RIVER INSTANTANEOUS PEAK FLOW ESTIMATION USING MEAN DAILY FLOW DATA

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Estimation of the design flood flow for hydraulic structures is often performed adjusting probabilistic models to daily mean flow series. In most of the cases this may cause an underdesign of the structure capacity with possible risks of failure, because instantaneous peak flows may be considerably larger than daily averages. Therefore estimation of the instantaneous peak flows is often needed for simulation of the reservoir operation based on the hydraulic characteristics of the structures and the operation rules. Because there is often a lack of instantaneous flow data at a given site of interest, the peak flow has to be estimated. This paper develops a new ANN based method to estimate the instantaneous peak flow from mean daily flow data. This methodology was successfully applied to a series of flow information from gauging stations in Iran, with important improvements compared to the traditional methods available in the literature.
Keywords: Peak flow, Daily flow, Estimation, Hydrology data, Flood flow, Hydraulic design

INTRODUCTION

The first step in designing a culvert or bridge for a particular location is to determine the design flood . This is the flood that the culvert or bridge must be able to carry safely. This involves first choosing the return period for the design flood, which involves considerations of cost, risk, consequences of failure, how to deal with uncertainty and so on. Design flood is an instantaneous peak discharge with a specific return period.

The design and operation of hydraulic structures often depends on knowledge of instantaneous reservoir inflows. In particular, estimation of the design floods of hydraulic structures requires the determination of instantaneous peak flows because there may be significant stream flow fluctuations within hours or even minutes, especially in case of small basins (drainage area up to 1000 km^2). Another interesting aspect of this issue is related to the process by which gauge operating agencies evaluate and maintain hydrological data. Usually these agencies publish only the mean daily flow data, and the use of these data in flood studies may cause underestimation of the design flood with possible risk of failure. In many hydrologic studies, particularly flood routing in reservoirs or channels, it is necessary to use the complete flood hydrograph. An important input to estimate this hydrograph is the instantaneous peak flow. There are several standard ways of estimating quantile, depending on the area and the type of data available.

Methods to estimate the peak flow based on mean daily data have been studied by hydrologists for almost a century. To tackle this problem, basically two different approaches have been used. The first approach includes methods that seek a relationship between the so-called peak flow coefficient, defined as the ratio of instantaneous peak, and the corresponding mean daily flow, with physiographic characteristics of the basin (Fuller [2]; Silva [7]; Silva and Tucci [8]). The second approach includes methods that use the sequence of mean daily flow data to estimate the peak flow (Jarvis [3]; Langbein [4]; Linsley *et al.* [5]; Sangal [6]). Using new data deriven techniques such as artificial neural networks (ANN) is another possibility to apply for solving this problem. In this research after evaluation of some existing methods, a ANN based model has been developed and used to estimate instantaneous peak flow using daily flow data.

MATERIALS AND METHODS

Methods used in this research are briefly presented in the following:

Fulle's method:

Fuller's [2] study used data from 24 river basins with drainage areas varying from 3.06 to 151,592 km^2 and proposed the following relationship:

$$Q_{\max} = Q\left(1 + 2.66A^{0.3}\right) \tag{1}$$

where Q_{max}= predicted peak flow (m^3/s);Q=maximum mean daily flow (m^3/s); A=drainage area (km^2).

Following Fuller's method, many other authors have presented some relationship between the ratio of peak flow and the mean daily flow as a function of the drainage area for different regions of the world. Table 1 summarizes several formulas proposed in the literature.

Table 1. Relation between Then Ratio of Peak Flow and Mean Daily Flow as Function of Drainage Area in Literature (Fill and Alexandre [1])

Equation	Region of study	Author
$Q_{max}/Q_d = 3.9A^{*-0.22}$	Rocky Mountains	Gray(1973)
$Q_{max}/Q_d = 10A^{*-0.46}$	Cypress Hills	Gray(1973)
$Q_{max}/Q_d = 11A^{*-0.26}$	Central Plains	Gray(1973)
$Q_{max}/Q_d = 0.37A^{*-0.38}$	Manitoba Encarp	Gray(1973)
$Q_{max}/Q_d = 1+1.2A^{-0.036}$	Portugal	Correia(1983)
$Q_{max}/Q_m = 1+68A^{-0.5}$	Italy	Tonini(1939)
$Q_{max}/Q_m = 32A^{-0.313}$	Italy (A<120km^2)	Cottechina(1965)
$Q_{max}/Q_m = 16A^{-0.19}$	Italy(A>120km^2)	Cottechina(1965)

Equation	Region of study	Author
$Q_{max}/Q_m = 2.39A^{-0.112}$	Italy	Tonini(1969)
$Q_{max}/Q_d = 1+15.03A^{-0.59}$	Brazil	Tucci(1991)

Sangal's method:

A more recently and the well known technique proposed by Sangal [6], which based on the assumption of a triangular hydrograph, proposes the equation:

$$Q_{max} = \frac{(4Q_2 - Q_1 - Q_3)}{2} \quad (2)$$

where: Q_{max} = predicted instantaneous peak flow (m^3/s);Q_2= mean daily flow of the day that contains the peak (m^3/s);and Q_1 and Q_3=mean daily flow for the posterior and anterior day (m^3/s), respectively.

In his study, Sangal used the mean daily flow data of three consecutive days. He tested the method with streams in Ontario, Canada, using 3,946 station-years of flow data collected from 387 stations. The method leads to results with reasonable accuracy, but it is downward biased for small basins.

Despite the fact that almost half of the data used in Sangal's study are from snow-melt floods, his method has been widely used in practice for flood routing through reservoirs for feasibility studies of hydroelectric plants in different parts of the World. For watersheds with drainage areas greater than 1,000 km^2, results based on Sangal [6].'s method have indicated that calculated peak flow values are significantly higher (about 50%) than the observed values. This trend of overestimating theoretical peak flows has been the motivation to review Sangal's methodology.

Fill and Alexandre Method:

Fill and Alexandre [1] presented a formula similar to Sangal's method to estimate the instantaneous peak flow from the mean daily flow of three consecutive days including the peak day was developed in this study. The three days are the day with maximum mean daily flow and the adjacent days. Similar to Sangal's formula, it is assumed that the peak flow could be estimated by a linear combination of the mean daily flows of these days:

$$Q_{max} = 0.8Q_2 + 0.25(Q_1 + Q_3) \quad (3)$$

where: Q_{max}=predicted instantaneous peak flow (m3/s);Q_2=mean daily flow of the peak day (m3/s);Q_1 and Q_3=mean daily flows of the day preceding and succeeding the peak day (m^3/s), respectively.

ANN based method:

In this research in addition to three above mentioned methods, the new ANN (Artificial Neural Network) technique was used to estimate instantaneous peak flow data series using daily measured flow data. The artificial neural network architecture used was a three-layer perceptron feedforward (MLP) network. This type of network is normally trained with the backpropagation algorithm. The backpropagation rule, propagates the errors through the network and allows adoption of hidden processing elements. One hidden layer with a tangent hyperbolic transfer function was used, while the output layer function was a logistic one.

Data Used

Records of mean daily flow and peak flow data from 12 stations from different places in Iran were applied in this study. Drainage area varied from 418 to 10110 km^2. Table 2 shows the gauging stations used, the river, drainage area, and location at each site.

Table 2. The gauging stations used used in this research

Station name	River	Latitude	Longitude	Elevation (above sea)	Drainage area (km^2)
Bande_ormieh	Shahrchai	37º 30'	45º 01'	1390	418
Vaniar	Ajichai	38º 07'	46º 24'	1450	7432
Miandoab	Siminerood	36º 57'	46º 03'	1290	3368
Sarabhandeh	Golpaygan	32º 21'	50º 00'	2000	817
Tamr	Gorganrood	37º 28'	55º 29'	132	1524
Ghazaghli	Gorganrood	37º 13'	55º 00'	30	6560
Agh-ghala	Gorganrood	37º 01'	54º 27'	-12	10110
Sira	Karaj	36º 02'	51º 09'	1790	725
Ghaleshahrokh	Zayanderood	32º 39'	50º 28'	2100	1440
Simindasht	Hablerood	35º 31'	52º 31'	1435	2254
Bonkooh	Hablerood	35º 18'	52º 25'	1000	3209
Mashin	Roode_zard	31º 23'	49º 43'	380	875

RESULTS AND DISCUSSION

For comparison between the proposed ANN method and those of Fuller, Sanga and Fill the values of correlation coefficient (R) and RMSE have been computed for each site and. The results are shown in Table 3.

Table 3. Comparison of correlation coefficient and RMSE of Proposed ANN and Fuller, Sangal and H.D.Fill Formulas and the ANN model.

Station name	Relative RMSE				R			
	Fuller	Sangal	H.D.Fill	ANN	Fuller	Sangal	H.D.Fill	ANN
Bande_ormieh	75.8	72.04	75.9	8.36	0.71	0.73	0.74	0.99
Vaniar	40.45	76.75	74.7	69.92	0.89	0.60	0.68	0.97
Miandoab	36.4	68.82	48	19.1	0.96	0.92	0.93	0.99
Sarabhandeh	26.9	30.48	32.13	13.04	0.93	0.92	0.94	0.96
Tamr	39.83	29.79	28.69	15.84	0.81	0.87	0.90	0.93
Ghazaghli	17	35.6	27.27	9.7	0.97	0.91	0.92	0.99
Agh-ghala	29	62.53	41.24	4.59	0.99	0.96	0.97	0.99
Sira	18	26.5	28.04	4.24	0.92	0.85	0.87	0.99
Ghaleshahrokh	102.7	181.43	185.01	36.67	0.90	0.61	0.62	0.85
Simindasht	11.8	13.93	16	21.11	0.90	0.86	0.85	0.96
Bonkooh	84.7	72.04	83.13	42.16	0.71	0.69	0.67	0.89
Mashin	329	29.79	238.28	74.39	0.87	0.91	0.91	0.93

It can be observed that the proposed ANN based method displays an average relative RMSE considerably lower and also R higher than any of the used traditional methods. The only case where the R of the Fuller method is higher than the ANN based one is the Ghaleshahrokh. Except this case in all other stations the accuracy of the ANN based method is higher than those produced by other three mentioned approaches. Comparing the results taken from this research shows high ability of ANN over the existing mentioned methods for this specific application, although there was a considerable improvement of the results for empirical methods after calibration. Important improvements of the results produced by the new method compared to the traditional methods, show superior abilities of new machine learning techniques to solve the problem inadequate measured peak flow periods, and optimize water related designs. In fact the proposed method improves considerably the accuracy and precision of other traditional methods. This suggests it is a good method for estimating instantaneous peak flows for flood studies in the design of hydraulic structures when only mean daily flows are known. A regional analysis is possible using different regressions for each basin or group of similar basins if a sufficient number of data is available. This approach may perhaps result in further improvement of the accuracy. Off course the methodology proposed in this study is not the last step for the estimation of instantaneous peak flows. More research in this subject is recommended in order to obtain better estimators including methods using basin physiographic characteristics.

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