Evaluation of equations on total bed material load

JUNAIDAH ARIFFIN
Faculty of Civil Engineering, University of Technology MARA,40450 Shah Alam, Selangor
Email:junaidahariffin@hotmail.com

AMINUDDIN ABD GHANI
River Engineering & Urban Drainage Research Centre (REDAC), University Sains Malaysia, Malaysia

NOR AZAZI ZAKARIA
River Engineering & Urban Drainage Research Centre (REDAC), University Sains Malaysia, Malaysia

AHMAD SHUKRI YAHYA
River Engineering & Urban Drainage Research Centre (REDAC), University Sains Malaysia, Malaysia

Abstract Predictions of total bed material load for Malaysian rivers using selected empirical equations were made based on 56 sets of field data. Data were obtained through observations made from three rivers namely Sungai Lui, Sungai Semenyih and Sungai Langat in Malaysia. The rivers are categorised under wide rivers with width to depth ratio greater than 10. Data covers flow discharges from 2.7 m^3/s to 54.078 m^3/s, flow velocities from 0.411 m/s to 1.422 m/s, flow depths from 0.3664 m to 2.4425 m and median sediment sizes between 0.582 mm to 2.415 mm. The equations used in the evaluation are Ackers and White, Engelund and Hansen, Yang and the equation proposed by Wu *et al*. The selection was based on the performance of these equations by past investigators who showed good agreement between observed and calculated transport rates. The range of data used by these investigators are tabulated. Graphical comparisons of the calculated and measured transport rates are shown. The accuracy and the reliability of these formulas are verified.

Keywords Total bed material load, sediment

INTRODUCTION

Total bed material load is a measure of rate of transport of sediments in a river. Predictions on the rate of transport of sediments are required for basis of design of hydraulic structures, managing scour related problems and others. The transportation of sediments is governed by several interrelated parameters that contribute to the complexity of the phenomena. A large number of sediment transport equations have been developed in the past by several investigators employing several theoretical approaches. Equations derived empirically and through laboratory measurements may predict well for laboratory concentrations only. This is because the conditions in the laboratory are more controlled and certain parameters are kept constant. Unlike natural channels the parameters change with time, so is the amount of sediment discharge. The derived equations when tested on field data may produce drastic values compared to the observed or measured values. The predictors derived experimentally or empirically may either over-estimate or under-estimate the total sediment concentrations in natural channels.

The formulation in predicting sediment discharge has started since 1879 by Du Boys who introduced the tractive force approach in his bed load formula. Work on quantification of fine-grained sediment movement based on the time-dependent, advection-dispersion equation was presented by Scarlatos and Li (1992). Yang and Molinas (1996) modified his unit stream power formula for the computation of total bed-material load in a sediment-laden river with a high concentration of fine suspended materials. Molinas and Wu (2001) showed that the relationships derived from flume experiments with shallow flows cannot be universally applied to large rivers with deep flows. His analysis indicated that the commonly used Engelund and Hansen, Ackers and White and Yang equations which were developed using flume experiments are not applicable for large rivers with flow depths and Reynolds numbers up to 100 times larger than those found in flumes.

Equation for calculating the fractional transport rates of sediments incorporating the non-uniformity of sediments was first carried out by Einstein in 1950. Later Egiazaroff (1965) introduced a formula for calculating sediment concentration for sediment mixture based on the generalized criterion of sediment mobility. Swamee and Ojha (1991) conducted similar studies in which the non-uniformity of sediments was described by an empirical three-parameter grain-size distribution equation for unimodal shapes. Modeling of non-uniform-sediment fluvial process based on a multimode characteristics method was developed by Yeh *et al*. (1995) which provides information on the formation of flow field, bed topography and bed material composition. The most recent study on the fractional transport rates of non-uniform sediments was conducted by Wu *et al*. (2000) where a correction factor that accounts for the hiding and exposure mechanism has been incorporated.

In this paper, predictions of total bed material load for rivers in Malaysia were made and analysed using the selected equations. Four equations namely Ackers and White, Engelund and Hansen, Yang and Wu *et al*. were selected based on the performance of these equations by the past investigators. The range of all data used in this study lie within the range of data used in the development of the selected equations. This is illustrated in Table 1. The accuracy and the reliability of the equations are discussed.

Formula	Data source	Flow depth (m)	Sediment type and size (mm)
Ackers-White	Laboratory	Up to 0.4	Non-graded / 0.04 – 4.0
Engelund-Hansen	Laboratory	Up to 0.34	Non-graded/ 0.19 – 0.93
Yang	Laboratory	0.022 – 0.86	Non-graded/ 0.137 – 1.35
Weiming *et al*.	Field & Laboratory	0.01 – 2.56	Graded/ 0.088 – 28.7

Table 1: Range of data used in the development of equations

Data sources

Data used in this study are collected from low to medium flow rivers. The river data include the data from Sungai Lui, Sungai Semenyih and Sungai Langat. All rivers under study are categorised as large river with aspect ratio greater than 10. Flow depths ranges between 0.3664 m – 2.4425 m with flow ranging between 2.7 m^3/s – 54.078 m^3/s. Width of the river ranges between 13.8 m - 30 m. Average flow velocities of 0.411 m/s – 1.422 m/s and median sediment sizes of 0.582 mm – 2.415 mm for the bed material composition were observed. The total bed material load ranges between 0.184 kg/s to as high as 118.664 kg/s. A summary of the data is given in Table 2.

All the 56 sets of data were used in the evaluations of total bed material load equations except in the evaluation of transport equation by Wu *et al*. A careful selection of data was made for use in Wu *et al*. equation as a good set of data that consist of all the sediment sizes are required in the calculation for fractional transport load. Thus only 26 number of data was used in the evaluation.

Data Source	Flow discharge (m3/s)	Flow velocity (m/s)	Flow depth (m)	Width (m)	Surface slope (m)	Median diameter (mm)	Total Bed Material Load (kg/s)
Sg. Lui	2.751 - 6.154	0.411 - 0.609	0.3664 - 0.5854	15 - 15.3	0.003 - 0.0093	0.489 - 3.415	0.184 - 5.987
Sg. Semenyih	6.256 - 7.724	0.713 - 0.852	0.5941 - 0.7087	13.8 - 14	0.0004 - 0.015	0.582 - 1.991	1.126 - 7.076
Sg. Langat	9.055 - 54.078	0.738 - 1.422	0.6234 - 2.4425	16 - 30	0.0043 - 0.0167	0.472 - 2.472	1.116 - 118.664

Table 2: Summary of river data

RESULTS AND DISCUSSION

The difference ratio between the calculated and observed total bed material load is as shown in Table 3. Difference ratio is the ratio between calculated and observed values. The values signify the accuracy of each formula. The distribution of accuracy of each equation by the use of the difference ratio criteria is as shown in Table 3. From the table, among all the four equations used in the evaluation, equation Wu *et al* gave the best results but not significant enough to be used on rivers in all countries. Engelund and Hansen and Yang equations showed a poor performance on these rivers and Ackers and White equation showed the second best performance.

A total number of 56 data has been used to evaluate all the equations except in Weiming *et al*. formula only 26 data were available with complete sets of all sediment sizes. The Ackers-White formula gave difference ratio of 33.93%, 14.29% and 23.21% for the range of 0.25 – 2.0, 0.75 – 1.75 and 0.5 – 2.0. By using Engelund and Hansen approach only 5.36% of the values lie within 0.25 – 2.0 and 0.75 – 1.75 limit and only 3.57% lies within the 0.75 – 1.75 limit. The same sets of data were tested against Yang's formula and the results were less favourable to that of Ackers-White formula. The Yang's method gave 12.5%, 8.93% and 10.71% for the range limits. Weiming *et al*. formula gave much better results of 42.31%, 34.62% and 34.62% for the same range limits.

Formula	Data in range of difference ratio (%)			No. of data
	0.25 - 2.0	0.75 - 1.75	0.5 - 2.0	
Ackers-White	33.93	14.29	23.21	56
Engelund-Hansen	5.36	3.57	5.36	56
Yang	12.5	8.93	10.71	56
Wu *et al*.	42.31	34.62	34.62	26

Table 3: Summary of comparison between computed and observed total bed material load

Figures 1-4, illustrate the graphs of observed against computed sediment discharge using Ackers-White, Engelund-Hansen, Yang and Wu *et al* equations. From the graph in Figure 1, it can be noted that the Ackers-White formula seemed to under-predict the values of sediment discharge. About 34% of the data which are within 0.25 - 2.0 to the line of perfect agreement (shown in Table 3) lie within low to medium flow range.

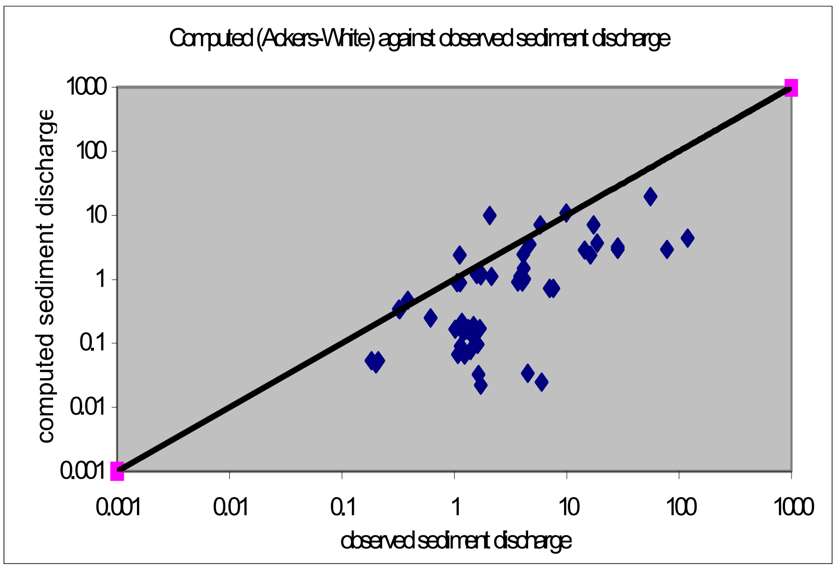

Figure 1: Comparison between the observed and computed sediment discharge for the 56 field data using Ackers-White's equation.

From the graphs of Figures 2- 4, all the three equations seemed to over-predict the values of sediment discharge. This indicates that on average all the three equations over-predict the values of sediment discharge for rivers with aspect ratio greater than 10. Engelund and Hansen equation showed a poor performance on these rivers and this is shown in Table 3. About 5% of the calculated values agree in the range of 0.25 - 2.0 limit with the observed values.

Similar performance resulted when using Yang's equation for the same sets of data where only 12.5% of the data are in the range of 0.25 - 2.0 limit. This is shown in Table 3. From the graph of Figure 3, it can be noted that only data in the medium flow range seemed to show a better agreement.

From Figure 4, Wu *et al* equation gave a good agreement for lower flow range. The performance of this equation is the best among all the four equations being evaluated. However, the results are still below the acceptable limit.

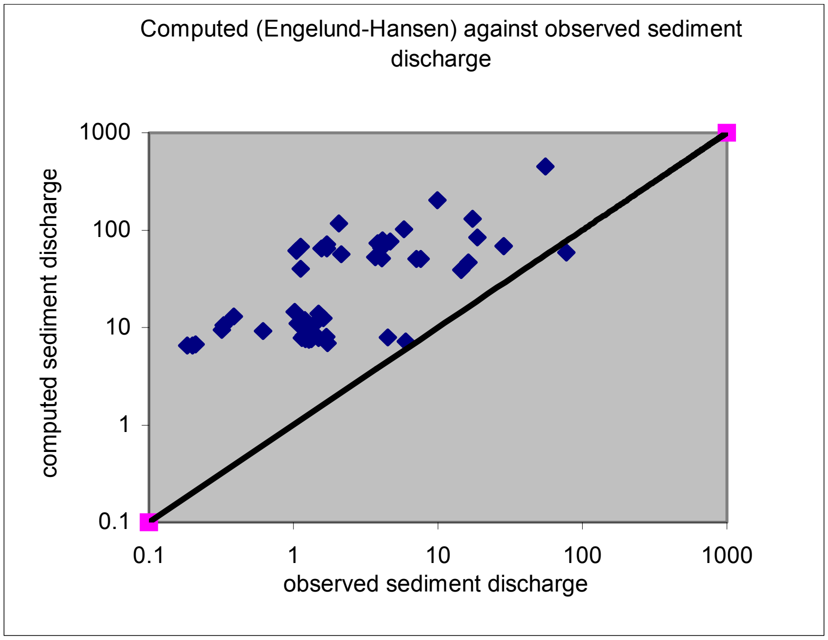

Figure 2: Comparison between the observed and computed sediment discharge for the 56 field data using Engelund-Hansen's equation.

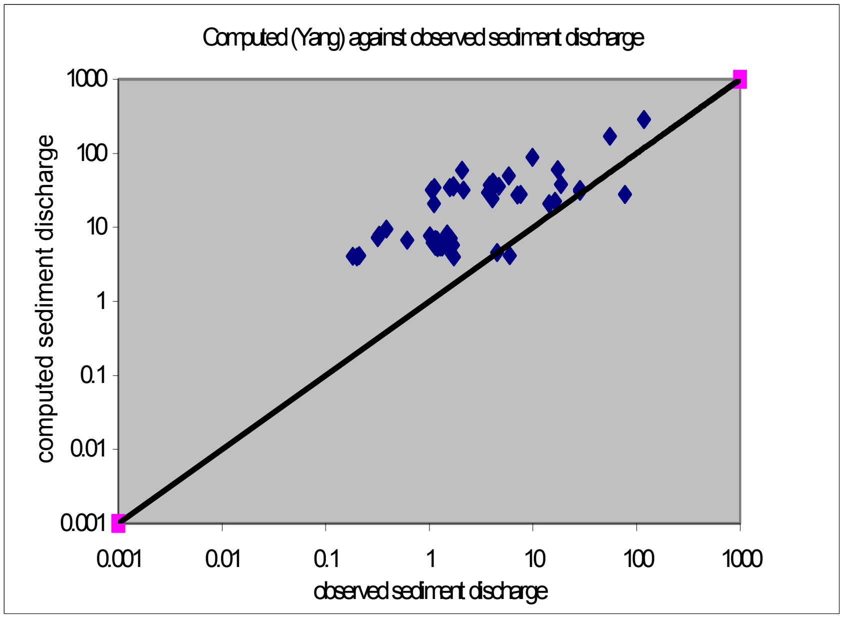

Figure 3: Comparison between the observed and computed sediment discharge for the 56 field data using Yang's equation

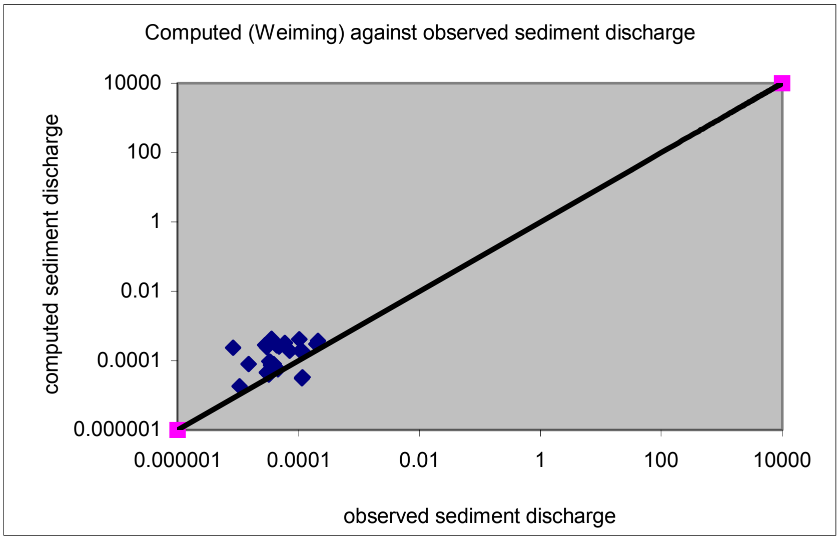

Figure 4: Comparison between the observed and computed sediment discharge for the 26 field data using Weiming's equation.

CONCLUDING REMARKS

A study on the sediment discharge on rivers with aspect ratio greater than 10 were conducted. From the evaluations on selected transport equations, the three equations namely Ackers-White, Engelund-Hansen and Yang which were derived using flume data gave poor performance when tested against field data. Even though Wu *et al* equation gave the best performance but still it is not significant enough to be used on rivers in other country despite a good data source used in the development of the equation. Further analysis is necessary to be done in the future and more sets of good field data are required for a good prediction of sediment discharge.

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REFERENCES

Ackers, P., and White, W.R. (1973). "Sediment Transport: New Approach and Analysis," *Journal of the Hydraulics Division*, *ASCE*, Proceedings of the American Society of Civil Engineers, **Vol.99**, HY11, 2041 – 2060.

Egiazaroff, I.V. (1965). "Calculation of Non-Uniform Sediment Concentrations," *Journal of the Hydraulics Division*, Proceedings of the American Society of Civil Engineers, **Vol.91**, HY4, 1965, 225-247.

Molinas, A., and Wu, B. (2001). "Transport of Sediment in Large Sand-Bed Rivers," *Journal of Hydraulic Research*, **39**, No.2, 135-146.

Scarlatos, P.D., and Li, L. (1992). "Analysis of Fine-Grained Sediment Movement in Small Canals," *Journal of Hydraulic Engineering*, *ASCE*, **Vol.118**, No.2, 200-207.

Swamee, P.K., and Ojha, C.S.P. (1991). "Bed Load and Suspended Load Transport of Non-Uniform Sediments," *Journal of Hydraulic Engineering*, *ASCE*, **Vol.117**, No.6, 774-787.

Wu, W., Wang, S.S.Y., and Jia, Y. (2000). "Non-Uniform Sediment Transport in Alluvial Rivers," *Journal of Hydraulic Research*, **38**, No.6, 427-434.

Yang, C.T., and Molinas, A. (1996). "Sediment Transport in the Yellow River," *Journal of Hydraulic Engineering*, *ASCE*, **Vol.122**, No.5, 237-244.

Yeh, K.C., Li, S. J., and Chen, W.L. (1995). "Modeling Non-Uniform-Sediment Fluvial Process by Characteristics Method," *Journal of Hydraulic Engineering*, *ASCE*, **Vol.121**, No.2, 159-170.