240.56	11.59
8	161268.71	4.05	203420.61	6.80	143400.62	11.42
9	151269.30	4.02	186406.44	6.69	286506.84	14.49
10	149879.91	3.99	157597.37	6.70	147617.36	11.35
Best	143052.022		142952.45		143252.35	
Worst	193287.34		203420.61		28650684	
Average	158314.4		165289.3		166319.3	
Best CPU time (s)	3.65		6.61		11.21	

**Fig. 4.** Scatter of observational and simulated data in karun River.

Results and discussion

The nonlinear Muskingum model parameters estimation using trial, and error is a difficult process. Over the past two decades, different methods have been used to estimate these parameters. Metaheuristic methods have been one of the solutions that have succeeded in estimating these parameters. In this study, the search algorithm for symbiotic creatures has been used to estimate the parameters of the nonlinear Muskingum model. In order to study the performance of the search algorithm for symbiotic creatures, the results of its implementation have been compared with other metaheuristic algorithms such as GA, and HS. For the purpose of estimating the optimal values of nonlinear Muskingum parameters in flood routing, one case i.e. Karun River were investigated. In order to evaluate the algorithms, the statistical indices, SSQ, and R2 were used. the statistical parameters obtained for the Karun River by the SOS algorithm are SSQ (143052.02), and R² (0.9986),

Table 3
Friedman rank test for meta-heuristic algorithms in the Karun River.

Algorithm	Mean rank	Rank	Std. Deviation
SOS (2014)	1.92	1	320.58
HS (2002)	1.98	2	322.05
GA (Base)	2.08	3	330.56

which indicates the proper functioning of the search algorithm for symbiotic creatures in estimating the values optimum parameters of the nonlinear Muskingum model in flood routing.

At the end, The Friedman-test results of the 3 algorithms are listed in [Table 3](#). The results of the peer algorithms, and their rankings are listed in ascending order (the lower the better). It can be seen from [Table 3](#) that SOS offers the best overall performance on the cost functions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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