Efficiency Assessment of Fuzzy logic membership models for evaluation SCS rainfall-runoff (Acase study: Kameh river watershed)

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ABSTRACT: This paper introduces a fuzzy rule-based model to estimate runoff in semi-arid regions (Kameh river watershed) using the Soil Conservation Service Curve Number model. In this study factors such as: Land used and hydrologic soil group are considered, to determine direct runoff or excess precipitation in the in Kameh river watershed the North East part of Iran. Thematic layers for the above parameters were prepared, in a RS environment by the means of Fuzzy logic (bell-shaped and linear membership function) and Boolean Methods. The evaluation of runoff derived from fuzzy and Boolean methods show that the calculated runoff closer to the measured runoff in the watershed but bell-shaped membership function is the best linear membership function and boolean method for application purposes.

Keywords: Fuzzy logic membership, Runoff, SCS model, Image satilate, NDVI Kameh river basin, Iran

INTRODUCTION

Rainfall-runoff modeling is a very important issue for hydrologists. River flow forecasting can play a significant economic role, as it can help in agricultural water management, water shortages management, water resources management and flood and drought prediction and management. Models can lead us to simulate the precipitation-runoff process and forecast the stream flows. Many techniques are currently used for modeling of hydrological process and generating of synthetic stream flow. (Shahraiyni, 2011) The hydrologic behavior of watershed in rainfall-runoff transformation process is very complicated phenomenon which is controlled by large number of climatic and physiographic factors that vary with both time and space. The relationship between rainfall and resulting runoff is quite complex and is influenced by factors relating the watershed and climate. (Anderson and Burt, 1985 and Watts, 1997). Most frequently used of these models are regression models, time series models, artificial neural network (ANN) and fuzzy logic (FL). ANN is one of the most frequently used methods in the last fifteen years. This method is quite suitable for non-linear systems. Many researchers have utilized of ANN for prediction of stream flow (Hsu et al., 1995; Firat, 2008). Zadeh developed fuzzy set theory allowing the mathematical modeling in zones of imprecisions and uncertainties. Fuzzy set theory is a generalization of the Boolean logic to situations where data are modeled by entities whose attributes have zones of gradual transition, rather than sharp boundaries. (Burrough, 1986). The fuzzy theory is for a mathematical description of imprecision.
and uncertainty in human experience and is used to reflect such complexities (Maskey et al., 2004; Gopakumar
and Mujumdar, 2008 and Chu and Chang, 2008). Fuzzy logic modeling has been applied to various engineering
problems in the past, e.g., a control of traffic junction, a water cleaning process, water level forecasting, stream flow
prediction, and rainfall-runoff modeling (Chau et al. 2005; Şen and Altunkaynak 2006; Alvisi et al. 2006;
Altunkaynak and Şen 2007; Özger 2009; Altunkaynak 2010). McBratney and Odeh (1997) showed the potential of
fuzzy set theory in soil science, such as mapping and numeric classification, landuse evaluation, modeling and
simulation of physical processes. Enea and Salemi (2001) and Klingseisen et al. (2007) used fuzzy logic for
evaluating environmental impacts these models are more useful since they can be applied as easily and avoid of
conceptual models complexities. The objective of this study was to develop a fuzzy rule based modeling to predict
runoff in a watershed using the Soil Conservation Service Curve Number (SCSCN) model (SCS, 1972) and the
PCRaster Environmental Modeling Language (EML) (Wesseling et al., 1996). Chiang et al. (2004) indicate that the
complex watershed rainfall–runoff process is non-linear and dynamic in nature. Aurelio Azevedo Barreto-Neto et
al. (2008) evaluation of runoff derived from fuzzy and boolean methods demonstrated that the former provided
calculated runoff closer to the measured runoff in the watershed, confirming the suitability of the fuzzy theory in
modeling natural phenomena.

**Study area**

The study area is the Kameh river watershed, located in Torbat heydariyeh, east of the Iran. (Fig. 1). It is
situated between the longitudes 59° 6’ E and 59° 13’ E and the latitudes 35° 28’ N and 35° 32’ N. The choice to
research this watershed was driven by the availability of Topography and geology maps, Satellite image (landsat
TM), rain record gage, and stream discharge record gage. The watershed has 51.1 km²2 is classified as medium-
sized. Other property of basin showed in table 1.

![Locality map kameh basin](image)

**Table 1. property of Kameh basin**

<table>
<thead>
<tr>
<th>Area (km²)</th>
<th>Perimeter (km)</th>
<th>Slope (%)</th>
<th>Min Elevation (m)</th>
<th>Max Elevation (m)</th>
<th>Mean Elevation (m)</th>
<th>Length of main stream (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>51.1</td>
<td>33.8</td>
<td>27.4</td>
<td>1700</td>
<td>2609</td>
<td>1955</td>
<td>13</td>
</tr>
</tbody>
</table>

The Soil Conservation Service Curve Number (SCSCN) hydrologic model

The Transformation of rainfall into runoff is highly complex, dynamic and nonlinear process which is affected by
many factors which are often inter-related. The SCSCN model is a well known archetype for estimating the storm
runoff depth from storm rainfall depth for watershed and thus, stream flow, infiltration, soil moisture content and
transport of sediments. Therefore, the model can assist hydraulic projects, soil conservation projects and flood
control (SCS, 1972; Engel et al., 1993; Mack, 1995; Johnson and Miller, 1997; Thompson, 1999; Pullar and
Springer, 2000; Tucci, 2000). The runoff equation defined by SCS and detailed on the National Engineering
Handbook (SCS, 1972) is the following

\[ Q = \frac{(p - 0.2S)^2}{(P + 0.8S)} \]  

\[ S = \frac{25400}{CN} - 254 \]
where Q is the direct runoff or excess precipitation (mm), P is the precipitation (mm), S is potential maximum storage (mm) in the watershed after beginning of the runoff and CN is curve number. Basically, five steps are necessary to evaluate curve number from a rainfall by the fuzzy SCSCN model: (i) to evaluate image processing to determination of land; (ii) to determine the hydrologic soil group (iii) to determine the runoff CN (on the basis of land cover plus hydrologic condition and hydrologic soil group of the soil); (iv) Enter membership fuzzy logic for land use by NDVI index and curve number (v) Runoff calculation. Concepts are given below.

**Hydrologic soil group**

In SCSCN model, the soils are classified to one of four HSG (A, B, C or D) defined by the SCS. This classification was accomplished by the analysis of the infiltration capacity of the soil. The description of each group, according to SCS(1972) is listed in Table 2. In this research measurement hydrologic soil group (HSG) Based on table 2 and field working by double-ring infiltrometer sampling and generated hydrologic soil groups map (Fig. 2).

<table>
<thead>
<tr>
<th>HSG Group</th>
<th>Area (km²)</th>
<th>Area (%)</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6.12</td>
<td>12.0</td>
<td>Soils with high infiltration rates</td>
</tr>
<tr>
<td>B</td>
<td>3.63</td>
<td>7.1</td>
<td>Soils with moderate infiltration rates</td>
</tr>
<tr>
<td>C</td>
<td>26.27</td>
<td>51.4</td>
<td>Soils with low infiltration rates</td>
</tr>
<tr>
<td>D</td>
<td>15.02</td>
<td>29.4</td>
<td>Soils with very low infiltration rates</td>
</tr>
</tbody>
</table>

**Land use map**

The landuse map was obtained based on image processing (Landsat Tm data and Erdas9.1 software) and checking in field observations. Firstly, the Lansat image was compensated for atmospheric effects and converted into surface reflectance, through the Atmospheric Correction. In this research estimate the land area by using normalized difference vegetation index (NDVI index) and Field observations and Evaluation. These spectral reflectances are themselves ratios of the reflected over the incoming radiation in each spectral band individually, hence they take on values between 0.0 and 1.0. By design, the NDVI itself thus varies between -1.0 and +1.0. It should be noted that NDVI is functionally, but not linearly, equivalent to the simple infrared/red ratio (NIR/VIS). The advantage of NDVI over a simple infrared/red ratio is therefore generally limited to any possible linearity of its functional relationship with vegetation properties (e.g. biomass) The simple ratio (unlike NDVI) is always positive, which may have practical advantages, but it also has a mathematically infinite range (0 to infinity), which can be a practical disadvantage as compared to NDVI. Also in this regard, note that the VIS term in the numerator of NDVI only scales the result, thereby creating negative values. NDVI is functionally and linearly equivalent to the ratio NIR / (NIR+VIS), which ranges from 0 to 1 and is thus never negative nor limitless in range. (Crippen, 1990) But the most important concept in the understanding of the NDVI algebraic formula is that, despite its name, it is a transformation of a spectral ratio (NIR/VIS), and it has no functional relationship to a spectral difference (NIR-VIS). The NDVI was calculated by:

\[
NDVI = \frac{NIR - VIS}{NIR + VIS}
\]

(III)
Where VIS and NIR stand for the spectral reflectance measurements acquired in the visible (red) and near-infrared regions, respectively. In general, if there is much more reflected radiation in near-infrared wavelengths than in visible wavelengths, then the vegetation in that pixel is likely to be dense and may contain some type of forest. Subsequent work has shown that the NDVI is directly related to the photosynthetic capacity and hence energy absorption of plant canopies (Sellers, 1985 & Myneni et al, 1995). The result show that figure 3 and table 3.

![Figure 3. Land use of watershed](image_url)

<table>
<thead>
<tr>
<th>Class</th>
<th>Area</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest planing</td>
<td>1.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Wood lands</td>
<td>0.1</td>
<td>0.2</td>
</tr>
<tr>
<td>Range</td>
<td>33.1</td>
<td>64.9</td>
</tr>
<tr>
<td>River</td>
<td>1.7</td>
<td>3.3</td>
</tr>
<tr>
<td>Rock</td>
<td>7.8</td>
<td>15.3</td>
</tr>
<tr>
<td>Agriculture</td>
<td>6.6</td>
<td>13.0</td>
</tr>
</tbody>
</table>

### Fuzzy theory

Zadeh (1965), a computer scientist, propounded the “fuzzy logic” or fuzzy set theory, based on the nature of fuzzy human thinking. Fuzzy Logic (FL) modeling refers to process whereby dynamical system is modeled not in the form of conventional differential and difference equations but in the form of set of fuzzy rules and corresponding membership functions. Fuzzy logic has been used as modeling methodology that allows easier translation between human and computers for decision making and better way to handle imprecise and uncertain information.

### Formation of Fuzzy Rule Base

For the developed model, each input variable was coded, fuzzified and, subsequently, input into the fuzzy inference system for decision making, using the PCRaster EML. The implementation of the computer model followed three steps: (i) the land use and hydrologic soil group (HSG) were transformed in a fuzzy set using the membership functions (linear and bell-shaped); (ii) using the fuzzy inference system, the CN map was generated based on the fuzzy soil map and the fuzzy cover map (both developed in the previous steps); (iii) calculation runoff by SCSCN model.

### Fuzzy CN map

Using the methods of fuzzy logic on polygon boundaries makes it simple to incorporate information about the nature of the boundaries. In this paper, the map-unit approach described for Akbarpour (2007) was employed.

### Fuzzy land used map

The fuzzy feature of the NDVI map (land used map) was calculated by the membership functions illustrated in Fig. 4. Field observations allowed the identification of transition zones on the nine classes.

### Evaluation of membership fuzzy logic

In the fuzzy rule-based modeling, the relationships between variables are represented by means of fuzzy if-then rules that assume the form:
If \( x \) is \( A \) then \( y \) is \( B \)

where \( x \) and \( y \) are linguistic variables, \( A \) and \( B \) are linguistic constants. The if-part of the rule “\( x \) is \( A \)” is named the antecedent, while the then-part of the rule “\( y \) is \( B \)” is named the consequent. Used the Matlab software and Calculate fuzzy rule-based modeling by two memberships linear and bell-shaped for fuzzy (fig 4).

The fuzzy inference system of the Fuzzy SCSCN model was accomplished through the following steps: (i) transformation of the input data in a fuzzy set; (ii) application of the fuzzy rules; (iii) computation of the information associated to transition zones on different soil and Land use map units; (iv) generation of CN raster maps with the CN values of all pixels of the studied watershed by two memberships (Fig. 5 and 6); and (v) runoff calculation.

RESULTS AND DISCUSSION

The CNs used here was selected on the basis of calibrations between modeled and observed runoffs. Once the CNs were selected, the runoff modeling was tested through a comparison between the modeled runoff depth and the recorded runoff depth observed in field. The validation of the CNs for the Kameh River (Table 4). The results indicate that the modeled and the observed runoffs are akin and, therefore, the employed CNs proved suitable but bell-shaped membership function is the best linear membership function and boolean method for application purposes. The CNs used here were selected on the basis of calibrations between modeled and observed runoffs.
CONCLUSION

A methodology for runoff modeling using fuzzy sets, fuzzy membership functions and fuzzy rules was presented in this paper. The computer model was created within a GIS environment and its use can be extended to other watersheds in Arid and semi-arid in Iran by simple changes on the database. Fuzzy logic has a great potential in hydrologic sciences. The Fuzzy SCSCN model can be used as a tool for predicting Curve number and, runoff in watersheds.

REFERENCES