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The Evaluation Models of the Maximum Daily Mean Discharge Using Physiographic Characteristics for the Western Watersheds in Iran

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Abstract: *Flood is one of the events that has attracted attention of hydrologists. In this work, one of the important indices of flood, the maximum-daily mean-discharge, is determined for some western Iran watersheds of indices: Gamasiab, Qaresoo, Seymareh, Kashkan, Sezar and Abshineh.*

Daily mean data was chosen from stream-gauging stations and a 30-year common period was selected and flood frequency analysis was done using HYFA and TR software and the best distribution was chosen using the goodness of fit tests. Then, discharge values with different return periods of 2, 5, 10, 25, 50, 100, 500 and 1000 years were evaluated. Modeling was done using the regional analysis by multiple regression technique between maximum-daily mean-discharge and physiographic characteristics of the basins. The main parameter for choosing the model was the adjusted coefficient of determination, and the meaningful level was standard error, and observed discharger was proved by computed discharge plot. So, different models with different parameters were selected from the power, exponential, linear and logarithmic models. But the power model was the one that was used more than the others. According to this work, the main parameters that affect discharge are: channel length, drainage density and time of concentration. Considering the errors, it is concluded that increasing the return period results in an increase in the model error, in a way that for a 1000-year return period, the error reaches 32.2%.

Keywords: *Flood, HYFA and TR Software, Discharge, Regression*

1. INTRODUCTION

Every year around the world lives and properties of people are destroyed because of flood. So it's crucial to consider the parameters of the discharge for both designing the water supplies facilities and flood control.

One of the parameters which is widely used in organizing water supplies, is the maximum-daily mean-discharge. The maximum-daily mean-discharge is the highest measured daily discharge in every year [3, 10]. Since the number of available data of the maximum *instantaneous* discharge is not enough in most of stations, the maximum-daily mean-discharge is used instead in most of the limitation modeling projects.

To evaluate the flood, discharge different models are used around the world. Most of the researchers study the maximum *instantaneous* discharge and then the maximum-daily mean-discharge because of their importance in water plans.

Using the data of 68 *hydrometric* stations in Scotland, Acreman [5] proposed an equation to calculate the maximum-daily mean-discharge:

$$Q = C(A)^{0.94}(R)^{1.03}(F)^{0.27}(S_0)^{1.23}(S_{10-85})^{0.16}(L_a+1)^{-0.85}$$

Where in:

Q=the maximum-daily mean-discharge (m^3 per sec)

C=regional constant

A=drainage area (km^3)

R=depth of the 1-day rainfall of 5-year return period (M51D) minus the effective mean soil moisture index (mm)

F=stream frequency (junctions in each km^2)

S_0=soil type index

S_{10-85}=slope of the 10-85% of stream (m per km)

L_a=fraction of the basin draining through a lake or reservoir.

Since the effective parameters in flood are used in this equation (although there are many difficulties in calculating them), it is applicable with god precision in Scotland and even other countries by varying the index C as the regional constant.

Mimikou and Gordios [9] proposed the below equation for 11 watersheds in Greece:

$$Q = 2.73\times10^{-8}(A)^{1.072}(P)^{2.317}(S)^{0.982}(F)^{0.216}(S_0)^{3.266}$$

Where in:

P=mean annual areal precipitation (mm)

S=slope of the main river course (m.km).

Using the data of 49 *hydrometric* stations in Fars, Mousavi and Sepaskhah [4] proposed an equation to calculate the maximum-daily mean-discharge:

$$Q_i = a_0(A)^{a1}(P)^{a2}$$

Where in:

Q_i= the maximum-daily mean-discharge with i return period (m^3 per sec)

A= drainage area (km^3)

P= mean annual areal precipitation (mm)

a_0, a_1 and a_2=regional index and constant.

The aim of this work is to predict the maximum-daily mean-discharge for some western watersheds of Iran, Gamasiab, Qaresoo, Seymareh, Kashkan, Sezar and Abshineh. This prediction is done establishing connection among the maximum-daily mean-discharge with physiographic characteristics of watersheds.

2. Materials and Methods

In the basins where the data of floods are available, it is easy to predict the maximum-daily mean-discharge. But in the basins without available data, modeling methods should be used. Some common methods are:

- index flood method
- statistical estimation of moments
- empirical equations
- *synthetic* unit hydrograph
- simulation
- Statistical and probability method.

A method should be chosen that:

- doesn't need complicated data

- doesn't need to be confirmed by a person
- isn't limited theoretically
- and is not time consuming.

According to the characteristics of the studied basin and available data and after required analysis, statistical method was selected as the optimum method to estimate the maximum-daily mean-discharge. In order to use this method these steps should be done:

2.1. Preparing Available Sources and Maps of the Basin

All of the sources for estimating the daily discharges in the basin like topographic maps were collected and statistic data of hydrometric stations are selected.

2.2. Controlling, Correcting and Completing the Statistical Data

Hydrologic data should be controlled so the statistical analysis be valid. Also, destroyed data should be obtained using the correlation of adjacent stations having more data.

2.3. Determining the Physiographic and Rainfall Characteristics of the Basin

Physical characteristics of the basin are the parameters whose values are constant during the time for each basin. Using these parameters as independent variant in regression equations, the maximum-daily mean-discharge can be obtained. In this work, parameters like the length of channel, the mean slope of the basin, forest cover, the elevation and elongation ratios are considered as independent variants. Table 1 represents the physiographic and rainfall characteristics of the basins. In this table, Do-ab and Pol-e-Chehr stations are located in Gamasiab watershed, Do-ab Marg, Pol-e-Kohnehand Qurbaqestan stations are located in Qaresoo watershed, Halilan station is located in Seymareh watershed, Pol-e-Kashkan, Afarineh and Pol-e- Dokhtarstations are located in Kashkan watershed, Yalfan station is located in Abshineh watershed and Sepid Dasht station is located in Sezar watershed.

station Parameter	Afarineh	Pol Jahar	Pol dokhtar	Pol Keshan	Pol kohneh	Doab	Doab Marg	Sepid Dasht	Ghorbaghestan	Helian	Yalfan
Space of zone (km^2)	7588.8	10884.4	9166.3	3711.7	4973.1	7753.8	2656.3	3139.3	5216.3	20474.4	260.0
Perimeter of area (km)	440.0	652.1	547.5	410	406.3	502.5	362.5	350.0	405.5	952.5	78.8
Mean height of zone (km)	1860	1827	1710	1790	1513	1889	1523	1874	1545	952	2408
Main channel(km)	245.0	245.3	287.5	197.5	190.0	177.5	122.5	123.0	207.8	365.5	33.4
total length of channels (km)	10396.6	13496.7	11366.2	5159.3	5520.2	10932.8	2921.9	1192.9	5894.4	27231.0	286.0
Main slope of zone	30.9	24.1	29.5	33.2	16.2	17.9	11.3	27.2	16.3	23.4	24.5
Flange slope	0.0061	0.0033	0.0055	0.0062	0.0052	0.0039	0.0043	0.0100	0.0052	0.0026	0.0220
circularity ratio	0.490	0.320	0.384	0.280	0.379	0.390	0.254	0.320	0.399	0.280	0.530
Elongation ratio	0.950	0.730	0.880	0.680	0.980	0.810	0.778	0.727	0.860	0.890	0.610
Diameter of sphere (km)	98.3	117.7	108.0	68.8	79.6	99.4	58.2	63.2	81.5	161.5	18.2
Gravelius index	1.41	1.75	1.60	1.88	1.61	1.60	1.97	1.75	1.57	1.86	1.37
Length of rectangle (km)	176.3	288.3	234.4	184.4	174.2	215.6	165.3	154.8	172.2	427.3	31.1
Drainage density (km on km^2)	1.37	1.24	1.24	1.39	1.11	1.41	1.10	0.38	1.13	1.33	1.10
concentration time (hours)	24.5	26.7	28.2	19.6	7.6	19.0	13.6	9.4	11.5	40.3	5.0
Annual main fall (mm)	482	443	417	307	489.6	490	490	697	393	433	395

2.4. Analyzing the Flood Magnitude

To analyze the flood magnitude, probability analysis is used. Previous data are used to predict and estimate future events in magnitude studies. If the data are reliable, estimations would be satisfying. But practically, there is no long-period data and usually flood prediction should be done for return periods longer then the data period.

According to the definition, average time until the next occurrence of a defined event is the mean return period or just return period [1, 7, 8]. It should be noted that the return period is a statistical concept and is not a periodic one. To analyze the flood magnitude, the distribution of each data should be determined. The most popular distributions in hydrology are normal, log-normal, Pearson type III, log Pearson type III, Gumbel, log Gumbel, gamma and log gamma. Cicioni and coworkers analyzed the data of 108 rivers in Italy using two and three parameters log-normal, two parameter gamma, Pearson type III and Gumbel distributions and concluded that two parameters log-normal distribution is the best. Also Mousavi and Sepaskhah [4] has chosen two parameters log-normal distribution to fit the data of the maximum-daily mean-discharge for 11 stations of Fars.

The answer to the question that which one of the above methods is the best is the goodness of fit test [2]. Actually none of these distributions perfectly fit data and a comparative analysis can be done. The most common methods for comparing these distributions are the chi-square, the Kolmogorov-Smirnov and the least square.

2.5. Regional Analysis

Regional analysis is a method that expands the site-based analysis to the whole area. Using this method data can be transferred from the basin having data to the basin without data. Because of the presence of all statistical stations in regional analysis, the multiple regression method is used to estimate the maximum-daily mean-discharge for the basins without data.

According to [2], Cruff and Rantzstudied many methods to analysis regional floods and concluded that the multiple-regression analysis is the best one to predict flood. Actually the multiple-regression analysis estimates the discharges using independent variants of the basin and the others are considered as chance parameters [1, 11].

To model by regression, two questions should be answered: which parameters should be included? And which model should be chosen? To answer the first question, in many cases the parameters are not pre-chosen in the model. So, the parameters should be chosen that are the most effective in flood and have the least in dependency to each other. In choosing the model, the simplicity and good fit of data should be considered. In this work, four models are used: linear, exponential, logarithmic and polynomial respectively:

$$Q = B_0 + B_1 X_1 + B_2 X_2 + \ldots + B_k X_k \quad [4]$$

$$Q = \exp(B_0 + B_1 X_1 + B_2 X_2 + \ldots + B_k X_k) \quad [5]$$

$$Q = B_0 + B_1 \ln X_1 + B_2 \ln X_2 + \ldots + B_k \ln X_k \quad [6]$$

$$Q = B_0 (X_1)^{B_1} (X_2)^{B_2} \ldots (X_k)^{B_k} \quad [7]$$

The assessment factor in choosing models is the determination coefficient of r^2 and the corrected determination coefficient of r^2_a [6]. Also the factors of standard error of the model and the calculated and observed diagrams of discharges are used as controller.

3. Error Analysis

To estimate the error of predicting the discharge by regression equation, error analysis is used. This is done in two ways:

a) standard error of the estimate

Standard error is calculated using this formula:

$$SE = \left[\frac{\sum (Q_0 - Q_E)^2}{n - p - 1} \right]^{0.5} \quad [8]$$

b) the average percent error of the model

In this method, firstly the percent error is calculated and then the average percent of error is used as the average percent error of the model:

$$E_i = \frac{Q_0 - Q_E}{Q_0} \times 100 \quad [9]$$

$$ME = \frac{1}{n} \sum E_i \quad [10]$$

SE= standard error

ME= mean error

Q_0= the reported discharge

Q_E= the calculated discharge

n and p= the number of hydrometric stations and parameters of the model

E_i= percentage of error

4. Results And Conclusion

After completing the statistics, a basic 30-year period was chosen for the maximum-daily mean-discharge. Spot-based analysis was done using HYFA and TR software and the probability distribution were fitted to the data. The results of the fitting of the distribution functions are presented in Table 2. As it can be seen in this table, the RSS is the selection factor; the less this parameter is, the better is the distribution. The Kolmogorov-Smirnov factors and chi-square are used as the controller.

Station	Distribution	Degree Of Freedom	Sum Of Squares	Kolmogorov Critical Smirnov	Kolmogorov Smirnov	Kai Scholes	Critical Kai Scholes	Best Distribution
Afarineh	Gama	3	38.01	0.097	0.188	1.097	7.81	Gama
	Gamble	2	39.17	0.085	0.188	0.452	5.99	
Pol chehr	Gama log	2	21.29	0.070	0.188	0.774	5.99	Gama Log
	Normal log	2	23.33	0.075	0.188	1.097	5.99	
	Gamble	2	28.49	0.116	0.188	4.968	5.99	
Pol dokhtar	Gamble	2	62.10	0.128	0.188	2.065	5.99	Normal log
	Gama	3	64.07	0.143	0.188	7.871	7.81	
	Pierson log type 3	1	65.87	0.134	0.188	6.903	3.84	
Pol Keshan	Normal log	2	35.21	0.092	0.188	1.097	5.99	Pierson log type 3
	Pierson log type 3	1	38.06	0.011	0.188	2.065	3.84	
	Gama log	2	38.29	0.078	0.188	1.097	5.99	
Pol kohneh	Pierson	2	74.92	0.121	0.188	7.548	5.99	Gamble Log
	Gambel log	1	109.11	0.302	0.188	1.270	3.84	
	Pierson log type 3	1	112.62	0.078	0.188	0.452	3.84	
Doab	Gama log	2	16.73	0.061	0.188	2.386	5.99	Gama Log
	Normal log	2	18.66	0.080	0.188	2.386	5.99	
	Cambertson log type 3	1	19.72	0.084	0.188	2.386	3.84	
Doab Marg	Normal log	2	11.27	0.096	0.188	1.097	5.99	Normal log
	Pierson log	1	11.29	0.091	0.188	1.742	3.84	
	Gama log	2	12.39	0.075	0.188	1.742	5.99	
Sepid Dasht	Pierson log type 3	1	53.43	0.079	0.188	0.774	3.84	Pierson log type 3
	Gama log	2	55.70	0.083	0.188	0.774	5.99	
	Pierson log	1	60.40	0.094	0.188	6.258	3.84	
Ghorba ghestan	Gamble log	2	44.37	0.117	0.188	5.260	5.99	Log Gamble
	Pierson log type 3	1	79.54	0.103	0.188	4.968	3.84	
	Pierson	1	81.00	0.230	0.188	15.290	3.84	
Helian	Log Gamble	2	78.08	0.091	0.188	0.774	5.99	Log Gamble
	Pierson log type 3	1	188.60	0.073	0.188	0.774	3.84	
	Pierson	1	198.02	0.119	0.188	2.065	3.84	
Yalfan	Gamble	2	0.18	0.081	0.188	2.471	5.99	Gamble
	Pierson log type 3	1	0.24	0.049	0.188	1.294	3.84	
	Pierson	1	0.25	0.168	0.188	1.294	3.84	

In all cases, the Kolmogorov-Smirnov factor is less than the crucial value. So, according to this test, no distribution is failed. In Pol-e-Kohneh station, the Pearson type III has less RSS value than log Gumbel distribution. But as the chi-square of this distribution is larger than the chi-square of the table, the log Gumbel distribution is chosen. Because for each station separate distribution is obtained, a common distribution for whole area couldn't be proposed and a different distribution should be used for each station.

The next step is determining the flood prediction model. This is done using SPSS software and the step by step approach. Using statistical analysis, the best model was selected from the four models of linear, exponential, logarithmic and polynomial. Among these four models, the selected one has these characteristics:

- The value of the determination coefficient and the corrected determination coefficient are closer to 1.
- Meaningfulness of the regression equation factors hypothesis is satisfied. This is done from the F, Fisher comparison calculated from the model and the value of the table.
- The error of the model is small.
- In the case of interpolating the reported value of discharge against the calculated values, the fitted line has these features:

➢ The line should be a good estimation of the data scattering

➢ The value of the slope of the line and distance from origin should be near 1 and 0 respectively.

➢ In the case of plotting the reliance curves, the number of data outside these curves should be minimum.

- The model should be simple (the number of independent variables should be minimum).

Based on what has been said, a comparison has been done among the mentioned factors and the best model was selected.

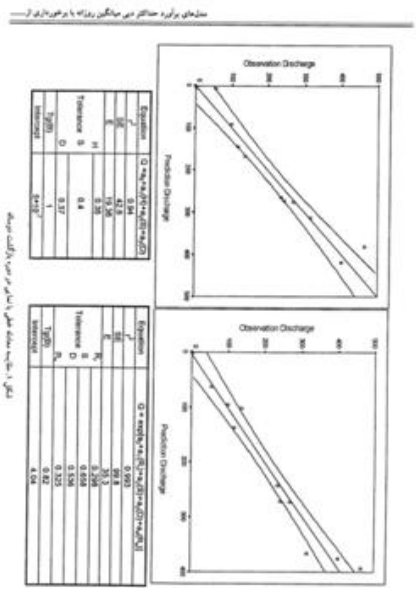

Figure1. *Comparison of linear equation with exponential over period of two-year return*

Figure 1 shows a model with a 2-year return period. Two linear and exponential models are compared here. Although the exponential model has the determination coefficient of 0.993 and the linear model has the determination coefficient of 0.94, the linear model is selected, because the linear model has less error compared to the exponential model and the fitted line has better features (the slope of 1 and the distance from origin of 0). Also, the number of data outside the reliance curves is less for the linear model. It should be noticed that the tolerance parameters are not crucial in these two methods (the values of tolerance are not close to 1).

Table 3 represents the characteristics of the basic models for different return periods and the way of selecting it. As it can be seen, the main factor for choosing the model is the determination coefficient and the F values and the number of parameters of the model have been used inspectionally.

Model Characterization								
Return period	Type of model	determination coefficient	Corrected determination coefficient	Number of model's parameter	F fisher model	F fisher from table	Level of identification	Selected model
2	linear	0.94	0.914	3	36	4.35	0.00012	linear
	exponential	0.993	0.988	4	199	4.53	0.0000016	
	Logarithmic	0.575	0.528	1	12	5.12	0.007	
	Power series	0.959	0.949	2	94	4.46	0.0000027	
5	linear	0.933	0.904	3	33	4.35	0.00017	Exponential
	exponential	0.988	0.980	4	123	4.53	0.0000069	
	Logarithmic	0.754	0.692	2	12	4.46	0.004	
	Power series	0.967	0.959	2	118	4.46	0.0000011	
10	linear	0.878	0.848	2	29	4.46	0.0002	Power series
	exponential	0.982	0.971	4	84	4.53	0.000021	
	Logarithmic	0.559	0.509	1	11	5.12	0.008	
	Power series	0.974	0.968	2	151	4.46	0.0000004	
25	linear	0.868	0.836	2	26	4.46	0.0003	Power series
	exponential	0.757	0.730	1	28	5.12	0.0005	
	Logarithmic	0.903	0.879	2	37	4.46	0.000087	
	Power series	0.975	0.969	2	157	4.46	0.0000004	
50	linear	0.701	0.668	1	21	5.12	0.001	Power series
	exponential	0.758	0.731	1	28	5.12	0.00048	
	Logarithmic	0.909	0.887	2	40	4.46	0.000068	
	Power series	0.968	0.959	2	119	4.46	0.0000011	
100	linear	0.698	0.664	1	21	5.12	0.001	Power series
	exponential	0.751	0.723	1	27	5.12	0.001	
	Logarithmic	0.891	0.864	2	33	4.46	0.00014	
	Power series	0.976	0.966	3	96	4.35	0.0000046	
500	linear	0.972	0.954	4	53	4.53	0.000083	Power series
	exponential	0.701	0.668	1	21	5.12	0.001	
	Logarithmic	0.802	0.780	1	36	5.12	0.00019	
	Power series	0.954	0.934	3	48	4.35	0.000048	
1000	linear	0.829	0.786	2	19	4.46	0.001	Power series
	exponential	0.696	0.664	1	21	5.12	0.001	
	Logarithmic	0.791	0.768	1	34	5.12	0.0002	
	Power series	0.906	0.882	2	38	4.46	0.000079	

The final result of selection of the maximum-daily mean-discharge is reported in Table 4. It is seen in this Table that the maximum-daily mean-discharge with two- or five-year return period are estimated using linear and exponential models, and other return period are estimated with polynomial model. The parameters of length of the main channel and drainage density have the most part in discharge. This can be because the area is mountainous. The parameter of the concentration time is negative in some equations. So for the basins which are extended, the magnitude of the discharge is more than the basins which are flat for the same area.

Equation	Determination Coefficient
$Q_2=83.37+1.4(L)+9.2(S)-167.98(D)$	0.94
$Q_5=4.86+289.91(R_r)+0.11(S)-1.88(D)$	0.988
$Q_{10}= 28.67*10^{-5}(L)^{2.772}(D)^{-1.541}$	0.974
$Q_{25}=37.4*10^{-5}(L)^{2.746}(D)^{-1.571}$	0.975
$Q_{50}=46.24*10^{-5}(L)^{3.41}(D)^{-1.304}(T_C)^{0.844}$	0.976
$Q_{500}=76.1*10^{-7}(P)^{2.412}(T_C)^{-2.13}(L)^{2.008}$	0.954
$Q1000=16.5*10^{-7}(P)^{4.455}(D)^{-2.188}$	0.906

As it can be seen the obtained figures are different from the figures obtained by other researchers, because the used physiological characteristics in this work is different from that are used in other works around the world. The physiographic and climate characteristics such as the basin area, the mean altitude of the basin, the maximum and minimum altitude of the basin, length of the main channel, the total length of channels, the soil type index, the mean slope of the basin, the slope of the 10-85% of the main stream, the elongation ratio, the circularity ratio, the diameter of the conclave circle, Gravois coefficient, the equivalent rectangle length, drainage density, stream frequency, time of concentration, the ratio of lakes, the altitude of rainfall and etc. changes place to place, so the form of obtained equations is not similar. So it is possible that a parameter which is effective in flood for some place doesn't appear in equation for other place.

The largest determination coefficient is for the 5-year return period equation. This equation also has the largest number of physical parameters that cause the regression equation to have more determination parameters. Analyzing the error showed that increasing the return period leads to increasing the value of mean error. This is represented in figure 2. The scope wherein the study is done for calculating the discharge with 2-year return period considering the maximum drainage density in western basins (D=1.5 km in km^2) and the least value of slope (S=10%) L>175 km.

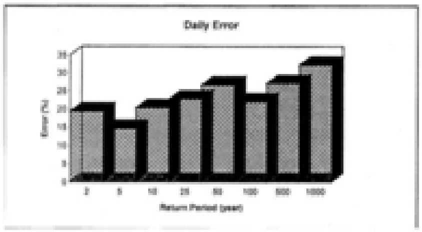

Figure2. *Ratio error rate and return periods*

For discharge with 5-year return period considering that the elongation ratio is rarely more than 0.01, and the drainage factor in western basins is less than 1.5, this equation can be used.

Generally, the channel length (with positive power) and drainage density (with negative power) has more effect on the maximum-daily mean-discharge than other parameters. The time of concentration also affects the maximum-daily mean-discharge with a negative power. Presence of two parameters of time of concentration and channel length in 500-year return period is fine because time of concentration is not just a function of channel length and depends on other parameters. The absence of annual mean rainfall doesn't mean that it has no effect on the maximum-daily mean-discharge, but its effect is less than the other parameters. Mousavi and Sepaskhah have also faced this in some studied basins.

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