Simulation of Rainfall-Runoff on Gharesou Watershed Using SWAT Model

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Abstract
SWAT Model is a promising tool to simulate stream flows, sediment and quality variables (nitrogen and phosphorus...) in watershed areas. Rainfall - runoff Simulation in many hydrological studies, such as investigating effect of climate changes on the river flow, flood prediction and planning of water resources, is very important. SWAT Model is a semi distributed time series model with physical basis, and is able to connect with GIS; hence vast volumes of data (information of layers such as land use, soil map and the DEM using GIS capabilities) could be simulated. The main purpose of the present study is testing SWAT Model as a simulator of flow at the catchment scale. Accordingly, the model was applied for Gharesou catchment, and parameters were optimized using SWAT-CUP optimizer. The model was calibrated for the years 1992-1996 and validated for the years 1998-2000. The coefficient of determination ($R^2$) for monthly stream flow was 0.82 and Nash-Sutcliffe coefficient ($E_{NS}$) was 0.8 and in the calibration and validation periods these coefficients were 0.77 and 0.73 respectively. These results indicated the success of the SWAT model, using optimized parameters, for the stream flow simulation in Gharesou catchment.

Keywords: Continuous distributed hydrologic model, SWAT, GIS, Calibration

1 – Introduction
Watershed hydrology simulation models are used to better understand the role of hydrological processes that control the movement of surface and sub-surface water. They also serve as assessment tools in decision making with respect to water quantity and quality results. Watershed models can be classified as: Empirical models versus Physical model, Event Base versus continuous, and Lumped versus Distributed parameter models. The choice of a suitable model depends on factors such as the ability to simulate design variables (surface runoff, groundwater, sediment load and etc.), accuracy, data availability and spatial and temporal scales (Singh 1995; Jothityangkoon et al. 2001; Leavesley 2002).
Spatial scale is one of the key problems in modeling. Validity of hydrologic models depends on making good distribution location specified by the basin is the model inputs. Lumped Models consider a basin as a unit for computations, and basin parameters are considered as an average of the total basin. Lumped models simulate only hydrological basin response in the basin outputs without considering the benefits of having distributed data. Showing the inherent spatial shifts of basin characteristics makes the distributed models more appropriate than lumped models. Distributed parameter models divide the basin into sub-basins (sub-basin, hydrologic response unit and network) for the purpose of simulating and specify their own parameters and characteristics for each unit. Recently the description and extraction of channel networks were presented by the help of Geographic Information Systems (GIS) and digital elevation models (DEMs) (Band and Moore 1995).
Spatial and temporal variations are crucial factors in the watershed modeling process; vast volume of
information, and spatial and temporal data, necessitate the application of new innovations such as remote sensing (RS), and make the Geographic Information System (GIS) inevitable. GISs have been created for processing and analyzing the information for which spatial position is important.

Another important feature of GIS is spatially establishing relation among the different layers of information. Watershed hydrology modeling is a widespread spatial phenomenon, so GIS play an important role in its simulation (Moore et al. 1988).

Hydrologic models with different physical basis are designed for rainfall-runoff simulation under different spatial and temporal scales. A number of models attempt to consider the heterogeneity of distribution topography, land use, soil characteristics, precipitation and evapotranspiration in the basin level.

Soil and Water Assessment Tool model (SWAT) is one of the basin models that play an important role in the analysis of land management changes on water in complex basins (Giertz and Diekkrüger 2003; Arnold and Fohrer 2005).

This model is used extensively in different parts of the world. Comprehensive review of the applications of this model has been reported by Gassman et al. (2007). Ability of basin models for simulating hydrologic processes is evaluated by parameter sensitivity analysis, model calibration and model validation (Shimelis et al. 2010).

Abbaspour and colleagues in a study (2006) on the river basin Thur (1700 square kilometers) on the northwest of Switzerland, reviewed and tested the performance of SWAT Model to simulate flow and pollutant transport (phosphorus and...) in the selected basin. They also used parameter optimizer program SUFI-2 for model Calibration. Comparison statistics of observation and computational variables indicated the good ability of model to simulate the flow and quality.

In this paper, we applied the hydrological Soil and Water Assessment Tool (SWAT) to simulate surfaceflow in the Gharesou basin in Iran.

2 – Materials and Methods
2-1 - Study area
The Karkheh basin has area of 50,764 square kilometers, and is located in the West, in the middle and southwest regions of the Zagros Mountains, between '06 ° 46 and '10 ° 49 east longitude and '58 ° 30 '56 ° 34 north latitude. Approximately 27,645 square kilometers of the river is located in mountains and 23,119 square miles belong to the plains and foothills. Mountainous parts of the basin are situated approximately in the eastern and middle sections, and plains which cover about 45 percent of the total area, are located in the northern and southern parts of basin.

The study area, Gharesou river basin, is located in the northwest of Karkheh basin and in the west of Iran (Figure 1). The area is approximately equal to 5793 square kilometers and the maximum and minimum height is 1237 and 3350 meters respectively. Its annual average rainfall varies between 300 and 800 mm.

Surface water resources of Gharesou basin consist of Gharesou, Marak, Razavar, Gerdab, Kotab and Zardab Rivers. The main river in this basin is Ghareso River for which Marak river (water collector of Mahidasht plain in west of Kermanshah province) is one of the first branches. Gerdab and Razvar Rivers also release into the Ghareso River. Finally the Gharesou River after passing from the Kermanshah plain and draining water at local sources at east west of Kermanshah, adds to Gamasiab River. Table 1 shows the Characteristics of selected stations.

2-2 - The process-based SWAT model
There are many models for assessing hydrologic basins that are used by water resource managers, decision makers and researchers. These models make a great help in predicting the effect of specific development plans on probable runoff produced in the future. Continuous models can provide a better understanding of watershed hydrological response due to its climate and vegetation changes.

The watershed models can be classified into two major groups based on their performance on spatial components. Lumped models consider the basin as an integrated unit without considering the spatial changes in the processes, inputs, boundary conditions or hydrological characteristics of the basin. In contrast, the distributed models consider the spatial changes by solving the equations of each pixel in the basin network (Wood et al. 1988). SWAT Model has been developed to simulate the effects of land management activities on water, creating sediment and agricultural chemical agents in basin scale with soil variation, and land cover and management conditions of a long period. This model is a Process-based and
semi distributed parameters model, and instead of using regression equations to describe the relationship between input and output variables, it receives specific information about climatology, soil, topography, vegetation and land use in the basin. This model is appropriate in terms of computational efficiency. It is possible to simulate very large basins or diversity management strategy without spending extra time and cost. This model enables users to simulate long-term simulation. SWAT Model is continuous in terms of time. This model is as an extension under the GIS software and uses its capabilities. In this model, water and sediment transport, plant growth and elements cycle for simulation are considered to be continuous. SWAT is extensively used for studies of basin scale in relation to the water quality and quantity.

SWAT is a semi distributed parameter simulation model based on process that works on a daily time step. The watershed is subdivided into sub basins that are spatially related to one other. The sub basin components can be categorized into the following components: hydrology, weather, erosion and sedimentation, soil temperature, plant growth, nutrients, pesticides and land management. SWAT Model requires be calibrated and validated on the study basin to ensure that model parameters represent the study area. SWAT Model uses the following hydrologic balance equation for hydrologic cycle simulation:

\[
\Delta SW = \sum_{i=1}^{n} (R_{day} - Q_{surf} - E_a - W_{deep} - Q_{gw})
\]

Where, \(\Delta SW\) = soil water content, \(R_{day}\) = daily rainfall, \(Q_{surf}\) = surface runoff, \(E_a\) = actual evapotranspiration, \(W_{deep}\) = the amount of water into the deep aquifer, \(Q_{gw}\) = output groundwater flow into river.

In the SWAT Model, sub-basins are divided into hydrological response units (HRUs). SWAT uses corrected curve number method or Green and Ampt infiltration method for calculating surface runoff for each HRU. Runoff in SWAT Model is predicted separately for each HRU, and routed to obtain the total runoff for the watershed (Arnold et al. 1998; Neitsch et al. 2005; Neitsch et al. 2009). Sub-basins of Gharesou Basin are shown in Figure 2.

This model includes various parameters because of complexity in distributing and considering many affective factors in rainfall-runoff process. Some important parameters which are needed for modeling are as following:
1) Snowmelt parameters
2) River network parameters
3) Parameters in surface runoff determination
4) Applied parameters to define and identify hydrological response units
5) Critical parameters in the simulation of groundwater flow

3 - Model Inputs

It is necessary to use appropriate high quality data for preparing Rainfall-Runoff model. Existence of some inaccurate data which are fed into the model could be an important factor in estimating parameters and simulating flow. Required meteorological data for the model include precipitation, and daily minimum and maximum temperature (period 1971 to 2000), which have been introduced as the data file. Other required meteorological data include radiation, wind speed and relative humidity, which are simulated by the present model. Rainfall data were obtained from Mahidasht and Jegolire rainfall stations, and two synoptic stations such as Kermanshah and Ravansar stations; daily temperature was derived from Kermanshah and Ravansar stations. The hydrometric station of Gharesou Basin located in the outlet of Gharesou basin and was selected as base station for model calibration (Table 1 and Figure 1).

Required data for simulation by SWAT model in addition to meteorological data include topography, climate, vegetation, soil, and management data. Topographic data in the form of digital elevation model (DEM) and soil map, both at the scale of 250,000: 1, (pixel size 50 × 50 m, Figure 3) were provided by the Institute of Agriculture Soil Conservation and Watershed Management. Land use map was extracted from satellite images. These data were used in the model after being cleaned and processed with GIS software and converted as raster data (Figure 4).
4- Model preparing and Results
Calibration of watershed models encounter many problems because of uncertainties available in the form of including simplification of processes, processes which are not considered, and the processes which are not specified for modeler.
Examples of these cases include: effect of reservoir on the hydrology of river transportation materials, the effect of interaction between surface water and groundwater, and construction of structures like dams and bridges that can have a strong impact on flow pattern and sediment rates; the flow of sewage discharge into River which is not known and more including agricultural irrigation management programs (Abbaspour 2006). Due to different uncertainties, the distribution of the calibration model for the catchment model is an important issue.
Part of climate and hydrometric data were used for model calibration. Thus, after entering data into the model and simulation of river flow, comparison was done with the observation river flow. At this stage, parameters values were changed until simulation flow was close to the observation flow. Running the model was considered successful when the objective function value as a benchmark to measure the performance of the model was optimal. After calibration, the model was validated by obtained parameters in the calibration phase, using data from observations in the calibration is not used, is measured. If the result of simulation be acceptable, the model would be ready to use (Zahabioon and Goodarzi 2008).

Automated model calibration needs the systematic changes of uncertain parameters, and then after the simulation of the model it needs the outputs of observable data related to computational data. The most important function is providing relationship between model and calibration program. SWAT-CUP is an optimum communicating program that is developed for SWAT model. Calibration and uncertainty associated with SWAT-CUP is easily achieved. The Sequential Uncertainty Fitting (SUFI-2) is one of the uncertainty analysis programs that is incorporated in an independent program called SWAT Calibration and Uncertainty Program (SWAT-CUP) (Abbaspour 2008).
Several parameters had been selected for calibrating the model. All parameters affecting the river flow were adjusted to match the observed flow (hydrometric station data of the Gharabaghestan). These parameters had selected according to the previous researches in the field of calibration of SWAT model (Kati et al. 2005; Neitsch et al. 2009; Omani et al. 2007). In this study, the calibration process begun by several parameters in the SWAT-CUP (SUFI-2) algorithm, but in the last iteration only 9 parameters were found to be sensitive to discharge, because high correlated parameters with the smallest sensitivities were not changed any longer in the iteration process. The sensitivity analysis has pointed out nine crucial parameters (CN2, SOL_AWC, SMTMP, ESCO, SMFMN, CH_K2, REVAPMN, GW_REVAP and ALPHA_BF) that control the hydrological processes of the studied area. However, CN2 and REVAPMN were found to be most crucial than other parameters.
Table 2 shows the optimum parameters of the calibration stage. It should be noted that parameters CN2 and SOL_AWC were optimized as a multiplier of initial values. Model calibration had been done with correlation function value, simulation of monthly flow, Nash-Sutcliffe (E_{NS}), coefficient of determination (R^2), average of monthly flow and variance of monthly flow between 1992 and 1996. Model validation was done from 1998 to 2000 and the results are available in table 3. Figure 5 and 6 show the results of model calibration and validation.

\[
R^2 = \frac{\sum_{i=1}^{n} (O_i - \bar{O})(S_i - \bar{S})^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2 \sum_{i=1}^{n} (S_i - \bar{S})^2}
\]

\[
E_{NS} = 1 - \frac{\sum_{i=1}^{n} (S_i - O_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2}
\]

Where \( S_i \) is runoff estimated by the model; \( O_i \) is the recorded runoff; \( \bar{O} \) is the mean recorded runoff; and \( n \) is the number of months in the simulation.
5 - Conclusion
The aim of the present study was to use continuous semi distributed rainfall-runoff model to simulate the flow, and get help from an optimizer program for model calibration. In this study, river flow of Gharesou basin from Karkheh sub-basins was simulated by using SWAT process based rainfall-runoff model. Parameters of this model were obtained by using basin observed data through the model calibration. Due to the model complexity and the difficulty of determining optimal values of parameters in a hand way to obtain optimal values, SWAT-CUP automatic program was used for model calibration. In the calibration stage, the coefficient of determination $R^2$ was 0.82 and Nash-Sutcliffe ($E_{NS}$) coefficient was 0.8. In the validation stage these values were 0.77 and 0.73 respectively. The statistics of observation flows were maintained with good approximation during simulation. The present results indicate the success of the model using optimized parameters in the simulation of monthly flow of Gharesou basin. Thus the SWAT Model was assessed as reasonable model for rainfall-runoff simulation in Gharesou basin. Large-scale hydrological catchment models can be used as an effective tool for simulating the hydrological processes and their results can be used in water resources management studies.

6 - References


Figures:

Figure 1: The location of Gharesou Basin in Iran

Figure 2: Sub-basins of Gharesou Basin using SWAT Model
Figure 3: Digital Elevation Model

Figure 4: Land use map (Left) and Soil class map (Right)
Figure 5. Observed and simulated (SWAT) stream flow (m$^3$/s) at Gharebaghestan station (1992 – 1996)

Figure 6. Observed and simulated (SWAT) streamflow (m$^3$/s) at Gharebaghestan station (1998 – 2000)
### Tables:

**Table 1. Characteristics of selected stations**

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Station type</th>
<th>Height</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kermanshah</td>
<td>Synoptic</td>
<td>1318.6</td>
<td>34 21</td>
<td>47 9</td>
</tr>
<tr>
<td>Ravansar</td>
<td>Synoptic</td>
<td>1379.7</td>
<td>34 43</td>
<td>46 39</td>
</tr>
<tr>
<td>jelogireh</td>
<td>Rain gage</td>
<td>1280</td>
<td>34 35</td>
<td>45 51</td>
</tr>
<tr>
<td>Mahidasht</td>
<td>Rain gage</td>
<td>1415</td>
<td>34 16</td>
<td>46 49</td>
</tr>
<tr>
<td>Gharebaghestan</td>
<td>Hydrometric</td>
<td>1238</td>
<td>34 14</td>
<td>47 15</td>
</tr>
</tbody>
</table>

**Table 2. Final values of applied parameters in the simulation**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter Definition</th>
<th>Range of changes</th>
<th>Optimized values</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMTMP</td>
<td>Snowmelt base temperature (°C)</td>
<td>±5</td>
<td>2.375</td>
</tr>
<tr>
<td>SMFMN</td>
<td>Minimum melt rate for snow during the year (mm°C⁻¹ day⁻¹)</td>
<td>0-10</td>
<td>4.615</td>
</tr>
<tr>
<td>ESCO</td>
<td>Soil evaporation compensation factor</td>
<td>0.01-0.1</td>
<td>0.6418</td>
</tr>
<tr>
<td>ALPHA-BF</td>
<td>Base flow alpha factor (days)</td>
<td>0-1</td>
<td>0.01542</td>
</tr>
<tr>
<td>GW-REVAP</td>
<td>Groundwater revap. coefficient</td>
<td>0.02-0.2</td>
<td>0.1772</td>
</tr>
<tr>
<td>SOL_AWC(1)</td>
<td>Soil available water storage capacity (mm H₂O/mm soil)</td>
<td>0-1</td>
<td>*0.1225</td>
</tr>
<tr>
<td>CN2</td>
<td>SCS runoff curve number for moisture condition II</td>
<td>20-90</td>
<td>*-0.22</td>
</tr>
<tr>
<td>CH_K2</td>
<td>Effective hydraulic conductivity in the main channel (mm hr⁻¹)</td>
<td>0-150</td>
<td>2.2625</td>
</tr>
<tr>
<td>REVAPMN</td>
<td>Threshold depth of water in the shallow aquifer for ‘revap’ to occur (mm)</td>
<td>0-500</td>
<td>105.875</td>
</tr>
</tbody>
</table>

*: parameter value is replaced by given value or absolute change

**Table 3. Model performance**

<table>
<thead>
<tr>
<th></th>
<th>$R^2$</th>
<th>$E_{ws}$</th>
<th>$ar{O}$</th>
<th>$ar{S}$</th>
<th>VAR₀</th>
<th>VARₛ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration 1992–1996</td>
<td>0.82</td>
<td>0.8</td>
<td>22.1</td>
<td>20.21</td>
<td>432.16</td>
<td>440.25</td>
</tr>
<tr>
<td>Validation 1998–2000</td>
<td>0.77</td>
<td>0.73</td>
<td>8.31</td>
<td>10.17</td>
<td>174.32</td>
<td>172.53</td>
</tr>
</tbody>
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