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Best Practice Approach to Stage-Discharge Rating Curve: Case Study of Selected Rivers in Selangor

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Abstract

A stage-discharge rating curve represents the relationship between the water level at a given point in a stream and a corresponding volumetric rate of flow. It is widely used for the analysis of flow regimes, designing hydraulic structures, flood forecasting, flow-sediment interaction and prediction, and river channel analysis. The reliability and stability of the stage-discharge rating curve are based on numerous numbers of discharges and stage data from the lowest to the highest bank full stage observed over a long period of time. Stage-discharge rating curves contribute to reliable discharge prediction for future flood forecasting. This study focuses on the best-practice approach to stage-discharge rating curve development for selected rivers in Selangor. The stage-discharge rating curve derived was evaluated in terms of the statistical parameter, which denotes the degree of determination or r-squared value. The polynomial function yields better accuracy at 68.6% than the exponential function at 60.3%. Model validation was performed using the discrepancy ratio and confirmed that the stage-discharge rating curve developed using both mathematical functions give good predictions with more than 80% accuracy for the specified flow range and stage levels.

Keywords: Stage-discharge relations, rating curve, rating table.

1. Introduction

A stage-discharge relation, also known as a stage-discharge curve or rating curve, is a plot of stage (also known as gauge height) versus discharge that provides a relation between stage and discharge. It provides an estimation of discharge from the stage reading or gauge height. A reliable stage-discharge rating curve is important and beneficial to water resource managers, engineers, policymakers, and researchers in hydraulic structures (Kim et al., 2016), flood management and mitigation (Steinbakk et al., 2016; Zakariah et al., 2021; Viera et al., 2022), prediction of streamflow discharge (Rozos et al., 2022), and water quality monitoring (Harmel et al., 2006).

A stage-discharge relationship is useful in instances where measurement for discharge is discontinued due to malfunctioning equipment (Mansanarez, 2019). Continuous records of discharge at gauging stations are computed by applying the discharge rating to the recorded stage at the stream. Stage-discharge ratings may be simple or complex, depending on the number of variables used to define the relationship (WMO, 2010). It is challenging, time-consuming, and costly to collect data as well as to maintain data continuity. It requires gauging data collection, calibration measurements, and, under extreme-flow events, curve extrapolation.

In this study, we explored the utilization of mathematic functions, namely exponential and polynomial functions in generating the stage-discharge rating curves for selected rivers in Selangor. The stage-discharge curve (rating curve) is converted into tabular form and is then referred to as the stage-discharge rating table. All discharges within the specified range of the established rating curve can be conveniently read from the stage values in the rating table. Secondary data was fitted into both mathematical functions and the stage-discharge relationship was established. Our specific objectives were to (1) establish a stage-discharge relationship using mathematical functions for selected rivers in Selangor, (2) develop stage-discharge rating curve based on the mathematical expression generated, and (3) evaluate the model performance of the generated rating curves.

2. Methods

This section covers the overall methodology used in this study to meet the objectives as highlighted in Figure 1, namely, (i) data collection and inventory, (ii) data filtering, (iii) stage-discharge curve construction, (v) model accuracy, (vi) rating table and rating curve development, and (vii) model evaluation. This study utilizes data from nine (9) existing discharge stations in Selangor provided by the Drainage Irrigation Department (DID) of Malaysia, as highlighted in Table 1 and Figure 2. Variables recorded include stage height (m), mean velocity (m/s), and discharge (m^3/s). Stage-discharge curve construction was based on two mathematical functions, namely (i) exponential function (power relationship), and (ii) polynomial function (quadratic relationship). The historical data of stage (m) and discharge (m^3/s) were fitted in both mathematical functions, and assessments using statistical parameters were observed.

This study emphasizes the significance of the data population in developing prediction models employing mathematical, statistical, and artificial intelligence systems (Saadon et al., 2021; Saadon et al., 2020; Dobbin and Simon, 2011). The data splitting approach used in this research involved optimal split proportions, where 60% of the data was allocated for constructing the discharge rating curve, and the remaining 40% was dedicated to model validation. This allocation was chosen based on the full dataset and the classification accuracy, with higher accuracy and fewer data points resulting in a larger portion assigned to model development. A common strategy for data splitting involves allocating 2/3 of the overall data for model development and the remaining 1/3 for model validation (for datasets with more than 100 data points). Given that each station's dataset in this study contains more than 100 data points, the 2/3 and 1/3 rule was applied to split the data. The number of data points used for constructing the rating curve and model validation at each station is provided in Table 1.

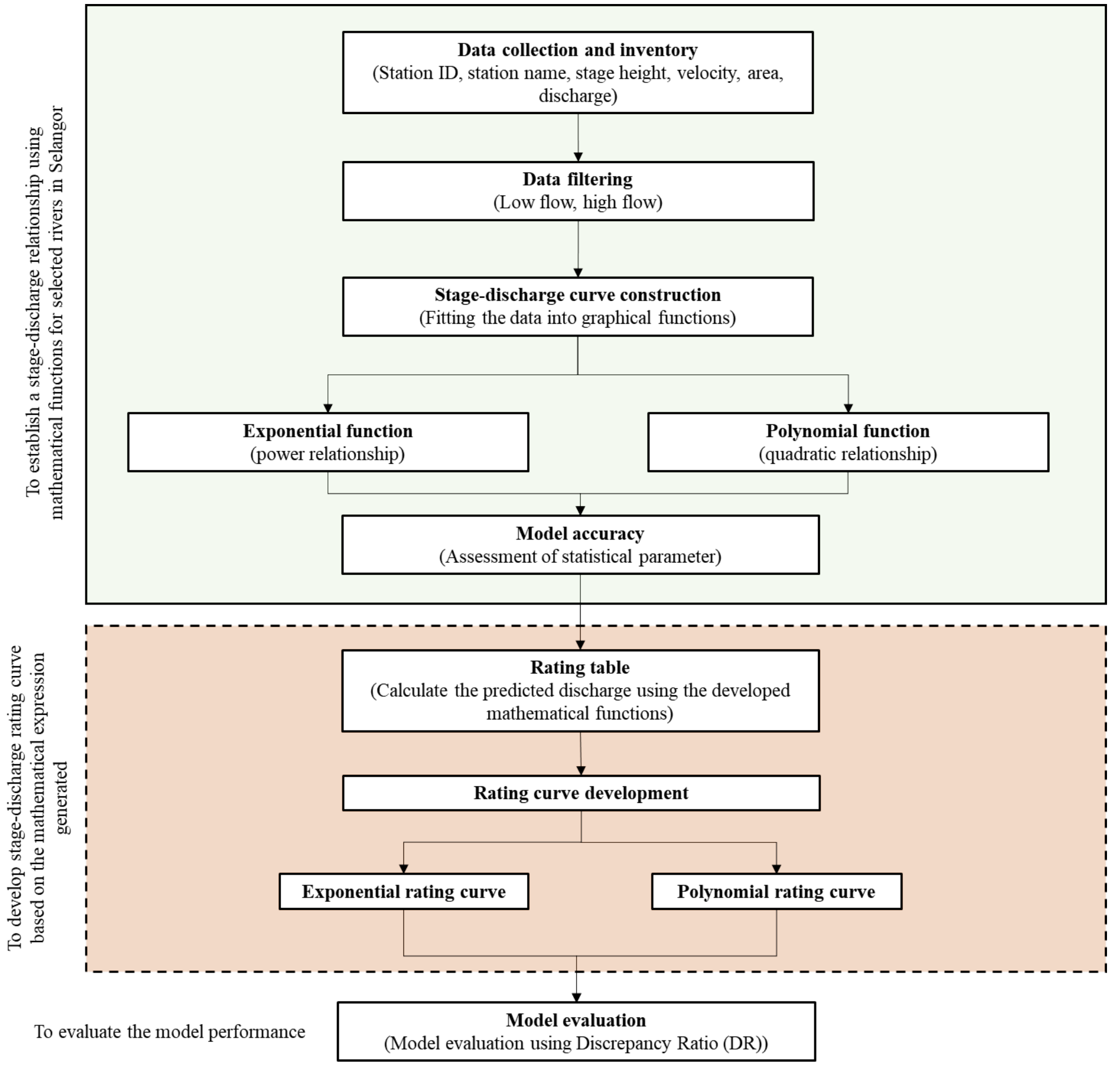

Figure 1. Flow Chart of the Overall Methodology

Empirical expressions derived from fitted graphs were utilized to predict discharge values based on the stage height at selected intervals. These intervals were determined by considering the historical data's minimum and maximum stage height values. The resulting predicted values were presented in both tabular and graphical form, known as a rating curve. Two types of rating curves were evaluated in this study: one using exponential functions and the other using polynomial functions. The assessment of these curves was based on the model performance criteria, specifically the discrepancy ratio (D.R.). The D.R. is a measure of the ratio between predicted values and observed values, which is supported graphically. Values within the range of 0.5 to 2.0 are considered accurate. This evaluation method has been widely employed in previous studies, including those by Ibrahim et al. (2017), Sinnakaudan et al. (2010), Saadon et al. (2021, 2020). The generated stage-discharge function with a higher D.R. value indicates the best representation for the selected rivers in Selangor.

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Table 1. List of Selected Stations River for Raw Data and Number of Data Points Used for Constructing the Rating Curve and Model Validation at Each Station

Station No.	Station Name	Data Range	No. of Data	Data for Curve Construction	Data for Model Validation	Data Obtained
2816441	Sg. Langat in Dengkil	2002-2019	364	219	145	
2917401	Sg. Langat in Kajang	2004-2019	336	202	134	
2918401	Sg. Semenyih in Kg Sg Rinching	2002-2019	317	190	127	
3118445	Sg. Lui in Kg. Lui	2005-2019	320	192	128	Velocity (m/s) Area (m^2) Discharge (m^3/s) Stage height (m)
3414421	Sg. Selangor in Rantau Panjang	2001-2019	357	214	143	
3415401	Sg. Selangor in Kg Timah	2008-2019	390	234	156	
3516424	Sg. Selangor in Ampang Pecah	2005-2019	322	193	129	
3615412	Sg. Bernam in Tanjung Malim	2004-2019	338	203	135	
3813411	Sg. Bernam in Jambatan SKC	2004-2019	330	198	132	

Figure 2. Study Area and Streamflow Stations in Selangor (Adapted from http://h2o.water.gov.my/v2/fail/rhnc/index.html).

2.1 Discharge Measurement and Computation

Discharge ratings for gauging stations are usually determined empirically by means of discharge measurements made in the field. Discharge measurements in the field makes use of several devices. The most common device used for measuring discharge is the current meter with concurrent stage recorded. It is applicable to both small and medium-sized rivers. Others include the use of structures which are permanent or non-permanent. Examples of man-made structures include weirs, flumes, and small dams. Common practice is to measure the discharge of the stream periodically, usually using the current meter and to note the stage height concurrently. There are several methods for discharge computations, namely (i) simple stage-discharge using control structures, (ii) discharge computation using velocity-area (VA) technique, (iii) velocity-index method, (iv) discharge approximation using float method, (v) acoustic doppler current profiler (ADCP) method, and (vii) flow measurement using radar flow measuring system. Regardless of the device and structures used in the measurements, both require scheduled calibration and maintenance to ensure accuracy and reliability of measurements. The computation of discharge within this study has been made using VA method at the gauging stations.

2.1.1 Velocity-Area Method

Velocity-area method is the most common method to measure velocity and area of flow for the computation of flow or discharge in a river cross-section. For each observation, the measurements of velocities and area in each vertical are carried out using a current meter (OTT current meter, Pygmy, Watts Mark IV, Amsler 505 and Mashpriborintorg Hydrometric Runner Propeller 1). Series of velocity and area measurements are required for the computation of discharges for the cross-section with the corresponding stage heights recorded. The following equation is used to compute the total discharge at each cross-section for each observation.

$$Q = \sum_{i=1}^{n} a_i v_i \tag{1}$$

where, Q is the total discharge, in cubic meter per second (m³/s); a_i is the cross-sectional area, in square meter for the i-th segment of the n segments into which the cross section is divided, and v_i is the corresponding mean velocity, in meter per second of the flow normal to the i-th segment, or vertical. Similar techniques are adopted in the measurements of velocity and area for all other observations. The range of observations should cover from low to high flow depths to ensure a well-defined curve be drawn.

2.2 Stage-Discharge Equation

Measured discharge is then plotted against concurrent stage on graph paper to define the rating curve. The general equation of a stage-discharge curve which is a parabolic, for flow in a uniform reach (cross-sections are approximately similar in shape and area in the reach) is:

$$Q = K(H - a)^{\alpha} \tag{2}$$

where Q is discharge in cubic meters per second (m³/s); K is a constant; H is the stage height; a is the gauge height for zero flow; and α is an exponent.

The logarithmic form of the general stage-discharge curve equation can be expressed as:

$$\log Q = \log K + \alpha \log\ (H - a) \tag{3}$$

The above equation is a straight-line equation for,

$$y = \mathrm{m\,x} + \mathrm{c} \tag{4}$$

where $y = \log Q$; $m = \alpha$; $c = \log K$ the intercept; and $x = \log (H\text{-}a)$.

The value a which is the gauge height for zero flow can be determined using linear scale plot. It is convenient to construct stage-discharge curves on logarithmic scales when only a few gauging measurements are available. It is inappropriate to pre-select a convenient exponent (say 2) in the general equation. In some cases, such an approximation may give a reasonable fit for the range of discharges considered but may be most misleading for discharges outside this range. The relation between stage and discharge is defined by plotting measurements of discharge with corresponding observations of stage, considering whether the discharge is steady, increasing or decreasing and noting the rate of change in stage. This may be done manually by plotting it into graphical paper or by using computerized plotting techniques. A choice of two types of plotting scales is available, either an arithmetic scale or a logarithmic scale. Each has certain advantages and disadvantages. It is customary to plot the stage as ordinate (vertical axis or y-axis) and the discharge as abscissa (horizontal axis or x-axis), although when using the stage-discharge relation to derive discharge from a measured value of stage, the stage is treated as the independent variable. The first step prior to making a plot of stage versus discharge is to prepare a list of discharge measurements that will be used for the plot. A minimum of 12 to 15 measurements, all made during the period of analysis, are needed for the plotting. The measurements should also include both high and low flows and might be useful in defining the correct shape of rating curve and for extrapolation the rating.

2.3 Stage-Discharge Curve Construction

Stage-discharge rating curves are developed by fitting a curve (linear scale) or a straight line (logarithmic scale) to a series of plotted discharge measurements. This fitting is easily performed using computational spreadsheets or generated using an automated system that is highly interactive. Fitting a curve that best fits the scatter plots and the trend of the dispersed array of the plotted points makes use of two function relations. They are the exponential function relation and polynomial function relation. Traditionally, these curves were hand-drawn, and the best-fit curve was done manually. With the advent of technology, plotting of discharge measurements and the construction of stage-discharge curve (either arithmetic plots or logarithmic plots), curve-shaping and the hydraulic relations can be easily established. Computer plots of discharge and gauge height values on either linear scale plots or logarithmic scale plots based on analysis requirement have several advantages. Among the advantages are (i) selection of measurements for plotting can be made quick and easy; (ii) scales changes can be made, and measurements can be replotted automatically and quickly; (iii) various vales of exponent can be easily tried for the purpose of defining a straight-line rating on a logarithmic plot; (vi) separate rating segments representing different control conditions can be easily and quickly plotted; and (v) plotting error are virtually eliminated. The simplest type of plots uses an arithmetically divided plotting scale as shown in Figure 3. Scale subdivisions should be chosen to cover the complete range of gauge height and discharge expected to occur at the gauging site. Scales should be divided uniform, even increments that are easy to read and interpolate.

Logarithmic scale ratings for stage-discharge stations requires slope measurement of the straight-line rating segments for comparison to the theoretical slopes that correspond to various control conditions. Rating slope computations can be carried out using spreadsheet or generated using an automated system. A check is necessary to ensure that the selected rating curve segment is reasonably close to a straight-line segment. Checking can be done through the computation of percentage difference in discharge between the actual rating and the straight line defined by the selected end points, at intermediate points along the rating segment. If the percentage difference exceeds ±1 percent (default value), the rating segment should be considered curvilinear, and the slope should not be computed. A different percentage may be selected for use in checking the differences or to select a different rating segment to check. If the rating segment is found to be a straight line (within the default, or selected percentage difference) then the slope should be computed and displayed. Displayed information should include the statement section control for slopes greater than 2.0 and channel control for slopes less than 2.0.

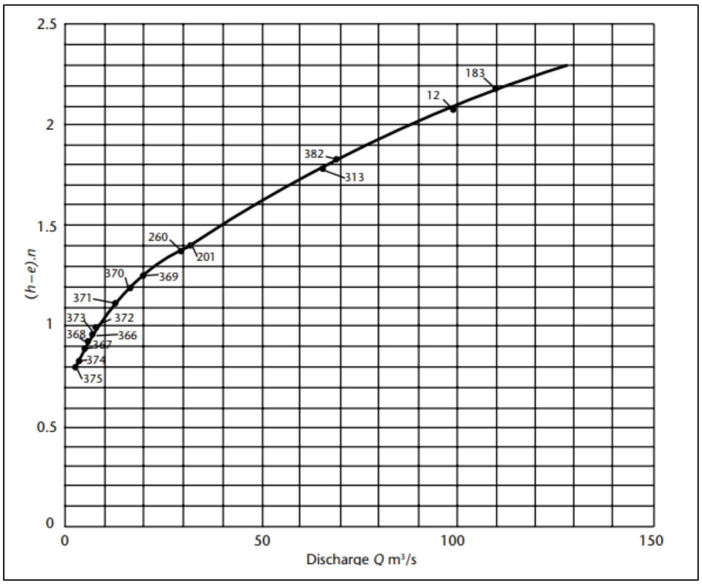

Figure 3. Arithmetic Plot of Stage-discharge Relation (WMO, 2010)

2.4 Stage-Discharge Curve Development Using Polynomial Function

Stage-discharge rating curve drawn using polynomial function will exhibit a curvilinear shape curve with the following mathematical expression:

$$f(x) = a_0 + a_1 x \; and \; a \neq 0 \quad (5)$$

where $f(x)$ is the stage (gauge height); a_0, a_1 are the exponents; x is the discharge. The above mathematical expression defines the rating curve.

2.5 Stage-Discharge Curve Development Using Exponential Function

Stage-discharge rating curve drawn using exponential function or power relationship will exhibit a parabolic shape curve with the following mathematical expression:

$$f(x) = ax^k \quad (6)$$

where $f(x)$ is the stage (gauge height); a is the exponents; k is the variance; and x is the discharge. The above mathematical expression defines the rating curve. An example of stage and discharge data fitting using exponential and polynomial functions are shown in Figure 4.

2.6 Rating Table for the Development of Synthetic Rating Curve

A synthetic rating curve can be presented in table form known as rating table for easy conversion of stage to the corresponding discharge. Its primary purpose is to display values of the dependent variable (stage or gauge height) for the complete range of the independent variable (discharge). The rating table facilitates the reading of discharge at any gauge height derived from the stage-discharge curve equation (power or polynomial with the least error). Complete range of discharge values can be interpolated from the gauge height values to the

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desired intervals and precision. It is to be noted that there is usually some percentage in errors between the measured and the estimated values calculated using the generated curve equation (exponential or polynomial). The smoothness of a rating curve and or rating table can be done by establishing the differences between successive values of the dependent variable (discharge). The differences at every tenth value of the independent variable (stage height) are to be computed and displayed for every 0.01 m. The rating table must include descriptive information that identifies the gauging station, type of rating, period of use and other items that are unique for that rating.

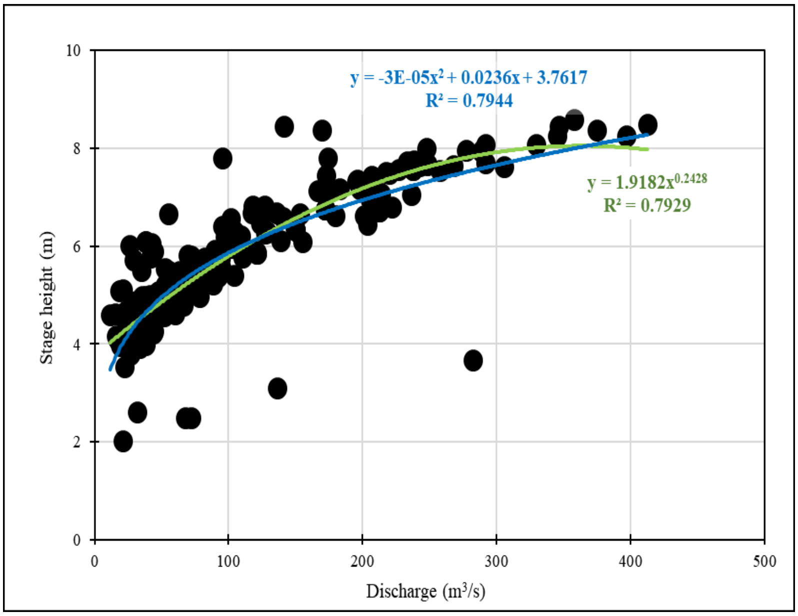

Figure 4. An Example of Stage and Discharge Data Fitting Using Exponential and Polynomial Functions

2.7 Rating Curve Validation

Model validation is a stage where to validate the values of estimates discharge. In this study, the discrepancy ratio (D.R.) was employed to validate the synthetic rating curves developed using both exponential and polynomial functions. The discrepancy ratio is calculated as the ratio between the predicted discharge and the measured discharge. A mathematical function is considered accurate if the ratio between the predicted and measured values falls within the range of 0.5 to 2.0. The number of data points that lie within these limits is counted, and the accuracy of the mathematical functions is evaluated based on the highest percentage of D.R.

3. Results and Discussion

3.1 Stage-Discharge Relationship

Based on the analysis, stage-discharge rating curves for selected rivers in Selangor have been developed using exponential and polynomial functions. Total of nine (9) existing river stations have been selected to represent these stage-discharge rating curves. Table 1 shows the summary of the developed empirical equations representing the stage-discharge rating curves, both exponential and polynomial functions. The accuracy of these functions was assessed using statistical parameters, known as degree of determination or r-squared (r^2) values. From the stage-discharge relationship, on average, polynomial functions yield accuracy better than exponential function with r-squared of 0.686.

Total of 18 stage-discharge relationships have been established for all 9 selected stations. Figures 5 and 6 show an example of the stage-discharge relationship plotted for Sg. Bernam at Jambatan SKC (Station no: 3813411) for both polynomial and exponential functions. The stage-discharge relationship using polynomial function for Sg. Bernam at Jambatan SKC (station no: 3813411) yields the highest degree of accuracy for both polynomial and exponential functions, with r-squared of 0.912 representing polynomial, and exponential function depicts r-squared at 0.757. Both polynomial and exponential functions for each station will be used in the development of synthetic rating curve.

Table 2. Summary of the Stage-discharge Relationship for Selected Rivers in Selangor

Station No	**Station Name**	**Stage-discharge relationship**			
		Polynomial function	**r^2**	**Exponential function**	**r^2**
2917401	Sg. Langat at Kajang	$y = -8x10^{-5}x^2 + 0.0327x + 22.176$	0.817	$y = 21.412x^{0.0242}$	0.717
2918401	Sg. Semenyih at Kg. Sg. Rinching	$y = -0.0003x^2 + 0.045x + 20.361$	0.493	$y = 19.966x^{0.0187}$	0.481
3118445	Sg. Lui at Kg. Sg. Lui	$y = -0.0043x^2 + 0.0832x + 76.425$	0.519	$y = 76.516x^{0.0012}$	0.397
3414421	Sg. Selangor at Rantau Panjang	$y = -3x10^{-5}x^2 + 0.0236x + 3.7617$	0.794	$y = 1.9182x^{0.2428}$	0.793
3813411	Sg. Bernam at Jambatan SKC	$y = -4x10^{-5}x^2 + 0.0242x + 15.728$	0.912	$y = 14.027x^{0.0489}$	0.757
3615412	Sg. Bernam at Tanjung Malim	$y = -0.0003x^2 + 0.055x + 36.545$	0.461	$y = 35.949x^{0.0146}$	0.429
2816441	Sg. Langat at Dengkil	$y = -1x10^{-5}x^2 + 0.0159x + 3.0678$	0.819	$y = 2.2443x^{0.1493}$	0.728
3415401	Sg. Selangor at Kg. Timah	$y = -3x10^{-5}x^2 + 0.012x + 17.071$	0.764	$y = 16.258x^{0.0211}$	0.721
3516424	Sg. Selangor at Ampang Pecah	$y = -0.0004x^2 + 0.033x + 49.961$	0.593	$y = 50.017x^{0.002}$	0.408

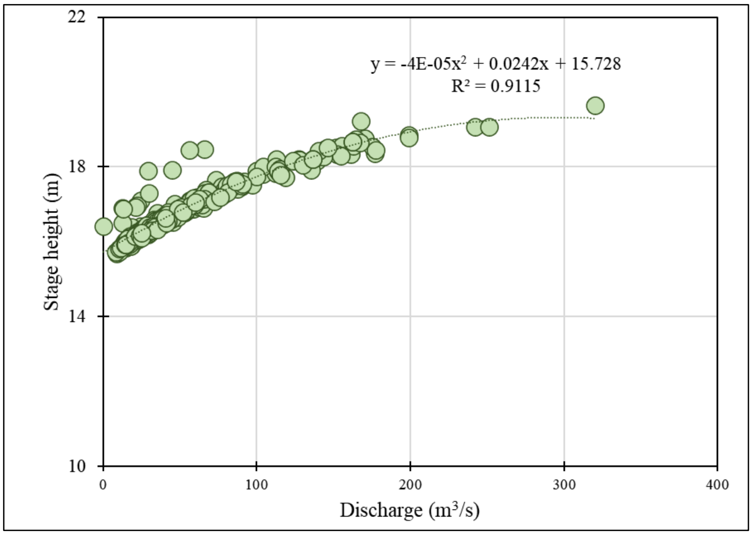

Figure 5. Stage-discharge Relationship for Sg. Bernam at Jambatan SKC Using Polynomial Function

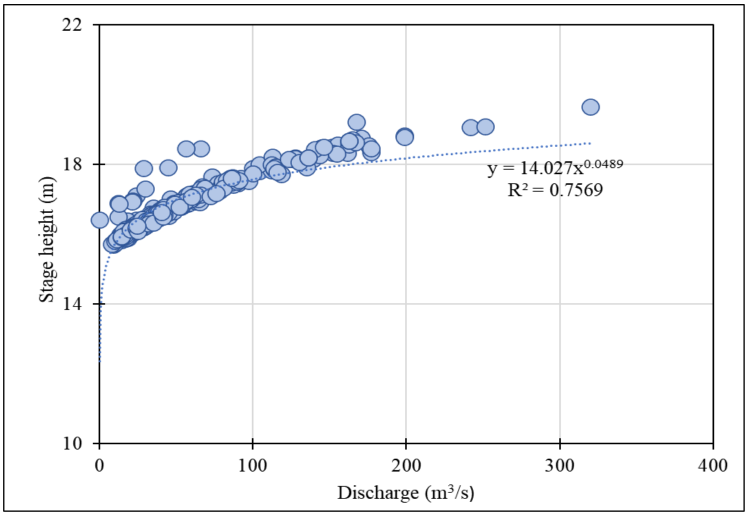

Figure 6. Stage-discharge Relationship for Sg. Bernam at Jambatan SKC Using Polynomial Function

The distribution of historical data for all 9 hydrological stations used in the stage-discharge rating curve construction is highlighted in Table 3. The discharge values range from 0.1 m^3/s (Station 3118445: Sg. Lui in Kg Sg. Lui) to 11.5 m^3/s (Station 3414421: Sg. Selangor in Rantau Panjang). Standard deviation is a measure of how dispersed the data is in relation to the mean. Low standard deviation means data are clustered around the mean, and high standard deviation indicates data are more spread out. A standard deviation close to zero indicates that data points are close to the mean, whereas a high or low standard deviation indicates data points are respectively above or below the mean. For stage height, Station 3118445 for Sg. Lui in Kg Sg. Lui indicates the least value of 0.1. Similarly, for discharge value, Station 3118445 for Sg. Lui in Kg Sg. Lui indicates the least value of 0.9, which is approaching zero. Based on the overall data distribution, eight out of nine stations indicate low standard deviation values less than 1.0. It can be concluded that the data distribution for all nine stations indicates low variability with dataset distribution close to the mean value.

Table 3. Summary of the Data Distribution Based on Minimum Value, Maximum Value, Mean and Standard Deviation

Station No.	**Station Name**	**No. of Data**	**Stage height (m)**				**Discharge (m^3/s)**			
			Min.	**Max.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Mean**	**Std. Dev.**
2816441	Sg. Langat in Dengkil	364	1.8	6.8	3.7	0.8	1.1	325.0	43.4	55.4
2917401	Sg. Langat in Kajang	336	21.9	26.1	22.6	0.6	1.8	195.4	14.7	21.3
2918401	Sg. Semenyih in Kg Sg Rinching	317	20.3	22.7	20.7	0.3	2.0	51.7	8.0	7.1
3118445	Sg. Lui in Kg. Lui	320	76.3	76.8	76.6	0.1	0.1	5.3	1.9	0.9
3414421	Sg. Selangor in Rantau Panjang	357	2.0	8.6	5.2	1.2	11.5	412.8	79.7	77.2
3415401	Sg. Selangor in Kg Timah	390	19.4	22.3	19.9	0.4	10.4	251.6	36.2	35.9
3516424	Sg. Selangor in Ampang Pecah	322	49.0	51.1	50.2	0.2	0.1	46.9	7.8	6.0
3615412	Sg. Bernam in Tanjung Malim	338	36.1	39.1	37.0	0.6	1.6	86.4	9.8	10.3
3813411	Sg. Bernam in Jambatan SKC	330	15.7	19.7	16.9	0.8	0.1	320.0	56.6	45.5

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3.2 Stage-Discharge Rating Curve for Selected Rivers in Selangor

Stage-discharge rating curve for all 9 stations were developed using both stage-discharge empirical functions generated previously using both polynomial and exponential functions. The empirical expressions generated from these fitted graphs were used to predict the values of discharges based on the stage height at selected intervals. The range of the intervals were identified based on the minimum and maximum values of stage height with the historical data. As highlighted previously, the differences at every tenth value of the independent variable (stage height) are to be computed for discharge values and displayed for every 0.01 m. The rating table must include descriptive information that identifies the gauging station, type of rating, period of use and other items that are unique for that rating.

These predicted values are represented in a table form termed as rating table and graphical representation termed as rating curve. Figures 7 and 8 show an example of rating curve developed for Sg. Bernam at Jambatan SKC (station no: 3813411) using both polynomial and exponential functions.

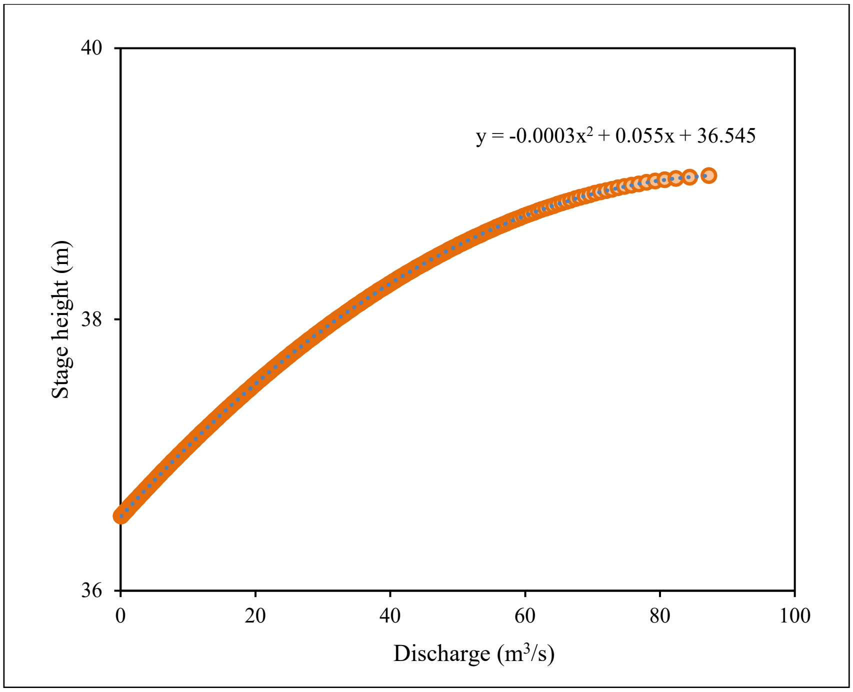


Figure 7. Rating Curve (stage-discharge relationship) for Sg. Bernam at Jambatan SKC Using Polynomial Function

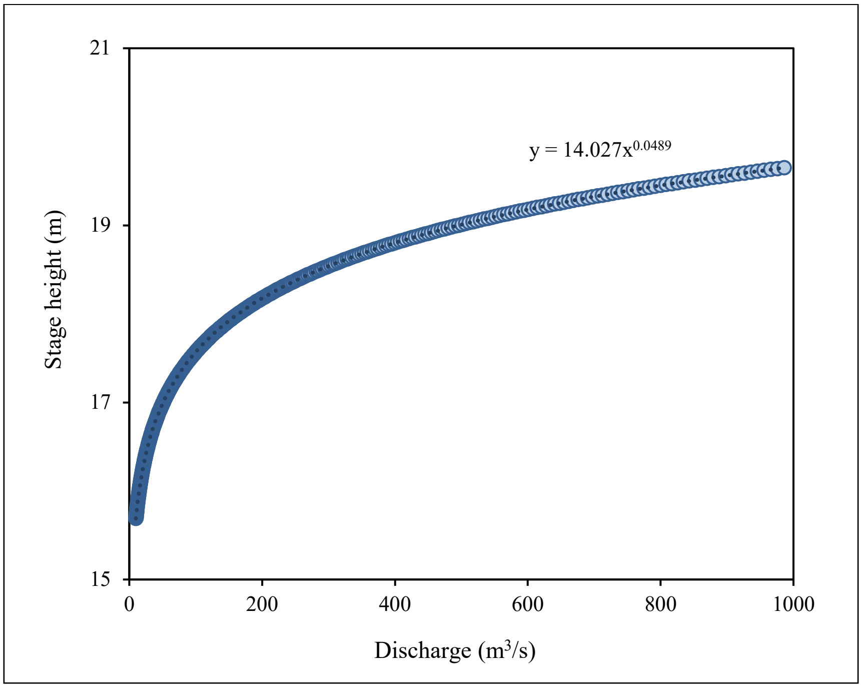


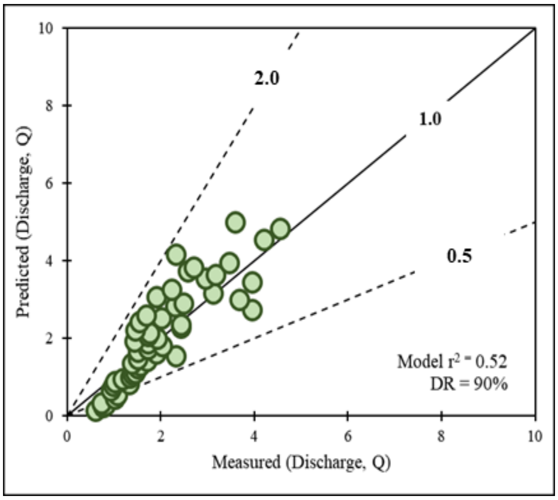
Figure 8. Rating Curve (stage-discharge relationship) for Sg. Bernam at Jambatan SKC Using Exponential Function

3.3 Rating Curve Validation

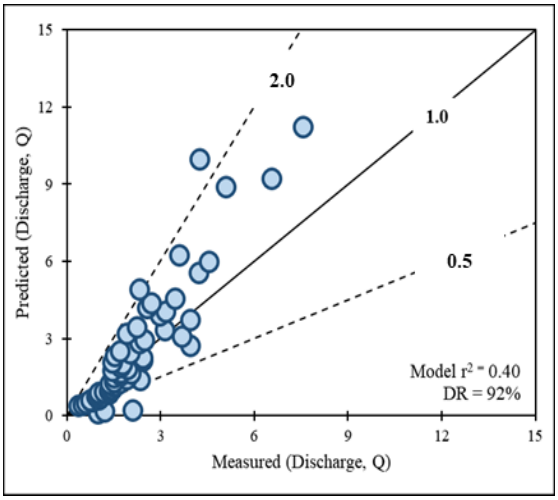
The study conducted model validation to assess the performance of both polynomial and exponential functions employed in creating the rating curve. The validation process utilized the discrepancy ratio (D.R.), which is a ratio between predicted values and observed values, and this was supported by graphical representations. The mathematical functions were considered accurate if the ratio between predicted and measured values fell within the range of 0.5 to 2.0. The number of data points falling within these limits was calculated, and the accuracy of the mathematical functions was evaluated based on the highest D.R.

The results of the model validation indicated that the stage-discharge rating curves developed using both exponential and polynomial functions provided good predictions with an accuracy of over 80% within the specified flow range and stage levels. Specifically, for the polynomial function, the rating curve developed for Sg. Selangor at Kg. Timah (3415401) demonstrated the highest D.R. with an impressive 98% accuracy. A similar trend was observed for the exponential function, with the performance of the exponential function rating curve for the same station achieving an accuracy of 94%. These findings underscore the effectiveness of both polynomial and exponential functions in accurately predicting stage-discharge relationships, particularly with the exceptional performance exhibited by the polynomial function rating curve for the specified station.

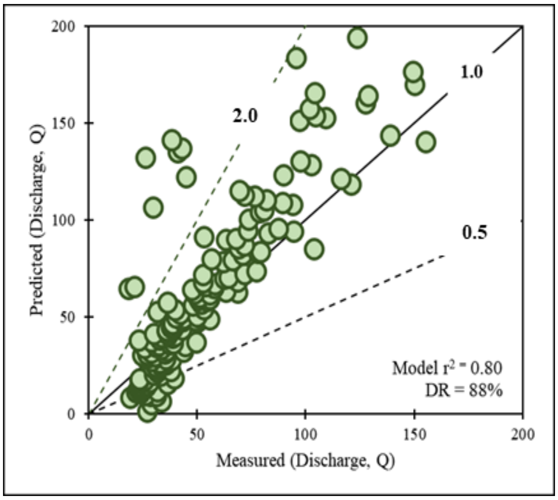
The same trend for both polynomial and exponential rating curve can be observed for Sg. Bernam at Jambatan SKC (3413411). The Rating curve using polynomial function and exponential function for Sg. Bernam at Jambatan SKC (3413411) performed well in the model validation, both at 93% and 92% respectively. Figure 9 (a) to (h) show the example of graphical plots of predicted discharge and measured discharge for 4 stations, namely Sg. Lui at Kg Sg. Lui (3118445), Sg. Selangor at Rantau Panjang (3414421), Sg. Bernam at Jambatan SKC (3813411) and Sg. Selangor at Kg. Timah (3415401). Table 4 shows the summary of model performances for all river stations based on the percentage of accuracy and discrepancy ratio.


Predicted (Discharge, Q)
Measured (Discharge, Q)
2.0
1.0
0.5
Model r2 = 0.52
DR = 90%

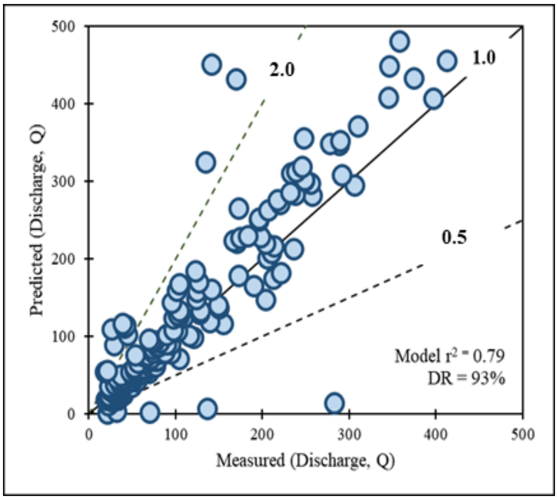
(a)


Predicted (Discharge, Q)
Measured (Discharge, Q)
2.0
1.0
0.5
Model r2 = 0.40
DR = 92%

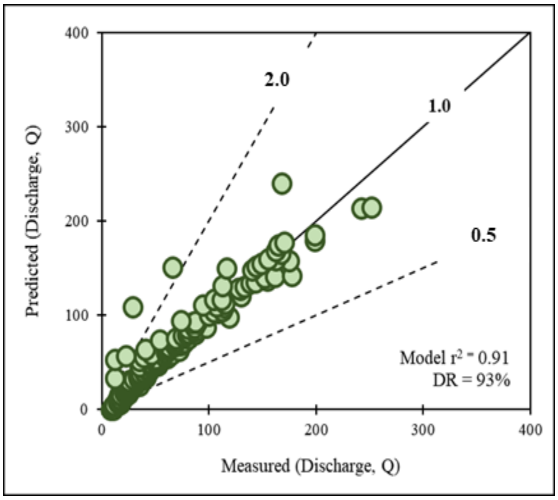
(b)

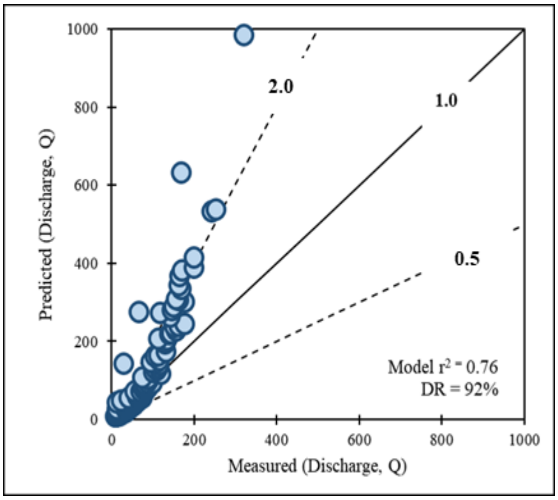

Predicted (Discharge, Q)
Measured (Discharge, Q)
2.0
1.0
0.5
Model r2 = 0.80
DR = 88%

(c)

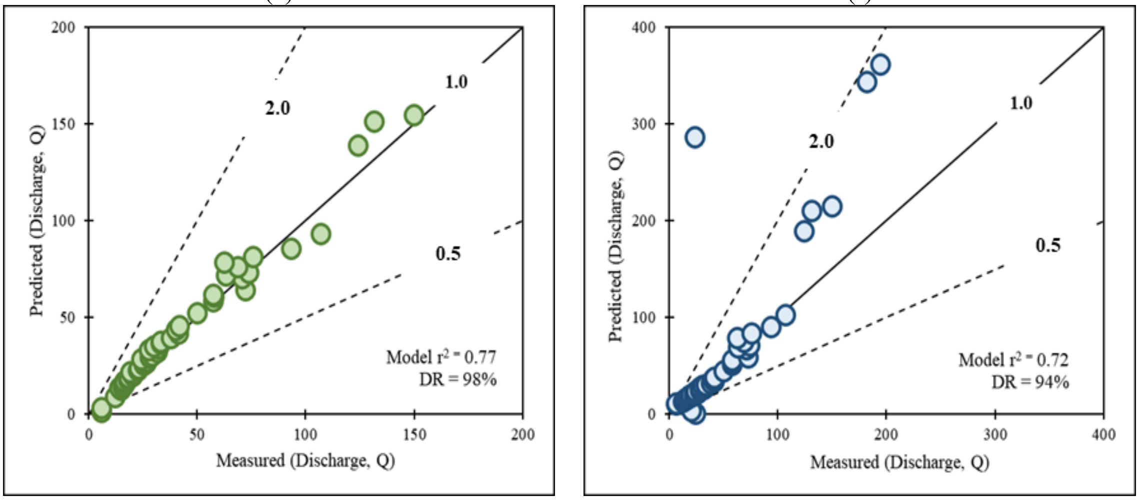

Predicted (Discharge, Q)
Measured (Discharge, Q)
2.0
1.0
0.5
Model r2 = 0.79
DR = 93%

(d)


Predicted (Discharge, Q)
Measured (Discharge, Q)
2.0
1.0
0.5
Model r2 = 0.91
DR = 93%


Predicted (Discharge, Q)
Measured (Discharge, Q)
2.0
1.0
0.5
Model r2 = 0.76
DR = 92%

(e) (f)



(g) (h)

Figure 9. Graphical plots of predicted discharge and measured discharge for (a) Sg. Lui at Kg Sg. Lui (3118445) using polynomial function; (b) Sg. Lui at Kg Sg. Lui (3118445) using exponential function; (c) Sg. Selangor at Rantau Panjang (3414421) using polynomial function; (d) Sg. Selangor at Rantau Panjang (3414421) using exponential function; (e) Sg. Bernam at Jambatan SKC (3813411) using polynomial function; (f) Sg. Bernam at Jambatan SKC (3813411) using exponential function; (g) Sg. Selangor at Kg. Timah (3415401) using polynomial function; and (h) Sg. Selangor at Kg. Timah (3415401) using exponential function.

Table 4. Summary of all Model Performance Using the D.R. for Both Polynomial and Exponential Functions

Station No	**Station Name**	**Discrepancy Ratio, D.R. (%)**	
		Polynomial function	**Exponential function**
2917401	Sg. Langat at Kajang	82	88
2918401	Sg. Semenyih at Kg. Sg. Rinching	81	89
3118445	Sg. Lui at Kg. Sg. Lui	90	92
3414421	Sg. Selangor at Rantau Panjang	88	93
3813411	Sg. Bernam at Jambatan SKC	93	92
3615412	Sg. Bernam at Tanjung Malim	51	46
2816441	Sg. Langat at Dengkil	88	75
3415401	Sg. Selangor at Kg. Timah	98	94
3516424	Sg. Selangor at Ampang Pecah	91	39

4. Conclusion

This study was successfully conducted to highlight the best practice approach to establish stage-discharge rating curve for selected rivers in Selangor. The stage-discharge rating curve is derived using two mathematical functions, namely exponential function, and polynomial function. Mathematical expression represented in polynomial function yields better accuracy at 68.6% than the exponential function at 60.3%. Model validation was performed using the discrepancy ratio (D.R.), a ratio between predicted values to the observed values that is supported graphically. The performances of the derived models confirmed that the stage-discharge rating curve developed using both exponential and polynomial functions gave good prediction at more than 80% accuracy for the specified flow range and stage levels. The exponential function performed better with D.R. more than 90% accuracy and is able to predict the discharge values at a larger scale. Within the boundaries of this study, several limitations were taken into consideration. Firstly, the development of the rating curve for selected rivers in Selangor, as presented here, takes into account the overall water level and flowrate for each respective station. However, a more detailed analysis, segregating the low flow and high flow conditions, is essential to construct distinct rating curves for these different scenarios. Secondly, this study primarily focuses on establishing the relationship between water level and discharge. Yet, a more comprehensive approach would involve the inclusion of additional channel-based or catchment-based characteristics and other parameters. These additional factors could enhance the rating curve's representation by accounting for various influential elements within a river catchment. Furthermore, the proposed methodology can be refined through the incorporation of more precise machine learning techniques and advanced statistical methods. These modern analytical tools could contribute to a more robust and accurate rating curve development process. In summary, while this study provides valuable insights, future research endeavors should address these limitations by conducting a more detailed analysis, incorporating additional relevant factors, and leveraging advanced statistical and machine learning techniques to refine the methodology and enhance the rating curve's accuracy and applicability.

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Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

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