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The Use of Suspended Sediment Rating Curves in Malaysia : Some Preliminary Considerations

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ABSTRAK

Kelok kadar endapan ampaian masih merupakan kaedah yang paling biasa digunakan untuk menentukan beban endapan ampaian di sungai-sungai di Malaysia. Dengan demikian, walaupun kaedah ini kasar dan mempunyai banyak kelemahan, prosedur-prosedur yang betul perlu dipatuhi. Tiga kesilapan yang selalu dilakukan semasa menggunakan kaedah ini telah dikaji dan dibandingkan dengan keputusan yang diperolehi dengan menggunakan kaedah yang betul. Hasil kajian menunjukkan bahawa kaedah yang salah telah menyebabkan keputusan beban endapan ampaian tahunan disalahtafsirkan iaitu lebih daripada 50%. Faktor pembetulan untuk mengambil kira pengunaan data kadar alir tidak berterusan juga diperolehi dalam kajian ini.

ABSTRACT

The suspended sediment rating curve technique is the most common method of estimating river suspended sediment loads in Malaysia. Thus, despite its crudeness, adherence to the correct procedures of this technique is very important. Three of the most common incorrect procedures in the suspended sediment rating curve technique were studied and compared to the results obtained from using correct procedures. Results of analysis showed that incorrect practices of this technique underestimate the annual suspended sediment load by more than 50%. A correction factor to compensate for the use of non-continuous discharge data is also derived in this study.

INTRODUCTION

As soil erosion and conservation is currently the subject of a great research effort, methods of estimating soil losses are being widely explored. The most common method in Malaysia in this respect is the use of river suspended sediment load to indicate the magnitude of soil erosion although such measures do not take into account the retention of eroded material on land, but in turn do include channel erosion.

River suspended sediment load can be determined by a number of methods. The use of theoretical and semi-theoretical equations, although quite common in more developed countries, is hardly used in Malaysia. The more popular method here is determining the suspended sediment concentration and multiplying it with river discharge value. The sediment concentration is obtained by laboratory analysis of water samples and river discharge values obtained by velocity-area measurements or by interpretation of stage readings. This method, although adequate for measurements of instantaneous sediment loads, is of little help in the computation of annual suspended sediment loads. In the typical Malaysian situation of inadequate manpower, funds and automatic sampling equipment, it is almost impossible to obtain daily sediment concentrations in the rivers for long periods of time. Considering the above mentioned factors, many researchers in Malaysia (Peh 1981; Lai & Samsuddin 1985; Mohammad Noor 1987; Balamurugan 1987; Wan Ruslan 1989) utilize the suspended sediment rating curve technique to estimate long-term suspended sediment loads of rivers vis-a-vis soil losses.

This paper investigates the use of the suspended sediment rating curve technique, some of the common mistakes made by users and the corresponding consequences on the process of estimating suspended sediment loads in Malaysian rivers.

SUSPENDED SEDIMENT RATING CURVE

The suspended sediment rating curve (or equation) is basically a relationship between river discharge and suspended sediment concentration or load. Instantaneous suspended sediment concentration or load and river discharge values are plotted together to derive a line of best-fit. The best-fit line equation is then used together with river discharge data to estimate suspended sediment transport rates or to analyze other sediment-related processes.

In Malaysia, the most common form of relationship assumed to exist between river discharge and sediment concentration or load (Sieh & Sivapakianathan 1977; Peh 1981) is

$$c = a\,Q^{b} \qquad (1)$$

or

$$L = a\,Q^{b} \qquad (2)$$

where C = suspended sediment concentration in mg/1
L = suspended sediment load in tonnes/day
Q = river discharge in cumecs
a = coefficient
b = exponent

Due to scarcity of relevant data, multiple regression analysis to derive different forms of relationships involving variables other than the above two have seldom been tested in Malaysia.

The most important assumption made when applying the suspended sediment rating curve technique is that the sediment concentration is dependent and only dependent on river discharge, which is quite clearly untrue (Geary 1981; Walling 1974). Sediment transport rates have been shown to be governed by complex relationships involving sediment parameters such as size, density and shape, flow parameters such as velocity, Reynolds number and Froude number and channel parameters like bed configuration channel slope and hydraulic radius (Lawson & O'Neil 1975; Kennedy & Brooks 1965). In addition to these factors, the availability of sediment, a major factor effecting the transport rates, is governed by many hydro-geomorphological factors such as rainfall intensity-duration, topography and land use.

The assumption that suspended sediment concentration or load is dependent on river discharge or in other words the fact that sediment content increases with discharge can be explained by the following:

(a) Higher discharge means the occurrence of heavier rainfall. Heavier rainfall normally has higher erosivity, thus the cause for higher sediment production.
(b) Higher discharge normally is accompanied by higher velocity and increased sediment carrying capacity of the river.

Although discharge is not the only explanatory variable, it has been reported as the most important one in explaining sediment concentration variations (Imeson 1971). Studies by Walling (1974) showed that discharge was the most important single variable compared to many other variables including time relation of sample to hydrograph peak, flow level preceding storm and index of flood intensity. However, several studies have shown that other parameters such as rainfall, basin morphometry and land use may have a stronger influence on annual sediment yield (Jansen & Painter 1974; Dunne 1979; Ogunkoya & Jeje 1987)

The above assumption also ignores the sediment exhaustion effect. In areas where exhaustion effects constitute an important characteristic of the suspended sediment response, the use of suspended sediment rating curves to calculate loads from streamflow records could give rise to significant errors (Golterman *et al.* 1983). Furthermore, it is an inherent assumption of the rating curve that the water and sediment concentration peaks are synchronous (Walling 1978) which in real time is usually not true, in that the suspended sediment concentration – discharge curves usually exhibit either clock-wise or anti clockwise hysterisis (Loughran *et al.* 1986; Lootens &

Lumbu 1986; Grimshaw & Lewin 1980; Klein 1984). Furthermore, the lead or lag effects of peak sediment concentration with respect to peak discharge is also ignored (Grimshaw & Lewin 1980).

DATA LIMITATION

Due to the tediousness and large volume of computations involved in using continuous discharge data, it is common practice to incorporate daily mean, weekly mean or monthly mean discharge values into the rating curves to calculate annual sediment loads. These data being averages of certain time series, have the peakedness of flow smoothened. A T-day mean flow is the average flow over T-days. Thus it will only represent the actual flow in a arithmetic relationship, unlike in the case of the suspended sediment rating curve where the relationship is geometric. Thus the computed annual sediment loads are actually underestimates when used together with rating curves with 'b' values other than unity. In this respect, the use of any set of discharge data other than continuous values will underestimate the long-term sediment loads. This effect will be more pronounced for small streams as compared to large rivers. In large rivers, the maximum instantaneous flow on a particular day may only be slightly higher than the daily mean flow but in small streams, the maximum values is usually very much higher than the mean flow. Thus, the underestimation of sediment loads will be much greater in small streams compared to larger rivers.

In order to obtain the actual annual sediment loads, a correction factor K(b, T) corresponding to the values of 'b' and 'T' has to be multiplied to the computed value. This is to compensate for the effect of smoothening of flow due to the use of mean flows. T represents the number of days from which the mean flow values were computed; eg. for weekly mean flow, T = 7.

$$\text{Actual load} = K\ (b,T) \times \text{Computed load} \quad (3)$$

LINEAR REGRESSION

The suspended sediment rating curve is usually a line fitted to the logarithmic transformation of a set of river discharge and sediment concentration measurements. Most researchers use the classical (least-squares) regression to derive the best-fit line for the rating curve which actually may not be the proper type of regression to be used in this case. The classical regression requires at least one of the variables to be subjected to no or minimal errors in its measurement (Poole & O'Farrell 1971) where as in the case of suspended sediment rating curves, both the variables are prone to errors in measurement (Loughran 1976; Walling 1977). Probably due to the abundance of publications and computer software on the classical regression, this fact has been frequently over-looked.

The least-squares regression of Y on X assumes that X is the independent variable, and Y, the dependent one. In a given set of data, one should be able to demonstrate a clear dependence of one variable on the other. For example, the weight of a chicken depends on its age and not vice-versa (Till 1973). In the example above, the age of the chicken in days can be determined without errors, thus the classical regression can be applied in this case. In the case of the suspended sediment rating curve, both variables are subjected to errors of measurement, thus the classical regression is inapplicable. Till (1973) has commented that despite such implications, most researchers have persisted in using the classical regression, when the *reduced major axis line* is in fact the correct sort of linear fit to apply to such data.

The reduced major axis line (R.M.A.L) is used to obtain best-fit line between two variables in cases where both are known to be with measurement errors. The R.M.A.L. sums the areas of the triangles between the set of data and the line to a minimum (CDE in *Fig. 1*) whereas the classical regression sums the vertical distances of a point from the line to a minimum (AB in *Fig.1*). The computation procedures of both the classical and the reduced major axis line are shown in Table 1.

Besides the above, many researches have also evaluated the rating curve in terms of relationship between sediment load (L) and river discharge (Q) when the C-Q relationship will be more meaningful (Walling 1977). A high correlation between sediment load and river discharge is inevitable due to the spurious correlation effects, in that the relationship

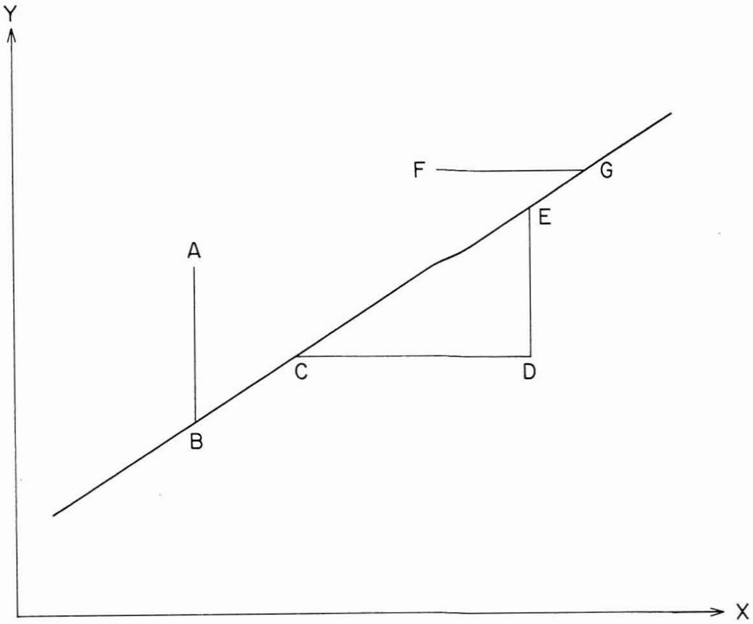

Fig. 1 Different ways of fitting a straight line to a set of data (Till, 1973)

TABLE 1
Linear regression computation procedures

	Classical regression	R.M.A.L.
Equation	$y = ax + b$	$y = ax + b$
Slope, b	$b = \frac{Sxy}{Sx}$	$b = \frac{Sy}{Sx}$
Intercept, a	$a = \bar{y} - b\bar{x}$	$a = \bar{y} - b\bar{x}$
Coefficient of correlation, r	$r = \frac{Sxy}{\sqrt{SxSy}}$	$r = \frac{Sxy}{\sqrt{SxSy}}$

where

$$Sxy = \frac{\sum(x - \bar{x}) \cdot (y - \bar{y})}{N}$$

$$Sx = \frac{\sum(x - \bar{x})^2}{N}$$

$$Sy = \frac{\sum(y - \bar{y})^2}{N}$$

involves one variable (discharge) and the product of that same variable and a second variable (discharge x concentration). This could lead to an incorrect significance of correlation, in that the L-Q relationship could be significant when the proper C-Q one might not be so.

EFFECTS OF ASSUMPTIONS AND DATA LIMITATIONS ON COMPUTED SEDIMENT LOAD

An analysis was performed to study the effects of the use of incorrect regression analysis and non-continuous discharge data on the annual suspended sediment loads calculated using rating curves. The main aim of this study was to obtain a general idea on the above effects, and thus only a small set of data was used. The following three effects were studied:

(a) Use of non-continuous streamflow records such as daily mean and weekly mean flows.
(b) Use of classical regression instead of reduced major axis line.
(c) Use of Load (L) – Discharge (Q) regression instead of Concentration (C) – Discharge regression.

Use of Non-continuous Discharge Data

As explained earlier, the use of daily mean or weekly mean discharge records will underestimate the annual suspended sediment loads. Thus, a correction factor (Eq. 3) has to be incorporated.

In order to obtain a preliminary set of correction factors K(b,T), 3 years of discharge data from the Drainage and Irrigation Department's (DID) river stations in the Kelang river basin were analyzed. The stations and years used were

(a) Sg. Kelang @ Jambatan Sulaiman 1978
(b) Sg. Kelang @ Lrg. Yap Kwan Seng 1982
(c) Sg. Batu @ Sentul 1982

Hypothetical rating curve equations (Equation 2) with exponent 'b' values of 1.5, 2.0, 2.5 and 3.0 were used to evaluate the reduction in annual suspended sediment loads computed with daily mean, 2-day mean, 7-day, 10-day, 30-day, 50-day and annual mean discharge. The 'b' values were chosen to represent the typical exponent values, which usually range from 1.0 - 3.0. The 'a' value was taken to be 1.0 because being the linear component of the equation, it will not effect the relative sediment loads computed using the rating curves.

As expected, the computed annual suspended sediment loads decreased with the increases in 'b' and 'T' values. Computation using weekly mean discharge resulted in annual loads being 3% – 47% lower compared to those computed using daily mean discharge. The use of monthly mean discharge produced annual loads which were 6% – 62% lower while the use of annual mean discharge resulted in annual loads being 11% – 80% lower than those computed using daily mean discharge records. The computed annual suspended sediment loads are shown in Table 2.

As neither the continuous nor hourly data were available to the author, the above findings were used to derive a relationship to enable sediment load reductions to be predicted based on 'b' and 'T' values. There was poor correlation between T and reduction factors (RF), so regression analysis were performed between the logarithmic transformation of 'T' and RF. The resulting equations are as shown below. L(T) is annual sediment load derived using T-day mean discharge data.

Using the regression equations above, it was possible to calculate the reductions in suspended sediment loads due to changes in 'b' values and discharge data interval. The correction factor K(b,T), which is the ratio

b	Equation	r	Significance
1.5	RF = 1.0046 - 0.0568 log T	0.915	0.01
2.0	RF = 1.0020 - 0.1340 log T	0.922	0.01
2.5	RF = 0.9863 - 0.2112 log T	0.918	0.01
3.0	RF = 0.9577 - 0.2740 log T	0.908	0.01

RF = L(T) / L(1) K(b,T) = RF(1-hour) / RF(T)

TABLE 2
Computed annual sediment loads

Discharge data	'b' values			
	1.5	2.0	2.5	3.0
Sg. Kelang @ Jambatan Sulaiman				
Daily	16378	67692	300272	1418363
2-Day	16177	65332	279989	1264104
Weekly	15802	61385	269615	1057070
10-Day	15782	61152	247628	1042133
Monthly	15361	57006	218215	859794
50-Day	15287	56271	212763	823973
Annual	14629	50062	171322	586295
Sg. Kelang @ Lrg. Yap Kwan Seng				
Daily	6140	20976	79388	323296
2-Day	6101	20665	77433	311892
Weekly	5956	19479	70092	270481
10-Day	5872	18765	65447	243185
Monthly	5709	17291	55780	187700
50-Day	5654	16873	53425	176099
Annual	4873	11559	27421	65050
Sg. Batu @ Sentul				
Daily	6949	23165	88092	379210
2-Day	6796	21648	76606	299328
Weekly	6514	19161	60207	201340
10-Day	6423	18373	55253	174120
Monthly	6296	17349	49326	144320
50-Day	6253	17011	47453	135388
Annual	6003	15266	38823	98737

between actual sediment load and the computed value may be obtained through interpolation for various values of b and T. However, from the above equations, it is obvious that there will not be a K value for T = 0 (continuous discharge data) and the values for $t \to 0$ will be very high. In this respect, T = 1 hour is assumed to represent continuous discharge. The K values are shown in Table 3.

The K(b,T) values shown in Table 3 were derived using just 3 years of data and are thus tentative and by no means universal. Furthermore, no efforts were made to distinguish the differences in catchment sizes. More detailed studies, involving catchments of varying sizes are required in order to establish applicable values. However, these results show that suspended sediment loads computed using daily

TABLE 3
Correction factor K (b, T)

b	Discharge Data			
	Daily	Weekly	Monthly	Annual
1.5	1.078	1.132	1.176	1.261
2.0	1.185	1.335	1.476	1.802
2.5	1.300	1.582	1.895	2.871
3.0	1.395	1.840	2.416	5.226

mean and weekly mean discharge data can be 40% and 84% respectively less than the actual loads. This is comparable with studies by Loughran (1976), where loads calculated using hourly discharge data were 28% – 47% higher than those calculated with daily mean data.

Classical Regression vs. Reduced Major Axis Line

Sediment concentration data from 2 DID stations for the period 1980 – 1984 were used to analyze the discrepancies between sediment loads computed with rating curves derived using the classical regression and the reduced major axis line. The two stations were Sg.Kelang @ Lrg. Yap Kwan Seng and Sg. Batu @ Sentul. The rating curves are shown in *Fig. 2* and *Fig. 3*. The suspended sediment rating curve equations that were obtained are as follows:

	Sg. Batu	Sg. Kelang
Classical regression	$C = 164.63\ Q^{0.854}$	$C = 64.34\ Q^{0.894}$
R.M.A.L.	$C = 87.48\ Q^{1.211}$	$C = 31.79\ Q^{1.395}$
Coefficient of correlation	0.705	0.641
Significance	0.01	0.01

The above equations were substituted into equations 4 to derive equations to compute the suspended sediment loads,

$$L = 0.0864 \times C \times Q \qquad (4)$$

where 0.0864 is the factor for converting the concentration and discharge units into tonnes/day. The subsequent equations to compute sediment loads and the computed annual sediment loads are as follows :

	Sg. Batu	Sg.Kelang
Classical regression	$L = 14.22\ Q^{1.854}$	$L = 5.56\ Q^{1.894}$
Sediment load (tonnes)	228698	89006
R.M.A.L.	$L = 7.56\ Q^{2.211}$	$L = 2.75\ Q^{2.395}$
Sediment load (tonnes)	302778	163759

In both cases, it was observed that the sediment loads computed using R.M.A.L. rating curves were higher than those computed using classical regression rating curves. At Sg. Batu, the sediment load calculated using R.M.A.L. was 32.8% higher while at Sg. Kelang,

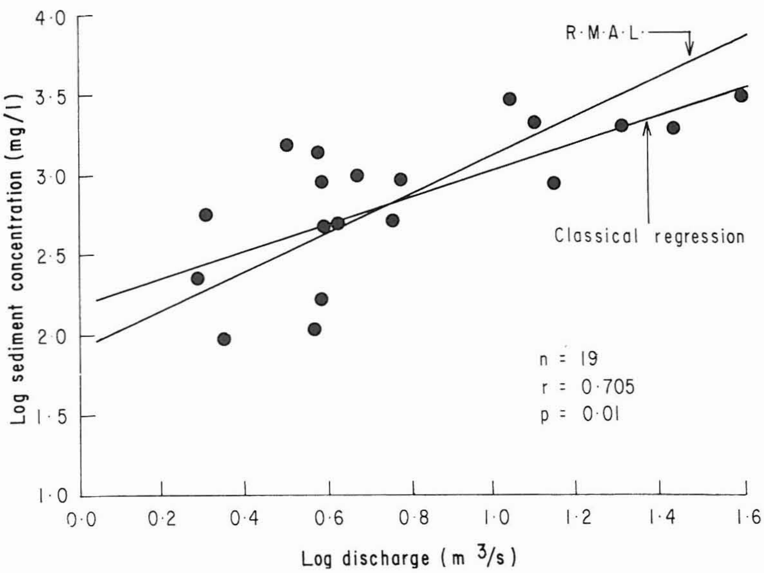

Fig. 2 Suspended sediment rating curve for Sg. Batu at Sentul

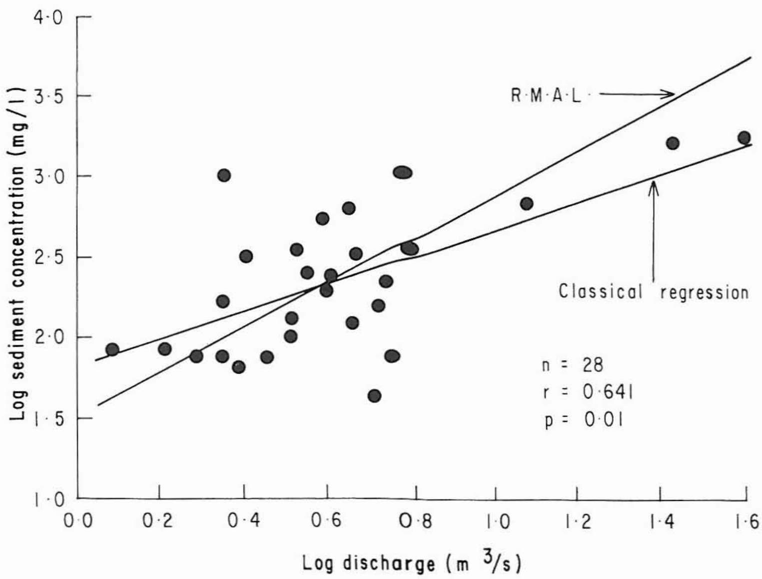

Fig. 3 Suspended sediment rating curve for Sg. Kelang at Lrg. Yap Kwan Seng

the increase was 84.0%. The R.M.A.L. produced higher 'b' values in the best-fit line, thus explaining the increase in the computed annual loads. The higher 'a' values in the classical regression equations do not compensate for the lower 'b' values, thus resulting in lower annual sediment loads.

C-Q regression vs. L-Q regression

Regression analyses using R.M.A.L. were performed between sediment load (L) and river discharge (Q) for both the stations. R.M.A.L. was used because the classical regression will produce equations similar to those derived using Eq. 4. The regression equations obtained from the above exercise as compared to those derived using Eq. 4 and the resulting annual sediment loads are as follows :

As expected, the coefficients of correlation were higher for the L – Q regression, increasing from 0.705 and 0.641 to 0.907 and 0.871 respectively. Although in this study, all regression were significant at p = 0.01, in other cases, the use of L – G regression may overlook the fact that the proper C – Q regression might not be significant. At Sg. Batu, the use of sediment load rating curves derived from L – Q regression produced an annual load of 263009 tonnes compared to 302778 tonnes obtained from using equations derived from C – Q regression or a reduction of 13%. At Sg. Kelang, it resulted in a reduction from 163759 tonnes to 124046 tonnes only, or 24%. Thus the use of L – Q regression instead of C – Q regression under-estimated the annual sediment load at both stations.

	Sg.Batu	Sg.Kelang
C - Q regression	$C = 87.48\ Q^{1.211}$	$C = 31.70\ Q^{1.396}$
L - Q Equation 4	$L = 7.56\ Q^{2.211}$	$L = 2.75\ Q^{2.396}$
Coefficient of correlation	0.705	0.641
Sediment load (tonnes)	302778	163759
L - Q regression	$L = 10.17\ Q^{2.043}$	$L = 3.74\ Q^{2.180}$
Coefficient of correlation	0.907	0.871
Sediment load (tonnes)	263009	124046

Cumulative Errors

The study of three aspects of the suspended sediment rating curve, namely the use of classical regression instead of R.M.A.L., the use of non-continuous discharge data without correction and the use of L-Q regression instead of C-Q regression has shown that all three practices underestimate the annual sediment loads. In order to evaluate the cumulative errors due to the combined effects of the three practices, annual loads were calculated for both the stations using both correct and incorrect procedures. The results are as shown below:

	Sg. Batu (tonnes)	Sg. Kelang (tonnes)
Incorrect method (no correction, use of classical regression	228698	89006
Correct method		
Load computed using C-Q & R.M.A.L.	302778	163759
Correction factor K(b,T)	1.229	1.271
Corrected load	372114	208138
% difference Correct/Incorrect	62.7%	133.8%

As expected, the combination of all three factors produced annual sediment loads that grossly underestimated the actual sediment load. The use of R.A.M.L. and C–Q regression resulted in the computed annual sediment loads at Sg. Batu and Sg. Kelang being 32.3% and 84.0% higher respectively. The incorporation of the correction factors resulted in further increases of 22.9% and 27.1%. The overall increase in the computed sediment loads for Sg. Batu and Sg. Kelang due to the use of correct procedures were 62.7% and 133.8% respectively.

CONCLUSION

The analyses using 3 years of discharge data and sediment concentration data from 2 stations permit several conclusions. The use of daily mean discharge or weekly mean discharge can underestimate the annual sediment loads by as much as 40% to 84% respectively. The difference is expected to be greater with the increase in 'b' values and decrease in catchment area. The use of rating curves derived using the improper classical regression can underestimate the annual loads by 33% to 84% while the use of rating curves derived from L-Q regression instead of C-Q regression can underestimate the annual loads by 13% - 24%. When all the three incorrect practices are combined, the actual sediment load can be 62.7% - 133.8% higher than the computed ones.

Among the three incorrect procedures studied, the use of classical regression and the use of L-Q regression can be easily rectified. However, the use of daily or weekly mean discharge data poses a bigger problem. To obtain continuous data is almost impossible and hourly data difficult for an average practitioner in Malaysia, and therefore the use of daily mean discharge data will continue in the future. Thus, it is important that the calculated sediment loads be corrected in this respect. Much more research is required before the correction factors derived in this study can be used in real-time. Although this study was based on only two stations, the findings require serious considerations as they indicate that previous publications of sediment yield data may be only half the actual value.

Despite all the above improvements, it must be reiterated here that the suspended sediment rating curve is still a crude method of estimating sediment loads. Scarce sampling during flood events and inadequate overall sampling will only produce rating curves which are suspicious in terms of reliability of the computed loads. Furthermore, laboratory procedures and methods of sampling can also influence the final results. However. it must be emphasized that the rating curve is still the most important tool in Malaysia in terms of estimating sediment yield. Until better methods are adopted, hydrologists and engineers should adhere to the correct methods when using the suspended sediment rating curve technique.

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