Optimization Linear Black Box Models of Rainfall - Runoff by using GIS and Neural Networks

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SUMMARY

In the recent year, many ways concerning hydrologic issues have been presented. One of these ways which is the most applicable is the system approach. In this approach a system is dealt with only in order to establish the relationship between input- Output for the reconstruction of events in the past or predicting the events in the future. In this study, the issue of rainfall- runoff as one of the most important issues in hydrology has been modeled using a black box system in GIS. At the beginning of this study, the components of this model which compares the spatio-temporal distribution of rainfall, infiltration in addition to the basin physiographic characteristics, the initial conditions and boundary conditions were identified and studied. In the second step, spatial, attribute and temporal data of each component were collected and these components were created as specified models in the GIS. Finally, by using neural networks the parameters of black box and the relationship between the components were extracted from the model and results were tested for a given basin.

Algorithm developed in this research was compared with the other conventional algorithms such as physical methods in simplicity and accuracy and based on the process itself not based on the need of GIS. Results showed that the issues of hydrology analysis increase accuracy using and maintaining efficiency.
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1. INTRODUCTION

In the last years, some attitudes are represented about rainfall-runoff models which is divided or classified in two major group methods include a physically-based and a systematically-based model (Najafi, M.R. 2001). Aim of the first group is, explaining of the reason attitudes in hydrology which is literally called causal, but the next one is that developing relationships will be between two measurable parameters in hydrology cycle is literally called black box. More complexity over major problem basin in the hydrology, defect information, uncertainty, defect of temporal data; these are, one of the main reason for lack of full composition component when is used on causal models.

On this condition, systematic attitude on composition of measurements is that the variable on the category, is related to this problem in the spatio-temporal domain and use of GIS in developing and analysis of the raw data with applying of artificial neural network in personal learning as a estimating process of an unknown dependence of input-output or structure of a black box is definitely studied by restricted number of inputs-outputs measurements or observations in one system. Even though, these are non linear, defect spatial-temporal information and complicated problem in model of hydrology cycle, in this study, rainfall-runoff phenomenon is proposed and reviewed from the systematical attitude.

2- BACKGROUND AND SCOPE OF THE PRESENT STUDY

ANN just can stimulate runoff – rainfall phenomenon with rainfall or temperature information (lorrai and Cechi, 1995 ). By determine of daily precipitation, temperature and meltsnow, estimation of runoff from ANN and a simple conceptual model ,were compared that the results illustrated which neural network has been used and give the precise measurement with the least data and the shortest time ( toner and markus 2000 ) . An approach for modeling daily flows during flood events using Artificial Neural Network (ANN) is presented. The rainfall-runoff process is modeled by coupling a simple linear (black box) model with the ANN. (M.p.Rajurkar , 2003) 

Ancitil et al. 2004, they compared the results of ANN and a conceptual model in predicting of flood in the next day, they evaluated layer Perceptron well.
To conditioning rainfall-runoff model parameters for ungauged basin, parameter regionalization may be used to constrain the parameter space prior to, or instead of, calibration (Bardossy, 2007; McIntyre et al., 2005; Yadav et al., 2007).

Rajurkar et al. 2004, they proposed for receiving of real answer from ANN, it is better to divide basin to sub-basin and survey of each one must be done separately.

In most of the studies cited above, the ANN was applied as an independent model and its performance was compared with other conventional models. In the study, we use from GIS for spatial distribution of initial data and so we apply the ANN for modeling rainfall-runoff process.

3- BLACK BOX ATTITUDE

In general, a system can be imagined as a set of related component that multiple inputs transform multiple outputs (Najafi, M.R. 2001). In this case, one system is just studied to establish the relationship between input and output whether it reconstruct previous events or predict future events. The system essentially composed of three parts that includes inputs are domain, outputs are range and function of system which mathematical description process will be relationship between inputs and outputs.

Hydrology or circumstance of water in the nature is water movement into several parts of earth that the describe and explain of the cycle will be difficult, because of complexity process. If we consider the hydrology cycle as a system, various component of this system from precipitation, runoff, evaporating and transpiration, infiltration–storage, surface runoff, subsurface flow in the last the flow is formed. (fig1)

In study of runoff–rainfall problem from systematic view, we consider the basin as one system and the rainfall as an input for system. (fig2)
The relationship between input and output or systematic function is established by combination of spatial discharge continuity equations and discharge-storage (equation 1). Also output will be a hydrograph to runoff discharge basin.

\[ I = Q + knQ^{n-1} \frac{dQ}{dt} \quad \text{Eq.(1)} \]

\( I = \text{Intensity of input flow} \) \( Q = \text{Intensity of output flow} \)

4- DATA AND METHODOLOGY

Basin of MANE is located in the Northeast of IRAN and this basin is apart of ATRAK river's basin that is between the SHIRVAN, GOCHAN and GOLSTAN province's basins. In the other word, basin of MANE is lied approximately between of longitudes 56.396 till 57.704E and latitudes 37.377 till 38.068N.

4-1- GIS Application

By use of these maps which include point maps are related to rainfall and hydrometry station and also linear maps are related to the boundary basin and contour lines, where data entry to GIS will be done then by interpolation methods, the digital elevation model (DEM) is generated.
This model has raster structure and any value of the pixel assigns the height pixels in the center pixel include the height. With DEM is generated, can determining flow direction map. The water in the cell flows in which one of the adjacent cells in this map. Of course, this map is as a network from numbers that each flow has its own unique number. The produced DEM may be one or several sink. Sink cell or group of cells that correspond to the height, less than the height of adjacent pixel .it is required for runoff modeling, the sink has been resolved to lead a hydrological DEM. There are several methods to eliminating sink with GIS functions. For example, the average height of adjacent cells is assigned to cell or sink cells.

In the use of direction flow map and application of GIS functions, can create a flow accumulation map. in this map, the value is assigned to each cell, the number of cells is up streamed which the water, has been flowed toward the cell (figure 4(a) ). in determine of the threshold number , whole cells that the value in the flow accumulate map is larger than threshold number, is considered as a river network even so the threshold will be smaller, river network density will be higher. This number of threshold, are usually considered as 0/01 maximum is the largest value on the flow accumulation map. The flow length map is the most important maps on the modeling are desired. Because the flow length map that is the water in each cell travels to reach in output cell. Linear maps can be produced with overlay river network maps, hydrometry station and basin boundary. With DEM of each subbasin is done the previous process until for each sub-basin is created a flow length map. Because of input data to neural network model, we are weighted the flow accumulation map with rainfall data and run off coefficient in the GIS. Until the data have the better precise .in this case, from two methods for providing the rainfall maps are used. In the first method, in order to provide the rainfall map, the Thiessen polygon method in the next method, the value of rainfall mean in the rainfall station, in the study area is interpolation.

**Fig.4-(a)-Digital Elevation Model, (b)-catchment map of the study area**
Runoff height map, use a formula of \( R = C \cdot P \), is conclude that in the \( P \), the value of height rainfall \( (C. \text{ mm}) \) is runoff coefficient and \( R \) is the value of runoff height \( (\text{ mm}) \). In attention to character of physical basin, the runoff coefficient is come from flowing table.

<table>
<thead>
<tr>
<th>Slope</th>
<th>Land cover in a pasture basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-30%</td>
<td>0.22</td>
</tr>
<tr>
<td>5-10%</td>
<td>0.16</td>
</tr>
<tr>
<td>0-5%</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>clay-loamy soil</td>
</tr>
<tr>
<td></td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>clay soil</td>
</tr>
<tr>
<td></td>
<td>0.55</td>
</tr>
</tbody>
</table>

\( \text{Table.1- runs off coefficient values in a pasture basin (Aminzade, 2000)} \)

In attention to the basin is the pasture and it has Clay-loamy soil, the correspond value of table in the raster file were substituted on the study area and with raster coefficient on rainfall map. The runoff height, in the study, this area is existed. with the map is taken, it identifies that the runoff height in the basin of MANE it is \( 64.872 \text{ mm} \) in the minimum and \( 151.221 \text{ mm} \) in the maximum during a year, therefore these data are prepared in GIS are ready to enter the neural network model.

4-2- HEC- HMS Model

One of model that is frequently used for flood and watershed management studies, it is HEC-HMS. this model is designed for simulation discharge runoff surface of a basin, to certain precipitation, this model show the basin as an integrated system with the hydrological and hydraulic component, each component of model consider an aspect of runoff-rainfall process in part of basin that usually simulated as watershed, in a the words, several
component are combined for simulation of physical system and any component do necessary calculate for complete the discharge hydrograph. In the HEC- HMS model, main input of rainfall is upstream and unknown output is runoff. The relationships between these two are determined by model, where physiographic characteristics of basin are more important in determine of runoff and calculate of output hydrograph.

4-3- Artificial Neural Network

Artificial neural network is the simplified model of human brain, the network is a mathematical structure and it can show the process and include the desire compounds of nonlinear function, as function in to sigmoid \( f(x) = \frac{1}{1+e^{-x}} \), type of back-propagation algorithm for relationship between inputs and outputs that have system (Birikundavyi, Labib, Trung and Rousselle. 2002). This data of the network, during the learning process, it is learned and used for predicting the future. Neural networks are model from nerve cells that are called neuron and communication units are called EXON. neuron is as the smallest unit that would be a network process.

One of the prepared data is their normalization until this balance is done between the network function and output data (Dimopoulos, Lek and Lauga. 1996).

\[
x' = 0.05 + 0.95 \frac{x - x_{\min}}{x_{\max} - x_{\min}} \quad \text{Eq. (3)}
\]

the criteria for the final test of network ,the value is originated from mean square errors. (eq.(4)).

\[
RMSE = \sqrt{\frac{\sum_{i=1}^{n} (x_{\text{obs}} - x_{\text{ann}})^2}{r}} \quad \text{Eq. (4)}
\]

In the whole survey that is done, the criteria for evaluation of network, coefficient covariance between discharge of runoff simulation network with their discharge observation (Rajurkar, Kothyari and Chaube. 2004).

\[
r = \frac{\sum_{i=1}^{n} (x_{\text{obs},i} - \bar{x}_{\text{obs}})(x_{\text{ann},i} - \bar{x}_{\text{ann}})}{\sqrt{\sum_{i=1}^{n} (x_{\text{obs},i} - \bar{x}_{\text{obs}})^2} \sqrt{\sum_{i=1}^{n} (x_{\text{ann},i} - \bar{x}_{\text{ann}})^2}} \quad \text{Eq. (5)}
\]

5- CONCLUSION

in table 2 the results of compare between the HEC-HMS and ANNS models are illustrated. hydrograph of HEC-HMS model has more RMSE rather than ANN models, how ever it is
pointed the introduction, modeling of rainfall–runoff with physically–based method depends on models’ effective parameters. Even though different components as Basins’ hydrologic elements and meteorology elements are composed for simulating the physical system. Defect information, uncertainty and defect of temporal data are main reasons, lead to estimate of calibration parameters with week precision. Because RMSE for HEC-HMS is more evaluated than ANN.

<table>
<thead>
<tr>
<th>Model</th>
<th>Calibration Period</th>
<th>Evaluation Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$R^2$</td>
<td>Coefficient of Correlation</td>
</tr>
<tr>
<td>HEC-HMS</td>
<td>0.75</td>
<td>0.82</td>
</tr>
<tr>
<td>ANN</td>
<td>0.88</td>
<td>0.91</td>
</tr>
<tr>
<td>ANN-GIS</td>
<td>0.91</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Table 2- Comparison between Coefficient of Correlation for 3 methods

ANNs prove that they can model the rainfall-runoff hydrograph perfectly. Using of suitable learning, defining system based on measurement data shows the less RMSE in these models. Use of ANN model with GIS comparing with ANN based on attribute data give better results. Providing of weighted rainfall map and height rainfall map is based on spatial changes, these are reasons that cause to be better on partially conclusion.

In the future research, the survey of effective parameters on physics earth, providing of the map is based on weight of spatial evaporation data, be consider as spatio-temporal distribution of moisture soil and use of other neural network methods will be effective.

Fig 6. Comparison between Observation Discharge and GIS-ANN Discharge
Fig 7. Comparison between Observation Discharge and ANN Discharge

Fig 8. Comparison between Observation Discharge and HEC-HMS Discharge
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