Determination of the Best Method for the Extension of Discharge Rating Curve in order to Estimate the corresponding Discharges with Maximum Stages

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Abstract : Direct discharge measurement in rivers costly and time-consuming, and at times, impossible under flood conditions. Therefore, the discharge-stage relation, known as Discharge Rating Curve is used. Moreover, to design hydraulical constituents, the maximum flood discharge and its maximum height are required. Therefore, to calculate the flood discharges, one should extend the discharge rating curve by using appropriate methods. In this study, in order to determine the best method for the extension of discharge-stage curve, and in order to estimate the corresponding discharge with high stages, the logarithmic method, the Manning method, the Chezy method, and the Area-Velocity method were compared and contrasted. In order to verify the methods, 13 hydrometric stations were selected at the Karkheh Area Water Management in Lorestan province. Data measured at each station were gathered for a ten-year statistical period. Results showed that the logarithmic method was more accurate than other methods, and that it was more appropriate for the extension of the curve at the average or lower average discharge stations. The Area-Velocity method, after the logarithmic method especially at the stations with higher average discharge, showed good results. The Manning and Chezy methods showed the least accuracy.

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Key Words: Discharge-stage relation, Discharge Rating Curve, curve extension, Lorestan, Iran.

Introduction

For the purposes of planning and management of water resources, execution .of watershed management projects, forecast of floods, engineering planning, reserve operations, water supplying, shipping, recreation, and environmental management, it is necessary to be aware of the flow discharge information and data. Discharge direct measurement is time-consuming, costly, and at times impossible under flood conditions. Therefore, most discharge data are obtained from changing the measured water height into discharge by the discharge rating curve (discharge-stage), with this curves causing discharge to be determined easily and at a low price [6]. Moreover, the designing of most hydraulical constructions such as dams, bridges, etc. is based on the maximum flood discharge and its maximum height. There are several difficulties in determining the flood discharge, such as the high speed of water, its transitory nature, the existence of different floaters along the water, and difficulties is getting access to a station [5]. Therefore, there are many instances when it is not possible to measure the peak discharge under flood conditions, and rarely the existing statistics for the discharge-stage relation optimal for the discharges of flood plans.

Moreover, due to the decreased cure slope at the end, the selection of the most appropriate method to extend the curve becomes increasingly important. E.M Shaw (1994), introduces the Manning method and the Chezy (Stevenson) method for the extension of discharge rating curve, preferring the Manning method to the Chezy method in the extension of discharge-stage curve [7]. Batacharya & Solomatine (2005) have expressed as positive the results of using the Artificial Neural Network in the extension of discharge-stage curve [1]. James (1998), introduces the principles of routing by Muskingum method for the optimization of discharge-stage curve parameters in the form of an power function in the Sabie River in South Africa [2]. Lee et.al (2002), compared radar remote sensing flood discharge measurement to the discharges estimated by discharge-stage curves. Results showed that the remote sensing technique for the measurement of river discharges were highly effective, especially for big river [4]. In the present research, we intent to compare different methods for the extension of discharge rating curve in order to estimate the corresponding discharge with high levels of the river water, the measurement of such discharges being impossible due to the difficulties mentioned above.

Materials and Methods

1. The region under study

To conduct the present study, 13 hydrometric stations were selected at the Karkheh Area water Management, situated in Lorestan province western Iran (Fig.1 and Table1). The area covers 16.85 thousand square kilometers, and it is situated at the geographical position 32 degrees and

48 minutes up to 34 degrees and 5 minutes Northern latitude, and 47 degrees and 9 minutes up to 48 degrees and 52 minutes Eastern longitude. The most important rivers in this area are as follows: the Saymareh River with an average water output of 92 cubic meters per second annually, and the Kashkan River with an annual average water output of 48 CM/S. For this study, an available ten-year statistical period, from the water year of 1997-1998 to 2006-2007, was selected for the stations.

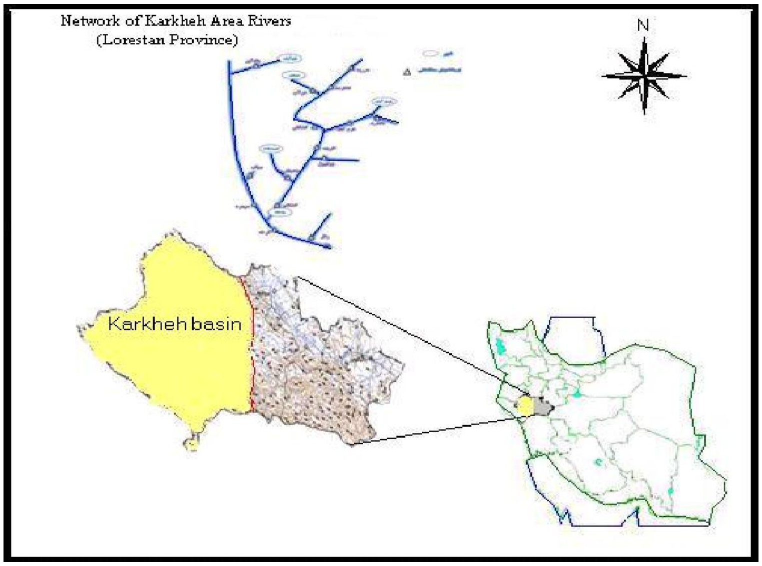

Figure 1. Situational conditions under study in Iran

Table 1. Detailed Information about the hydrometrical stations in the region under study

No.	River	Station	Rank or class station	Height from the sea level (m)	Area (flowing area) (km^2)	Year of inauguration
1	Bad avar	Noorabad	1	1870	615	1967
2	Saymareh	Nazarabad	1	780	2643	1959
3	Dare dozdan	Tangsiab	2	880	548	1970
4	Har rood	Kakareza	1	1530	1152	1954
5	Har rood	Dehno	3	1770	1960	1969
6	Do ab	Sarab seidali	1	1520	776	1954
7	Kashkan	Doab vaysian	1	1000	3668	1968
8	Khoramabad	Cham anjir	1	1140	1590	1954
9	Kashkan	Afrineh	1	820	6700	1955
10	Cholhol	Afrineh	2	1800	800	1955
11	Madianrood	Baraftab	3	790	1108	1970
12	Kashkan	Poldokhtar	1	650	9060	1955
13	kakasharaf	Chenar khoshk	2	1420	234	1988

2. Methods under study for the extension of discharge-stage curve

Among different methods recognized as ways for the extension of discharge-stage curves, four methods which have been commonly used were selected. These methods are as follows: the logarithmic method, the Manning method, the Chezy method, and the Area-Velocity method.

2.1. The logarithmic method

It is often assumed that the general equation of discharge rating curve is almost partial in form, and their general formula is follows:

$$Q = c(H - a)^b \quad (1)$$

Where, Q is the river discharge (m^3/s), 'H' is the height of water on the stage (cm), and a, b, c are the constant values (or quantities) of each station. As compared to a simple scale, the logarithmic scale has an advantage in that the curve is drawn in the form of a straight line, making it easily extendable; if we take logarithmic form the sides of the above equation, it will be in the following form: [9]

$$LogQ = bLog(H-a) + Logc \tag{2}$$

$$Y = \beta X + \alpha \qquad \{\, Y = \log Q \;,\quad X = \log(H-a) \;,\quad \alpha = \log c \,\} \tag{3}$$

To choose the best straight line from N observation of X, Y, we have:

$$\beta = \frac{[N(\sum XY) - (\sum X)(\sum Y)]}{[N(\sum X^2) - (\sum X)^2]} \tag{4}$$

$$\alpha = \overline{Y} - \beta \overline{X} \tag{5}$$

Now, the discharge-water height relation is obtained by the following equation:

$$(H-a) = \alpha_1 Q^{\beta}$$

$$\{\alpha_1 = antiLog\alpha\} \tag{6}$$

In the above equations, the value of "a" is unknown, and the following way is used to find it:
- The value of "a" may be positive or negative. By trial and error, we choose the value of "a" in a way that a straight line is obtained from the drawing of the quantities Q against (H-a) on the logarithmic paper. In fact, "a" is the height between zero stage and the height in which the discharge is zero [5].

2.2. The Manning method

This method is based on hydraulical principles and the characteristics and morphology of the river. The manning formula, according to the SI units, is as follows:

$$Q = A\overline{V} = \frac{\sqrt{S}}{n} * AR^{\frac{2}{3}} \tag{7}$$

Where, "Q" is the discharge on the basis of (m^3/s), "S" is the slope or slant of river floor (m/m), "n" is the coefficient of river coarseness ($sm^{-1/3}$), $\overline{V}$ is the average velocity of flow (m/s), "A" is the area of flow cross-section (m^2), R is the average hydraulical radius (m).

Since "A", "R" are subsets of the flow, the value of $AR^{\frac{2}{3}}$ was calculated for different values of the stage, and a graph was drawn against $AR^{\frac{2}{3}}$ on the basis of the stage. The value of $\sqrt{S}/n$, which is a constant value for the measurement station, was obtained by means of the greatest discharge ever measured. Now, for the estimation of flood discharge, it is necessary for this curve to be extended in a way that the value of $AR^{\frac{2}{3}}$ can be read from the outlined curve for the new stage, and given that $\sqrt{S}/n$ is available, the discharge of new stage was calculated from the Manning equation [9].

2.3. The Chezy method

The Chezy equation can, additionally, be used successfully for the extension of discharge rating curve. For a steady flow, the Chezy method is as follows [6]:

$$Q = A\overline{V} = AC\sqrt{RS} \tag{8}$$

Where, the parameters like those of equation (7), and "C" showing the Checy coefficient.

In this method, the value of $C\sqrt{S}$ is assumed to be constant for the station. For the extension of the curve in this way, the values H and $A\sqrt{R}$ were drawn correspondingly in the form of the graph for all the observed records; for the required stage, the value $A\sqrt{R}$ was estimated from the outlined curve, and assuming the station as constant, and given the Chezy equation, the value of discharge was calculated, corresponding to the stage [6].

2.4. The Area-Velocity method

In this method, two curves were drawn, one based on the average velocity ($\overline{V}$) against the stage (H), and the other on the area of flow cross-section (A) against the stage (H). These two curves can be easily extended. Then, the discharge values were calculated from the required stages (the maximum stages) through establishing correspondence of "$\overline{V}$" and "A" values [6].

3. Calculation of Hydraulical Radius (R)

For all the discharge measurements, the length of wetted area (P) and the area of wetted cross-section were calculated, and the hydraulical radius of flow (R) was obtained on the basis of equation (5):

$$R = \frac{A}{P} \tag{9}$$

4. Calculation of the Chezy coefficient (C)

There are different methods for the determination of Chezy coefficient. The method used in this study is based on the Manning equation [4]. In 1889, an Irish engineer with the name of Manning showed that Chezy coefficient is directly related to $R^{1/6}$ ($C \propto R^{1/6}$). Later it is shown that the coefficient of this proportion is $\frac{1}{n}$, i.e.:

$$C = \frac{1}{n} R^{1/6} \tag{10}$$

5. The criteria or standards for the evaluation of methods under study

For each hydrometric station, all discharges measured data along with other parameters accompanying the ten-year statistical period under study were employed for the execution of methods; for each station, there were about 100 discharge measured during the period. After the data were sorted down in the descending form, 20 percent of upper discharge (the maximum) was left out so that the accuracy of methods under study, in term of extending the discharge-stage curves, could be evaluated; Based on the remaining data, each method was executed, and the values of corresponding discharge of above stages were estimated, and compared to the real values. For the evaluation of methods, two statistical parameters were used: the Root Mean Square Error (RMSE), and the Mean Bias Error (MBE).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Q_o - Q_c)^2} \tag{11}$$

$$MBE = \frac{\sum_{i=1}^{n}(Q_o - Q_c)}{n} \tag{12}$$

Where, Q_c is the estimated discharge value, Q_o is the value of observed (real) discharge, and "n" is the number of data.

In general, the accuracy of method signifies the distance, nearness or farness of estimations to the true or real values. The RMSE parameter shows the accuracy of results, and MBE shows the deviation of results of the used method. And the positive and negative values of MBE show the higher and lower estimates of real values, respectively. The nearer these two criteria to zero, the less difference between estimated values and the observed values, are indicating that the used method has simulated the reality accurately.

Results

After 20 percent of the maximum statistical set of data for a ten-year period for each station was excluded, the extension of discharge rating curve was carried out by means of four methods under study on the basis of the remaining 80 percent of statistical data.

Discharges corresponding to the maximum stages (20 percent) were estimated on the basis of the curve extension by different methods in 13 stations under study, and the MBE and RMSE values of each method in each station were calculated, the results of which are shown in Table 2. Figure 2 shows the extension of discharge rating curve by means of different methods at the Karkheh-Afrineh hydrometrical station.

The results of comparison of error and deviation of different methods for the extension of discharge rating curve at the stations under study show that the logarithmic method is accurate at more stations (7stations), and that, therefore, it has, on average, less error and deviation.

The Manning and Chezy methods showed the same results concerning the extension of discharge-stage curve, each having less error and deviation at three hydrometric stations. Results obtained from the calculation of mean error value in all the 13 hydrometric stations showed that the logarithmic method has the least mean error, following by the Area-Velocity, Manning, and Chezy methods with the least error (Fig. 3).

In the two stations of Khoramabad-Chamanjir and Dareh Dozdan-Tangsiab, due to the absence of a significant relation between the stage and the flow cross-section area, one can not use the Area-Velocity method for the extension of discharge-stage curve.

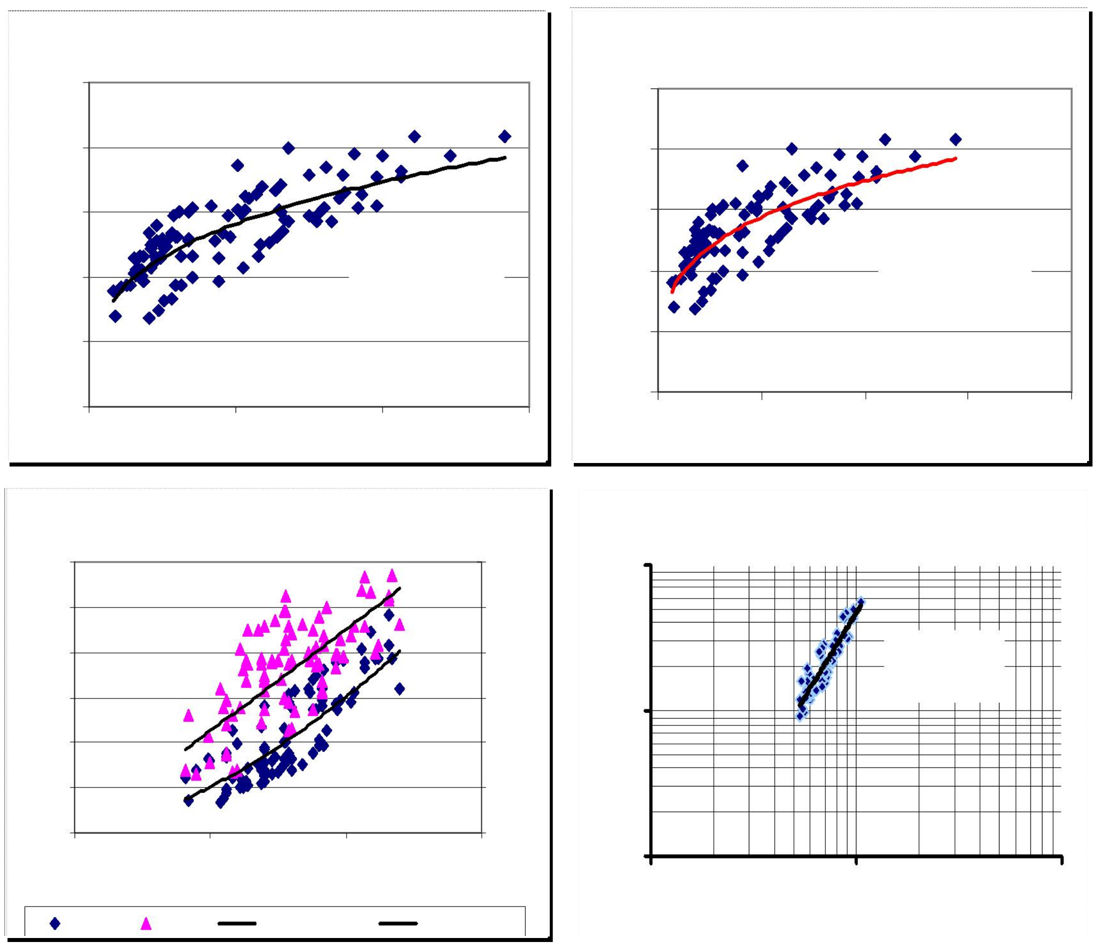

Figure 2. Extension of Discharge Rating Curve by different methods at the Kashkan-Afrineh Station

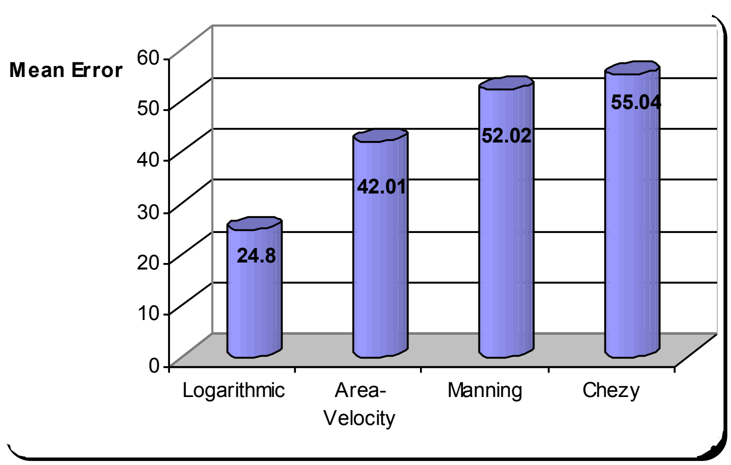

Figure 3. Comparison of Different Methods for the Extension of Discharge-Stage Curve in terms of Mean Error at 13 Stations under study

Table 2. Comparison of Accuracy and Deviation (Bias) among Different Methods for the Extension of Discharge-Stage Curve at the Stations under study

Method	Logarithmic method		Area-Velocity method		Manning method		Chezy method	
Hydrometric Station	**MBE**	**RMSE**	**MBE**	**RMSE**	**MBE**	**RMSE**	**MBE**	**RMSE**
Badavar-Noorabad	-1.72	2.61	-1.42	1.7	-0.06	0.94	0.61	1.69
Khoramabd-Chamanjir	-12	15.35	*	*	-3.61	11.99	0.60	11.16
Dareh dozdan-Tangsiab	-0.15	0.46	*	*	0.71	0.84	0.02	0.40
Saymareh-Nazaabad	-3.20	60.29	-33.96	94.04	-110.9	155.58	-134.52	186.72
Kashkan-Afrineh	-7.74	33.59	-30.54	45.1	-21.21	36.71	-22.73	39.11
Kashkan-Doab Vaysian	-5.31	51.03	-47.65	91.98	-45.71	86.99	-47.48	91.86
Madianrood-Baraftab	-0.10	1.06	1.20	1.75	0.10	0.91	0.72	1.05
Harrood-Dehno	-5.15	8.53	-4.26	7.48	-6.12	9.59	-5.60	9.17
Cholhool-Afrineh	-5.14	12.75	-5.19	11.3	-5.15	9.99	-4.37	9.35
Doab-Sarab Seidali	-2.86	6.36	-2.88	7.13	-3.00	4.85	-6.84	9.87
Kakasharaf-Chenarkhoshk	-0.34	1.79	1.93	2.45	-2.82	4.24	-2.71	4.21
Kashkan-Poldokhtar	-7.71	118.64	-114.1	182.96	-183.8	280.86	-180.4	284
Harrood-Kakareza	-0.7	9.69	-7.56	16.24	-29.58	72.77	-22.27	66.92
Mean	**-4.01**	**24.78**	**-22.22**	**42.01**	**-31.63**	**52.02**	**-32.69**	**55.04**

Discussion and conclusion

Based on the results obtained from the present research, the logarithmic method was recognized as the best method for the extension of curve among the four methods understudy in most stations. In accordance with this method, the discharge-stage curve, which has a partial form, is changed into a straight line, paving the way to extend it easily.

Throughout the stations under study, the logarithmic method is negatively biased (that is, it has a negative deviation), underestimating the discharge, conforming with the results obtained from the studies conducted by Sivapragasam & N.Muttil (2005), concerning the estimation of discharge corresponding to the very high stages by means of the logarithmic method. The comparison of two experimental methods of Chezy and Manning showed the relative superiority and merits of the Manning method. This arises from the fact that the Manning coarseness coefficient, as compared to the Chezy coefficient with the flood and high-stage hydraulic radius shift, will undergo little (if any) change (Shaw, 1994). In the stations which have a lower average discharge, since it is not possible to measure the speed by current meter accurately enough, and, consequently, there is not any appropriate fitness between speed and stage, the Area-Velocity method has a small degree of accuracy in the curve extension; accordingly, it is recommended that such stations be equipped with the measurement constituents of flow such as kinds of weirs. Moreover, the results of this research showed that different methods give different results under changeable conditions of the stations (U. Torsen, M. Gerd, T. Schlurmann, 2002); this fact indicates that there are differences among different methods in the extension of discharge-stage curve. In general, one can say that there is not any method which is absolutely optimal to be used confidently for the extension of discharge-stage curve, and, depending on the conditions of each station, one should test different methods and select the most appropriate one.

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