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Influential Parameters for Sediment Transport Prediction in Headwater Streams

INFLUENTIAL PARAMETERS FOR SEDIMENT TRANSPORT PREDICTION IN HEADWATER STREAMS (HWS).

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ABSTRACT

Various studies have been conducted to quantify the sediment transport pattern in Malaysia. However, specific study which is mainly focused on HWS with relatively higher slopes is still lacking. Further more, there are no specific studies conducted to derive the most influential parameters for sediment transport prediction in HWS especially in Malaysia. The present study reports the selection procedures employed to derive the most influential parameters for sediment transport prediction in HWS. The governing parameter that has high influence on sediment transport is selected based on literature survey and field data. The data were normalized using the log and quadratic transformation in conjunction to reduce the percentage error. Two approaches are used to find the trend between the selected parameters. The first method is using Pearson correlation coefficient and another approach using the scatter plot to show the rough trend of the data. The highly correlated variables with the transport parameter are suggested for empirical formulation.

Keywords: correlation, dimensionless parameters, headwater streams, sediment transport

1. INTRODUCTION

Wohl (2000) defines the HWS as reach having average gradient of ≥ 0.002 m/m. The reach indicates a length of channel at least ten times the average channel width and having relatively constant morphology and having average slope greater than the middle gradient of low gradient rivers. Beside that, the HWSs having coarser bed material; ranging from fine gravels to big boulders. It is evident that various dependant and independent sediment transport parameters were introduced in previous studies to describe the behavior of sediment transport movement (Yang, 1972 & 1984; Julien, et al., 2003; Karim, 1998; Wu et al., 2000; Cheng, 2002; Smart, & Jaeggi, 1983; Cao, et al., 2006; Egiazaroff, 1965). However, the applicability of the suggested parameters was never being test with the hydraulic conditions of a HGR. Thus, it is assumed that the existing parameters are good enough to represent the sediment transport parameter in HGR however a right and highly influential combination is yet to be found.

2. LISTING of INFLUENTIAL PARAMETERS

The frequently used parameters (Yang, 1972 & 1984; Julien, et al., 2003; Karim, 1998; Wu et al., 2000; Cheng, 2002; Smart, & Jaeggi, 1983; Cao, et al., 2006; Egiazaroff, 1965) are analyzed and grouped into 8 classes namely mobility, transport, sediment, conveyance shape, flow resistance, hiding-exposure functions, sheltering factors and fractional functions as listed in Table 1. These parameters are evaluated and validated with set of selected 55 data from 22 HWS in Malaysia (Table 2). (Φ) and (C_V) are used as dependant parameter (Y-axis) while the rest of the parameters as the independent parameter (X-axis). Most of the existing equations are using the transport parameter as the dependent variable to develop the sediment transport relationship trend with the independent variable. Table 2 shows the descriptions of parameters as stated in Table 1.

Table 1: Parameters and Dimensionless groups

Parameter class	Dimensionless groups
Mobility	$\Psi = \frac{(S_s - 1)d_{50}}{RS_o}, \frac{V}{\sqrt{gd_{50}(S_s - 1)}}, \frac{U_*}{V}, \frac{VS_o}{\omega_s}, F^* = \frac{V}{\left[g(s-1)D\cos\theta(\tan\phi - \tan\theta)\right]^{1/2}},$ $\Omega = \frac{\tau_b u_*}{\rho\left[(s_s - 1)gD_{50}\right]^{3/2}}, \tau_{cj}^* = \tau_c^* \cos(\arctan S_o)\left[1 - \frac{S_o}{\tan\phi}\right]$
Transport	$C_v, \Phi = \frac{C_v VR}{\sqrt{g(S_s - 1)d_{50}^3}}$
Sediment	$D_{gr} = d_{50}\left(\frac{g(S_s - 1)}{\nu^2}\right)^{1/3}, d_{50}/B, \frac{U_*}{\omega_s}, \frac{\omega_s d_{50}}{\nu}$
Conveyance shape	$B/y_o, B^2/A$
Flow resistance	$\lambda_s = 8gRS/V^2, R/d_{50}, y_o/d_{50}$
Hiding-exposure Function	$\xi_i = \frac{1.66667}{\left[\log\left(19\frac{D_i}{D_{50}}\right)\right]^2}, \eta_i = \left(\frac{p_{ei}}{p_{hi}}\right)$
Sheltering Factor	$\eta = C_1\left(\frac{D_i}{D_{50}}\right)^{C_2}$
Fractional Function	$\Phi_i = P_{ai}\eta,\ P_{ai} = P_i/D_i \Big/ \sum_{i=1}^{n} P_i/D_i$

Table 2: Description of the characteristics Parameters

R/d_{50}	Roughness on the bed
y_o/d_{50}	Dimensionless flow depth (water depth ratio) and relative roughness on bed
λ_s	Friction factor
B^2/A	Channel width factor
B/y_o	Stream width ratio
D_{gr}	Dimensionless grain size
d_{50}/B	Relative sediment particle size
$U*/\omega_s$	Ratio of shear velocity and fall velocity
$\omega_s d_{50}/\nu$	Fall velocity Reynolds Number
Φ	Transport Parameter
ψ	Flow Parameter
C_v	Volumetric sediment concentration
F_{gr}	Sediment mobility number-the ratio of the shear force on unit area of the bed to immersed weight of a layer of grains
$U*/V$	Ratio of shear velocity and average velocity
VS_o/ω_s	Dimensionless unit stream power. The time rate of potential energy expenditure per unit weight in an alluvial channel.
F^*	Particle Densimetric Froude Number for initiation of motion
Ω	Motion of near-bed particles
τ^*_{cj}	Critical Shield Parameter
η_i	Hiding-Exposure factor
ξ_i	Hiding-Exposure function
η	Sheltering factor due to entrapment of small particle behind larger particle
$C_1 = 1.15\left(\frac{\omega_s}{U*}\right)$	Coefficient to represent flow intensity
$C_2 = 0.60\left(\frac{\omega_s}{U*}\right)$	Exponent to represent flow intensity
P_{ai}	Areal fraction of bed sediment particles dislodged from the bed.
Φ_i	Weighting function

Table 2: Hydraulics and sediment data range for HWS in Malaysia

No of Data	Data Range (Primary Data)									
	Discharge Q (m^3/s)	Average Velocity V (m/s)	Width B (m)	Flow Depth Y_o (m)	Area A (m^2)	Hydraulic Radius R (m)	Water Surface Slope S_o (m/m)	Sediment Size d_{50} (mm)	Fall Velocity ω_s (m/s)	Total Bed Material Load T_j (kg/s)
55	0.154 - 7.208	0.210 - 2.070	6.00 - 20.00	0.15 - 1.28	0.571 - 10.905	0.107 - 0.939	0.002 - 0.027	2.000 - 147.430	0.139 - 1.220	0.001 - 0.122

3. CORRELATION TREND

The correlation trend between the parameters were checked and verified using two approaches. The first approach is using the Pearson correlation coefficient and another approach is using the scatter plot. The intensity of the correlation coefficient is given in Table 3 (Cohen (1988). The parameters having correlation coefficient values which fall within the "large" category are selected.

Table 3: Correlation Coefficients

Correlation	**Negative**	**Positive**
Small	−0.29 to −0.10	0.10 to 0.29
Medium	−0.49 to −0.30	0.30 to 0.49
Large	−1.00 to −0.50	0.50 to 1.00

The transformations were made to normalize the data and to minimize the percentage error. The logarithmic and quadratic forms were produced to evaluate the best form of transformation and based on results shown in Table 4, the logarithmic transformation is selected. By applying the Pearson correlations, the coefficient for both form of transformation were shown in Table 4. Some of the parameters having falls within the large negative or positive correlation class are dimensionless unit stream power, time rate of potential energy expenditure per unit weight in an alluvial channel, dimensionless flow depth (water depth ratio) and relative roughness on bed, roughness on the bed, fall velocity Reynolds Number, relative sediment particle size, flow parameter, ratio of shear velocity and fall velocity, dimensionless grain size, sediment mobility number-the ratio of the shear force on unit area of the bed to immersed weight of a layer of grains, motion of near-bed particles, hiding-exposure function, particle densimetric Froude Number for initiation of motion and last but not least the sheltering factor. Beside that, the correlation trends can also be observed by plotting the scatter plot among the parameters. Figure 1 shows the plot of the selected parameters using logarithmic transformation which shows good fit between dependant and independent parameter.

Table 4: Pearson coefficient Value

Parameters	Logarithmic Form		Quadratic Form	
	(C_V)	(Φ)	(C_V)	(Φ)
$\Psi = \frac{(S_s - 1)d_{50}}{RS_o}$	0.175	-0.738	0.115	-0.486
$\frac{V}{\sqrt{gd_{50}(S_s - 1)}}$	0.053	0.854	0.05	0.808
$\frac{U_*}{V}$	0.114	-0.185	0.091	-0.202
$\frac{VS_o}{\omega_s}$	0.338	0.7220	0.188	-0.562

Table 4: Continuation …

$F = \dfrac{V}{\left[g(s-1)D\cos\theta(\tan\phi - \tan\theta)\right]^{1/2}}$	0.053	0.865	0.049	0.818
$\Omega = \dfrac{\tau_b u_*}{\rho\left[(s_s-1)gD_{50}\right]^{3/2}}$	0.283	0.598	0.127	0.310
$\tau_{cj}^* = \tau_c^* \cos(\arctan S_o)\left[1 - \dfrac{S_o}{\tan\phi}\right]$	0.041	-0.498	-0.128	-0.453
$D_{gr} = d_{50}\left(\dfrac{g(S_s-1)}{\nu^2}\right)^{1/3}$	-0.015	-0.886	0.034	-0.578
$\dfrac{d_{50}}{B}$	0.051	-0.830	0.101	-0.498
$\dfrac{U_*}{\omega_s}$	0.15	0.827	0.099	0.605
$\dfrac{\omega_s d_{50}}{\nu}$	-0.014	0.867	-0.024	0.776
B/y_o	-0.057	-0.368	-0.163	-0.342
$\dfrac{B^2}{A}$	0.032	-0.193	-0.059	-0.246
$\lambda_s = \dfrac{8gRS}{V^2}$	0.114	-0.185	0.059	-0.137
$\dfrac{R}{d_{50}}$	-0.026	0.862	0.009	0.810
$\dfrac{y_o}{d_{50}}$	-0.028	0.848	0.007	0.789
$\xi_i = \dfrac{1.66667}{\left[\log\left(19\dfrac{D_i}{D_{50}}\right)\right]^2}$	-0.042	-0.722	-0.077	-0.376
$\eta_i = \left(\dfrac{p_{ei}}{p_{hi}}\right)$	-0.207	-0.321	-0.184	-0..408
$\eta = C_1\left(\dfrac{D_i}{D_{50}}\right)^{C_2}$	-0.497	-0.504	-0.18	-0.098
$\Phi_i = P_{ai}\eta$	-0.231	-0.307	-0.012	-0.027

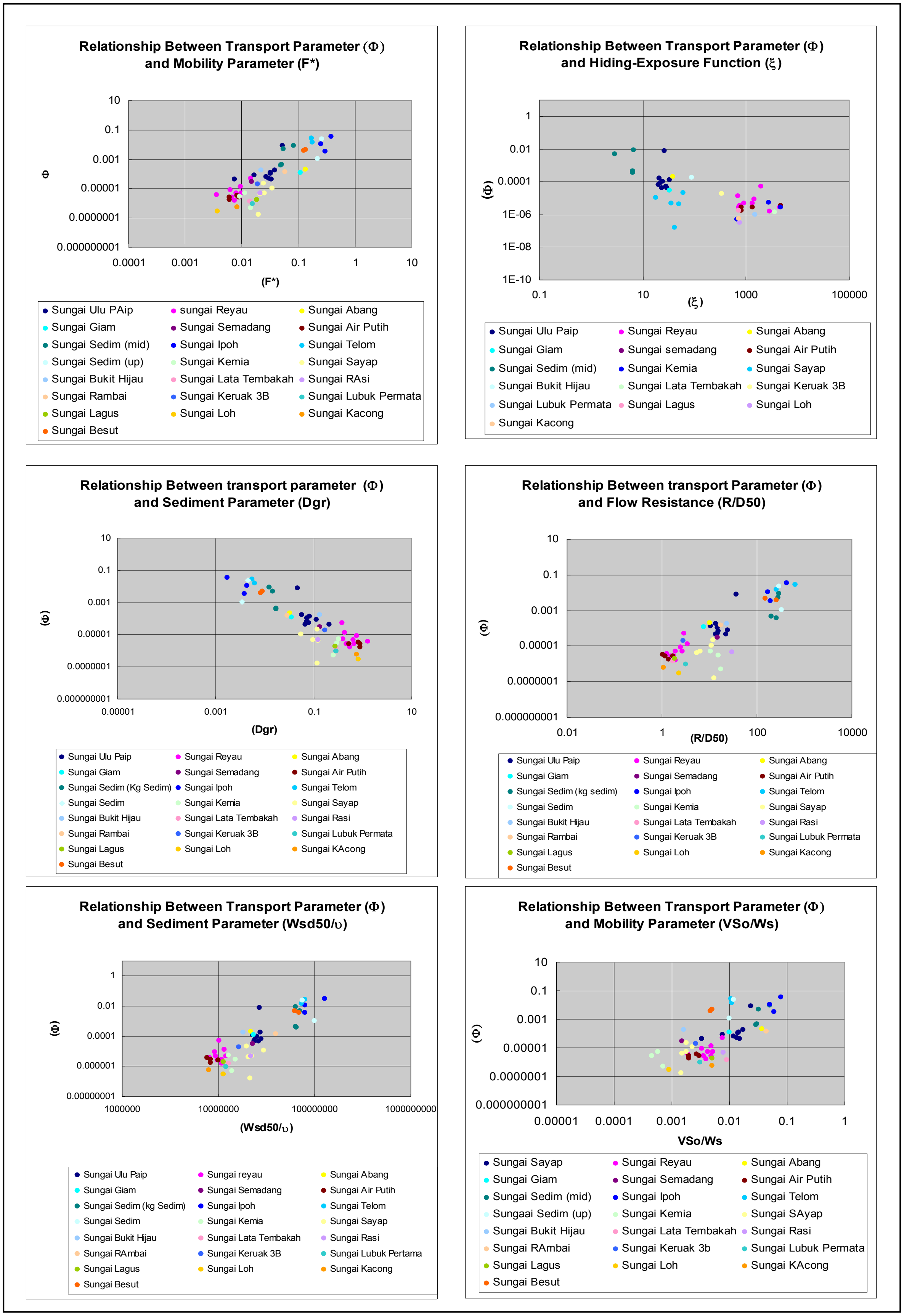

Figure 1 Selected scatter plots showing good correlation between transport parameter (dependant) and other independent variables and

4.0 Transformation Verification

The selected highly correlated 13 variables with the transport parameter (Φ) were further verified by determining the skewness value. The transform is said well applied if the skewness $\approx$ 0 (Hair et al., 2006). Table 5 showed the skewness values obtained and the variables which have the skewness values $\approx$ 0 were proposed for numerical analysis and equation development.

Table 5: Comparison for Skewness value

Parameters	$\Psi = \frac{(S_s - 1)d_{50}}{RS_o}$	$\frac{V}{\sqrt{gd_{50}(S_s - 1)}}$	$\frac{U_*}{V}$	$\frac{VS_o}{\omega_s}$
Skewness	-0.402	0.491	-0.051	0.099

Parameters	F^*	$\Omega = \frac{\tau_b u_*}{\rho[(s_s - 1)gD_{50}]^{3/2}}$	τ_{cj}^*	$D_{gr} = d_{50}\left(\frac{g(S_s - 1)}{\nu^2}\right)$
Skewness	0.474	0.633	-0.406	-0.465

Parameters	$\frac{d_{50}}{B}$	$\frac{U_*}{\omega_s}$	$\frac{\omega_s d_{50}}{\nu}$	B/y_o
Skewness	-0.099	0.724	0.457	0.150

Parameters	$\frac{B^2}{A}$	$\lambda_s = \frac{8gRS}{V^2}$	$\frac{R}{d_{50}}$	$\frac{y_o}{d_{50}}$
Skewness	-0.119	-0.051	0.466	0.312

Parameters	$\xi_i = \frac{1.66667}{\left[\log\left(19\frac{D_i}{D_{50}}\right)\right]^2}$	$\eta_i = \left(\frac{p_{ei}}{p_{hi}}\right)$	$\eta = C_1\left(\frac{D_i}{D_{50}}\right)^{C_2}$	$\Phi_i = P_{ai}\eta$
Skewness	-0.040	-5.891	0.325	1.229

The estimated skewness values clearly shown that the log- transform is applicable to be used except for the dimensionless parameter for $\eta_i = \left(\frac{p_{ei}}{p_{hi}}\right)$. Since this parameters shows weak correlation with the transport parameter (-0.321), thus there is no further check for this parameter and omitted from the analysis list.

4. CONCLUSION

It is statistically proven that selected 13 parameters namely $\frac{VS_o}{\omega_s}$, y_o/d_{50}, R/d_{50}, $\frac{\omega_s d_{50}}{\nu}$, $\frac{d_{50}}{B}$, $\Psi = \frac{(S_s - 1)d_{50}}{RS_o}$, $\frac{U_*}{\omega_s}$, $D_{gr} = d_{50}\left(\frac{g(S_s - 1)}{\nu^2}\right)^{1/3}$, $\frac{V}{\sqrt{gd_{50}(S_s - 1)}}$, Ω, ξ_i, F^* and η showed high correlation with the transport parameter (Φ) for Malaysian headwater streams. Those influential parameters were considered significant to be included in the empirical formulation of the sediment transport prediction.

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