Evaluation of SURM and GR4J rainfall runoff models, for the Nazloo River catchment in northwest of Iran

Hossein Rezaie1, Anahita Jabbari2, Javad Behmanesh3, Ben Jarihani4 and Behzad Hessari5

1Associate professor in Department of Water Engineering, Urmia University, Urmia, Iran
2PhD candidate of water engineering, Urmia University, Urmia, Iran
3Associate professor in Department of Water Engineering, Urmia University, Urmia, Iran
4Post-doctoral Research fellow, University of the Sunshine Coast, Queensland, Australia
5Assistant professor in Department of Water Engineering, Urmia University, Urmia, Iran

ABSTRACT

The right hydrological model selection is an important task in today's hectic race of developing powers of modelling platforms. In this regard, there is a newly developed modelling system which meets all needs of Integrated Water Resources Management practices, under a same modelling platform which nowadays is a very important lost part of the management cycle. Source Integrated Modelling System (IMS) as a very comprehensive product of CRCCH (Cooperative Research Center for Catchment Hydrology) Australia is a new attempt in order to model the whole catchment procedures in one platform. In the current study the two of most well-known rainfall runoff (RR) models from modelling component of the Source have been selected in order to compare their application and the possibility of applying Source package in the different climate from Australia. The GR4J and SURM models have been studied by daily input data, and results showed that the GR4J model with a NSE (Nash–Sutcliffe Efficiency) amount about 0.62 represents a better simulation of the catchment. At the same time the survey form was designed and sent to hydrological modelers in order to ask some of the most challenging RR modelling problems. The results illustrated that the NSE coefficient is the most popular efficiency criterion for modelling practices and choosing the GR4J model parameter sets as preferred parameters is in agreement with survey form results to. The overall outcome is that the Source platform can be applied for other climates than Australia as well.

Key words: Source integrated Modelling System –Rainfall Runoff Modelling– Urmia Lake basin – Survey Form

Corresponding author: Anahita Jabbari
e-mail: anahita.jabbari@yahoo.com

Received: 12 September 2016
Accepted: 16 December 2016

INTRODUCTION

Today, hydrological models have become widely used for gaining the proper solutions for various aquatic and environmental problems of catchments. The computational rainfall runoff (RR) models have the most application in hydrological practices and are the most crucial part of the water resources management procedure. Along with the rapid growth of the computing capabilities and modelling powers, and availability of new data sources such as remote sensing, the choose of appropriate model has become important task to produce the acceptable output by minimum data requirement and in lower time. Nearly 150 years ago the first widely used RR model was developed by the Irish engineer Thomas James Muhaney which was named rational method (Beven 2011), but Stanford catchment model (SMW) is the first attempt for numerical modelling of the catchments (Crawford 1966). Ever since then, a rapid improvement has occurred in developing catchment models. Today there are numerous models that can be used to address similar problem in a catchment. However the right model selection became the hot topic of modelling practices especially in data sparse environments. This decision is even more difficult under the different circumstances of modelling practices, as a result nowadays one of the most important factors in managing the water systems is the ability to gather all of the management tools in one platform. Along with the growing need to identify similar modelling bases, As a very new modelling platform, eWater Source, the Australia’s national hydrological modelling platform is presented to address lots of water management problems. Source Integrated Modelling System (IMS) gathers the all required components of catchment water resources management in one frame. It includes three modes (catchment runoff, river management and river operations) for different applications which have been presented in a very new researches (Dutta, Wilson et al. 2013, Rassam, Peeters et al. 2013, Hughes, Dutta et al. 2014, Peeters, Podger et al. 2014, Podger, Cuddy et al. 2014, Turner, Markow et al. 2014). The catchment component of the Source system contains some of the most famous conceptual rainfall runoff models (Belgado 2013). There are eleven choices of runoff generation options in Source, in order to simulate RR processes. This is one of the most important advantages of Source that run multiple models in the same platform.

The GR4J (Génie Rural) model is the last modified version of the GR3J model developed by Edijatno (1989), in a French Research Center. Traore compared the two GR2J and GR4J models on the Koulountou river basin (Vieux Boukhaly Traore 2014). This model Due to its fully automatic procedure and lower number of parameters to be optimized, has a simple calibration procedure (Perrin and Littlewood 2000). The SURM (Simple Urban Runoff Model) is a simplified version of well-known SimHyd (Simple Hydrology) model (Chiew 2002). The model allows for separate runoff generation processes on impervious and pervious portions of a catchment. It is a default model of Music package version 4 (Tony Weber 2010) another eWater product which is mainly target the urban floods. It is a widely used model through Australia but there are few applications of it have been reported from other countries (Chiew 1997).
MATERIALS AND METHODS

Study site and data sets

The study site is in the Urmia Lake Basin (ULB) one of the most important water bodies in the area and the second largest salt lake in the world. Due to its important hydrologic component at the region, the balance of input and output of the lake has been disturbed. The ULB is an internally draining catchment with two main water inputs, river discharge and direct rainfall on the lake surface. The mean annual volume of all the water input to the lake basin is about 17 Billion cubic meters which about 10.8 Billion cubic meters of it returns to atmosphere due the evaporation. So the remaining volume about 6.2 Billion cubic meters is the whole available water at the current circumstances. All above mentioned factors causes the shrinkage of the lake level most rapidly at the recent 10 years. The ecologic water level of the lake is 1274.1 m and the maximum observed level was 1278.41 m in the historic period from 1967.

There are 15 rivers which reach to the lake and the Nazloo River is one of them at the west side of the lake. This catchment is located at 44° 24´ and 45° 53´ longitudes and 37° 30´ and 37° 58´ latitudes. The maximum and minimum elevations of the catchment are 1291 m and 3600 m, respectively. This river is one of the main rivers draining into the ULB (Fig. 1). The total area of the catchment is about 2020 km² which the area about 505 km² of it is located in Turkey, that are mountainous regions with the most snow fall and the least available climate measured data(Hessari 2010). The catchment outlet is at the Abajaloo hydrometry station with the elevation of 1290 m. The upstream basin is the most agricultural land use dominant region in all over the catchment. Indeed the most agricultural activities take place between Tapik (where the head flow to the Abajaloo sub basin is measured), located about 1400 m above the sea level, and Abajaloo stations. Figure 1 illustrates the case study catchment and its condition on the map.

The input data requirements are the same in both the daily rainfall for the studied catchment was collected from three rain gauges with most overlapped historical data with 16 years daily data, from September 23th 1997 up to September 22th 2013. The rainfall data of all three stations were averaged through all catchment areas by using Thiessen method. Then, in order to have the best representation of catchment processes, the rainfall data was modified in comparison with long term monthly data. Because of poor data availability in region, it was assumed that the mean monthly data for a long term period should be close to the mean daily data for each month, so the data were modified...
considering corrective coefficients. The daily evapotranspiration was calculated from evaporation data as well.

**Model description**

**Source integrated modelling system and its catchment runoff component**

For the current study case although it is better to use distributed physically based models but in the aspect of available data in the region we need the conceptual models platform like the one eWater has been developed. Source IMS has a capability to relate several components of catchments using a comprehensive node-link net. It allows users to understand the complex relationships between catchment elements in a much more simple way. The integration of multiple modules in one package is another advantage of Source. The components of Source are as follows: (Littlewood, Down et al. 1997, Post and Jakeman 1999, Barnett et al. 2004), GR4J (Perrin, Michel et al. 2003), and SURM, as a simplified version of SimHyd model. GR4J and SURM models both are daily, conceptual rainfall runoff models which belong to the family of explicit soil moisture accounting models (ESMA), varied in the number of storage elements used, the functions controlling the exchanges, and consequently in the number and type of parameters required (O’Connell 1991). So the all differences between these models related to the selected model factors that make them more complex or simple to use. As a result there is no separation between the rainfalls that is occurred on pervious or impervious surfaces. The model then goes through the series of two vertically located stores and calculates the equations of model. Originally the model had four parameters of $X_1$, $X_2$, $X_3$, and $X_4$. However in Source the GR4J includes six parameters, all four parameters above plus additional $C$ and $K$ parameters. These two parameters are used to separate the base flow and quick flow in output results without any changes in model simulation results. Using these two parameters are optional and leaving them in their default values as zero will terminates this operation of model, and all runoff will be proposed as quick flow.

**Table 2 illustrates the GR4J model parameters, and their descriptions. The detailed processes of the model and its equations are presented elsewhere (Perrin and Littlewood 2000, Perrin, Michel et al. 2003).**

**Model setup**

Source supports two types of model setup: geographic and schematic. In order to model the RR processes of a catchment, the catchment is defined through geographic scenario by following a step by step procedure. First, the catchment DEM is loaded to the source. The common input data for all models are daily rainfall and temperature data as an extra input. Then the model was run over the configured run time. It was the all single analysis procedure. At the end of this step the node-link system is generated and the relation between sub catchments and the water transmitting links are defined. Figure 4 shows the geographic and schematic representation of the Nazloo River catchment.

The schematic view is best for understanding the node-link relations and identifying the node types in catchment. The next step is configuring the catchment for RR modelling. The models are selected at this step and the input data is loaded to the model. The common input data for all models are daily rainfall and evapotranspiration, but some models require daily temperature data as an extra input. Then the model was run over the configured run time. It was the all single analysis procedure. In the current study two of the most well-known models were selected in order to compare the catchment behavior towards
each of them. The SURM model which is the default model for MUSIC package by CRC catchment hydrology and GR4J catchment model which was used numerous times in successful researches although it’s simple structure (eWater 2013).

Calibration analysis is the next step in RR modelling. The observed daily runoff data in order to calibrate the models is loaded at this stage. The data is collected from Abajalo station at the outlet of the Nazloo River, after the main agricultural water use in the catchment and right before the lake estuary (Figure 1). This station is the last station which the entire catchment water yield crosses from that point and there are no noticeable agricultural activities after that point. So the recorded runoff represents all water yield of the catchment reaches to the lake.

The other advantage of Source system is definition of Meta parameters which enables the user to group the parameters with the same changing domain in order to run the calibration stage more easily. The possibility of auto grouping the parameters for producing Meta parameters is another facility of the package. All same named parameters were defined as Meta parameters because the selected models were applied for the entire of catchment regardless of functional units or catchments.

So in calibration stage the models are calibrated by the use of different objective functions and optimization methods. The results of calibrated method are the reported numbers of Meta parameters and the table of all calibrated parameters of each calibration. The simulation is then applied at the last stage by using the best parameter set which is identified by objective functions. Source provides lots of facilities to represent output data, such as tables, figures and statistical properties of observed and simulated flows.

**Efficiency assessment and survey form**

Source provides four optimization method options plus manual optimization possibility, as follows: Shuffled Complex Evolution (SCE), Uniform Random Sampling, Rosenbrock and SCE-then-Rosenbrock. As a global widely used method, we chose SCE in current study which has been widely used and tested in other studies (Wu and Zhu 2006, Goswami and O’CONNOR 2007, Muttill and Jayawardena 2008, Seong, Her et al. 2015, Zhang, Wang et al. 2015). SCE (Duan, Sorooshian et al. 1992, Duan, Gupta et al. 1993, Duan, Sorooshian et al. 1994) is the most widely used optimization method for calibrating catchment models in recent years (Shoemaker, Regis et al. 2007).

Moreover, several objective functions which may be selected by the modeler in calibration stage, are available in Source. The combination of all objective elements produces seven objective functions choices as follows: Nash-Sutcliffe Efficiency (NSE) Daily, NSE Monthly, NSE Daily and Bias Penalty, NSE Daily and Flow Duration, NSE Daily and log Flow Duration, Minimize Absolute Bias, NSE Daily and Bias Penalty. Source provides lots of facilities to represent output data, such as tables, figures and statistical properties of observed and simulated flows.

**RESULTS**

**SURM model**

Although the Source integrated system was first developed to meet the needs of Australian water management problems, but this is an advisable system for other catchment systems. The two models were both calibrated through optimization methods by using the best parameter set which was identified by objective functions. Source provides lots of facilities to represent output data, such as tables, figures and statistical properties of observed and simulated flows.

**GR4J model**

The calibration results for best calibrated model in GR4J model is illustrated by the 0.62 as the best amount for NSE daily objective function. The optimization method which was used is Shuffled Complex Evolution. Figure 6 shows the comparison between observed and simulated discharges. The best parameters set with NSE daily objective function were recorded as follows: X1: 397.856, X2: 3.271, X3: 20.033, X4: 1.481, C = 0.443 and K: 0.783. Approximately all the parameters are in 80% confidence interval except the X2 moderate bias from the upper range of the 80% interval.

**DISCUSSION**

As it mentioned above, the SURM model is originally an RR model for urban areas (CRCCH 2010). The Nazloo River catchment is a combination of urban and agricultural and other land uses, so the weaker performance of SURM in comparison with GR4J may be described in this way.

The other important difference between two models performances rather than the NSE values is a time lag between the observed and simulated curves in SURM model simulated time series. The simulation performance of both models are acceptable despite of poor data availability in the region, but generally the GR4J is preferred for few reasons; (i) the structure of model is so simple at the same time is very comprehensive and sufficient for the region’s needs, (ii) the NSE daily coefficient was obtained over 0.6 which is acceptable range for daily runoff simulations which is reported as a sufficient amount in many studies, as a result the performance of GR4J model in current study is acceptable. The other remarkable point is the poor estimation of peak flows by both models. The GR4J model as a preferred one totally underestimates the peak flows and the NSE daily coefficient is far from its perfect value (+1) generally because of this underestimation. The main reason is that the Nazloo River Catchment is a generally mountainous catchment with noticeable snow fall at winter months, so as a result snow melt generated is dominant source of discharge during spring months (March – May). The snow water in spring is the main contributor to stream flow volume, however there is no snow depth measurement information available to consider as input to model. Considering the input rainfall data are substantially lower than actual values, the peak flows were underestimated by model especially during spring months.

while another study (Yu and Zhu 2014) adopted their reported ranges for daily simulations They have found that NSE values over 0.7 show acceptable performance for daily simulations.
Figure 7 illustrates the two pictures of a same river reach, at Nazloo River, very close to the river outlet, (about 2 km), which were taken in a two weeks interval in month April 2016. Picture (a) was taken two weeks ahead, and both are for spring months. The average occurred rainfall on that time period was as little as ignorable in the all catchment, but there was a significant occurrence rainfall on that time period. The complexity level was ranged from 1 to 10, which 10 was the most complex model. The complexity level was determined by NSE daily coefficient) showed significant difference between two models when applied in a same river catchment. So the overall results illustrate the excellence of GR4J model in comparison with SURM model in the case of Nazloo catchment. So the overall results illustrate the excellence of GR4J models, however, the model performance, (as the last factor was determined by NSE daily coefficient) showed significant difference between two models when applied in a same river catchment. So the overall results illustrate the excellence of GR4J model in comparison with SURM model in the case of Nazloo River Catchment RR modelling.

The model choice in current study was performed based on comprehensive series on model choice guide from CRCCH Australia(eWater 2005a). The guideline indicates choosing the best model on the base of three important parameters: (i) model performance, (ii) model complexity, and (iii) data availability. The current study was performed at the same catchment with the same data availability. Moreover, the data requirements and user interface for both models are the same due to applying Source integrated modelling system. The model complexity is almost identical with SURM having slightly more complex functions. The survey form also indicated the same result. The complexity level was ranged from 1 to 10, which 10 was the most complex model. Although the results show similar complexity level for these two models, however, the model performance, (as the last factor was determined by NSE daily coefficient) showed significant difference between two models when applied in a same river catchment. So the overall results illustrate the excellence of GR4J model in comparison with SURM model in the case of Nazloo River Catchment RR modelling.

Table 1: The parameters definition of the SURM model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Units</th>
<th>Default</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>bfac</td>
<td>Ground water to Base flow coefficient</td>
<td></td>
<td>0.05</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Coeff</td>
<td>Infiltration coefficient</td>
<td></td>
<td>200</td>
<td>0</td>
<td>400</td>
</tr>
<tr>
<td>seep</td>
<td>Deep seepage</td>
<td></td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Frac. Field capacity</td>
<td>The field capacity, expressed as a fraction of the maximum soil moisture capacity</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>IMPC</td>
<td>Impervious fraction</td>
<td></td>
<td>0.5</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>GW</td>
<td>Initial groundwater level</td>
<td>m</td>
<td>0</td>
<td>0</td>
<td>500</td>
</tr>
<tr>
<td>initial moisture</td>
<td>Initial soil moisture content, as a fraction of the maximum store capacity</td>
<td>-</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Rfac</td>
<td>Recharge coefficient</td>
<td>-</td>
<td>0.25</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>SMSC</td>
<td>Soil moisture store capacity</td>
<td>mm</td>
<td>120</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>sq</td>
<td>Infiltration loss exponent</td>
<td></td>
<td>1</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>thres</td>
<td>Impervious threshold</td>
<td>mm</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 2: The parameters of GR4J model

<table>
<thead>
<tr>
<th>parameter</th>
<th>description</th>
<th>units</th>
<th>median value</th>
<th>80% confidence interval</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1</td>
<td>maximum capacity of production store</td>
<td>mm</td>
<td>350</td>
<td>100-1200</td>
<td>1</td>
<td>1500</td>
</tr>
<tr>
<td>X2</td>
<td>groundwater exchange coefficient</td>
<td>mm</td>
<td>0</td>
<td>-5 to 3</td>
<td>-10</td>
<td>5</td>
</tr>
<tr>
<td>X3</td>
<td>one day ahead maximum capacity of the routing store</td>
<td>mm</td>
<td>90</td>
<td>20-300</td>
<td>1</td>
<td>500</td>
</tr>
<tr>
<td>X4</td>
<td>time base of unit hydrograph UH1</td>
<td>days</td>
<td>1.7</td>
<td>1.1-2.9</td>
<td>0.5</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>base flow filtering parameter</td>
<td></td>
<td>0</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>K</td>
<td>base flow filtering parameter</td>
<td></td>
<td>0</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3: the statistical characteristics of observed and simulated runoff time series

<table>
<thead>
<tr>
<th>Stream flow</th>
<th>Minimum (m$^3$/s)</th>
<th>Maximum (m$^3$/s)</th>
<th>Mean (m$^3$/s)</th>
<th>Median (m$^3$/s)</th>
<th>Std. deviation (m$^3$/s)</th>
<th>Skew</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed</td>
<td>0</td>
<td>108.5</td>
<td>4.8</td>
<td>2.9</td>
<td>6.2</td>
<td>4.3</td>
</tr>
<tr>
<td>GR4J</td>
<td>0</td>
<td>67.1</td>
<td>3.6</td>
<td>2.54</td>
<td>4.8</td>
<td>3.3</td>
</tr>
<tr>
<td>SURM</td>
<td>0</td>
<td>56.2</td>
<td>4.03</td>
<td>1.9</td>
<td>5.2</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Figure 5: the observed (red) and simulated (blue) discharges by SURM model

Figure 6: The observed (Red) and stimulated blue discharges by GR 4j Model

Figure 7: the river reach very close to catchment outlet, pictures a (right) was taken two weeks before picture b (end of April 2016)

REFERENCES


21) eWater (2005a). SERIES ON MODEL CHOICE, Designed to assist you to better understand catchment modelling and model selection. eWater Ltd, cooperative research center for catchment hydrology.

22) eWater (2005b). SERIES ON MODEL CHOICE Designed to assist you to better understand catchment modelling and model selection2: Water quality models- sediments and nutrients. eWater Ltd, cooperative research center for catchment hydrology.


large urban water resources system. Water Resources Research 50(4): 3553-3567.


