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EFFICACY OF VAN RIJN MODEL OVER ENGELUND-FREDSOE MODEL IN THE PREDICTION OF SEDIMENT TRANSPORT

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ABSTRACT. *This paper deals with the efficacy of two sediment transport models in predicting the sediment transport in the Atrai basin of northwest Bangladesh. The adopted models are Van Rijn and Engelund-Fredsoe. Related data collected from the Atrai basin were used in this study. Bed and suspended loads were computed to get the total sediment transport. Rating curves and power relationship were also established for practical use. Besides, comparison of the two models has also been done and presented. It has been revealed in this study that the Van Rijn model is more efficient than Engelund-Fredsoe model for the prediction of sediment transport. This finding confidently recommends the Van Rijn model for the computation of sediment transport in any natural canal and river.*

KEYWORDS. Bed load, Suspended load, Total sediment transport, Atrai basin, Rating curves, Power relationship

INTRODUCTION

Many studies relating the sediment transport in the major rivers of Bangladesh had been conducted in the past. First mentionable work was reported by Coleman (1969). His studies were based on the measured data for the period of 1958 to 1962. Examples of similar studies are the works of Master Plan Organization (1986), Jamuna Multi-purpose Bridge Authority (1986), Bari (1978), Bari and Alam (1979) and Hossain (1992). However, these studies were concentrated towards the morphological study that had been done for the major rivers of Bangladesh. In connection with the morphological study, Bangladesh Water Development Board and Howard Humphreys and Partners (1989) carried out the study for sediment transport in the rivers of Atrai basin. Matin and Mohiuddin (1994a, 1994b) also studied the sediment characteristics of the rivers of Atrai basin.

The phenomenon of sediment transport is of great economic importance. The design and execution of a flood control scheme is chiefly governed by the peak flood level, which in turn depends upon the scouring and deposition of sediment. Firstly, direct scouring and deposition of sediment may change the bed levels and thereby the flood levels. Secondly, the scouring of the riverbanks may create sharp and irregular curves, which increase the flow resistance of the channel and thereby the flood level for the same discharge. Natural rivers used for navigation get silted due to heavy siltation and thus reduce the clear depth required for navigation. Sediments deposited in the rivers and harbors may sometimes require costly dredging. Besides, silting affects the storage capacity of the reservoirs and thereby reduces their usefulness and life. Sediment transport thus poses numerous problems and therefore is a subject of great importance. It is necessary to predict the total sediment transport in order to remedy or prevent the problems caused by sediment loads in the water bodies. This study has used Van Rijn and Engelund-Fredsoe models in order to compute the amount of sediment transport. The intention is merely to show their efficacy in computing the sediment transport.

VAN RIJN MODEL

This sediment transport model computes bed load and suspended load separately and is valid for particles in the range of 0.20 to 2.0 mm (Van Rijn, 1984). It takes into account empirically the effect of high concentration of sediment load.

Bed Load Calculation by Van Rijn Model

In Van Rijn model, the bed load transport rate (q_{bvr}) has been computed from the particle velocity (u_{bp}), saltation height (δ_b) and bed load concentration (c_b) as follows:

$$q_{bvr} = u_{bp} \times \delta_b \times c_b \tag{1}$$

Where,

$u_{bp} = [(s-1)\, gd_{50}]^{0.5} \times 1.5\, T^{0.6}$

$\delta_b = 0.30\, d_{50} \times (D^*)^{0.7} \times T^{0.5}$

$c_b = 0.18\, c_0 [T/(D^*)]$

Combining the above three relations, Van Rijn established the following equation:

$$q_{bvr} = 0.054\, [\{(s-1)\, gd_{50}\}^{0.5} \times c_0 d_{50} \times \{T^{2.1}/(D^*)^{0.3}\}] \tag{2}$$

Where,

particle diameter, $D^* = [\{(s-1)\, g\}/\nu^2]^{1/3} \times d_{50}$

Transport stage parameter, $T = [(u^*)^2 - (u^*_{cr})^2]/[(u^*_{cr})^2]$

$= [\theta - \theta_{cr}]/[\theta_{cr}]$

s = specific gravity (2.65)

g = acceleration of gravity (9.81 m/sec^2)

d_{50} = grain size (50% finer)

c_0 = maximum bed load concentration

V = kinematic viscosity
u^* = bed shear velocity
u^*_{cr} = critical bed shear velocity
θ = Shield parameter
θ_{cr} = critical Shield parameter

Suspended Load Calculation by Van Rijn Model

In Van Rijn model, the suspended load transport rate (q_{svr}) has been computed by using the following equation:

$$q_{svr} = F \times V \times D \times c_a \qquad (3)$$

Where,

V = mean velocity of flow
D = mean depth of flow
Reference concentration, $c_a = 0.015\,[(d_{50}/a) \times T^{1.5}/(D^*)^{0.3}]$
Correction factor, $F = \{(a/D)\,Z' - (a/D)^{1.2}\} \,/\, \{(1-a/D)\,Z' \times (Z' - 1.2)\}$

Where,
Bed load concentration = a
Modified suspension or Rouse parameter, $Z' = Z + \varnothing$

Suspension or Rouse parameter, $Z = 2W_s/(\psi\kappa u^*)$
Overall correction factor, $\varnothing = 2.5\,[(W_s/u^*)^{0.8} \times (c_a/c_0)^{0.4}]$ for $0.01 \leq W_s/u^* \leq 1.0$

c_0 = maximum bed load concentration
Von Karmen constant = κ (0.4)
Bed shear velocity = u^*
Diffusion coefficient of sediment, $\psi = 1 + 2\,(W_s/u^*)^2$ for $0.1 < W_s/u^* < 1.0$

Fall velocity of suspended sediment,
$W_s = [(s-1)\,gd_{50}^2]/[18\,\nu]$ for $d_s < 100\ \mu m$
$= [10\nu/d_s]\,[\{1+\{0.0117\,(s-1)\,gd_{50}^3\}/\nu^2\}^{0.5} - 1]$ for $100\mu m < d_s < 1000\ \mu m$
$= 1.1\,[(s-1)\,gd_s]^{0.5}$ for $d_s > 1000\ \mu m$

d_s = representative particle diameter of suspended sediment
$= d_{50}[1 + 0.1(\sigma_s - 1) \times (T - 25)]$ for $T < 25$
$= d_{50}$ for $T > 25$

σ_s = geometric standard deviation
$= 0.5\,[d_{84}/d_{50} + d_{16}/d_{50}]$
$= 1.5$ and 2.5

ENGELUND-FREDSOE MODEL

This sediment transport model considers bed load and suspended load separately (Engelund & Fredsoe 1976). It is based on the ideas of Bagnold (Ranga Raju 1985) and describes the dispersive stresses due to grain collisions. This model gives a more detailed description of the sediment transport and its relation to the flow resistance.

Bed Load Calculation by Engelund-Fredsoe Model

In Engelund-Fredsoe model, the bed load transport rate (q_{bef}) has been determined by using the following equation:

$$q_{bef} = \phi_b \, [(s-1) \, g d_{50}^{3}]^{1/2} \tag{4}$$

Where,

ϕ_b = bed load parameter = $5p \, (\sqrt{\theta} - 0.7\sqrt{\theta_{cr}})$

θ = Shield parameter

θ_{cr} = critical Shield parameter

p = probability factor = $[1 + \{(\pi\beta/6)/(\theta - \theta_{cr})\}^4]^{-1/4}$

β = dynamic friction coefficient

π = constant (22/7)

Suspended Load Calculation by Engelund-Fredsoe Model

In Engelund-Fredsoe model, the suspended load transport rate (q_{sef}) has been computed by using the following equation:

$$q_{sef} = 11.6 \, [c_a \times u^* \times a \, \{\ln(30D/k) \, I_1 + I_2\}] \tag{5}$$

Where,

reference concentration, $c_a = [0.65] / [1 + 1/\lambda_b]^3$

u^* = bed shear velocity = $[\kappa\nu]/[\ln(30D/k) - 1]$

a = bed load concentration = $2d_{50}$

Grain size constant, $k = 2.5 \, d_{50}$

D = mean depth of flow

$I_1 = 0.216 \, [A^{z-1} / (1 - A)^z] \int_A^1 \{(1 - s) / s\}^z \, ds$

$I_2 = 0.216 \, [A^{z-1} / (1 - A)^z] \int_A^1 \{(1 - s) / s\}^z \ln s \, ds$

λ_b = linear concentration = $[\{\theta - \theta_{cr} - \pi\beta p/6\}/\{0.027 s\theta\}]^{1/2}$

κ = Von Karmen constant (0.4)

A = integration constant = a/D

Z = suspension or Rouse parameter = $2W_s / (\psi \kappa u^*)$

ν = kinematic viscosity

s = specific gravity (2.65)

ψ = diffusion coefficient of sediment

θ = Shield parameter = $[u^*]^2/[(s-1)\ g\ d_{50}]$

Critical Shield parameter:

$$
\begin{aligned}
\theta_{cr} &= 0.11\ (D^*)^{-0.54} && \text{for } D^* \leq 10 \\
&= 0.04\ (D^*)^{0.1} && \text{for } 10 < D^* \leq 20 \\
&= 0.013\ (D^*)^{0.29} && \text{for } 20 < D^* \leq 150 \\
&= 0.055 && \text{for } D^* > 150
\end{aligned}
$$

Where, particle diameter, $D^* = [\{(s-1)\ g\}/\nu^2]^{1/3}\ d_{50}$

POWER RELATIONS

Simple power relations can be developed relating sediment discharge or transport with average water discharge and mean velocity of flow. The power relations are similar to the following forms:

$$Q_s = CQ_w^n \tag{6}$$

$$Q_s = KV^m \tag{7}$$

Where,

Q_s = sediment discharge

Q_w = average water discharge

V = mean velocity

K, C, n, and m are constants

The coefficient of regression (r^2) for the above equations can be determined by the following equation:

$$r^2 = [\{\Sigma X_i Y_i - nXY\}/\{(n-1)\ S_x S_y\}] \tag{8}$$

Where,

X_i = independent variable

Y_i = dependent variable

n = number of variables

X = mean of X_i

Y = mean of Y_i

S_x = standard deviation of X's

S_y = standard deviation of Y's

STUDY AREA

The major rivers of the northwest region of Bangladesh are Dudkumer, Teesta, Dharala, Atrai and Mohananda. In the present study, the Atrai basin was chosen to examine the efficacy of Van Rijn model over Engelund-Fredsoe model. The Atrai basin is the lower part of the river system spreading within Rajshahi and Pabna districts. The Atrai enters Bangladesh from Indian Territory at Chakhorihorpur and flows south and then southeast in broad low land area, bounded on the south by the river Ganges and on the north by the elevated lands of Barindra Tract. The system falls out to the Jamuna at Baghabari. Based on the availability of relevant data, the station named Mohadevpur was selected to study the efficiency of Van Rign and Engelund-Fredsoe models in predicting the bed and suspended load transport rate. Sediment discharge and other flow characteristics data collected from Mohadevpur station were used in the study. Figure 1 shows the river system of Atrai basin and locates the position of Mohadevpur station.

RESULTS AND DISCUSSION

The cross-sectional profile of the Atrai at Mohadevpur station was established from the collected data. It is shown in Figure 2. Cross-sectional areas and mean velocities were computed from the relevant collected data and these are given in Table 1.

Table 1: Cross-sectional Areas and Mean Velocities at Different Water Levels

Collection Date	Average Water Level (m)	Average Width (m)	Average Discharge (m^3/s)	Cross Sectional Area (m^2)	Mean Velocity (m/s)
01-06-91	1.48	98.0	262.06	144.74	1.81
02-06-91	1.69	106.0	330.92	178.74	1.85
06-06-91	1.42	94.0	243.90	133.42	1.83
10-06-91	1.00	95.0	173.34	95.24	1.82
13-06-91	0.91	93.0	157.32	84.64	1.86
16-06-91	3.51	137.0	1155.00	480.54	2.40
20-06-91	3.12	129.0	939.92	403.10	2.33
23-06-91	2.63	122.0	687.00	321.36	2.14
26-06-91	3.01	125.0	852.46	376.43	2.26
30-06-91	2.20	112.0	486.76	246.07	1.98
03-07-91	2.66	123.0	706.66	327.49	2.16
06-07-91	3.51	136.0	1150.40	477.53	2.41
10-07-91	3.30	133.0	1047.18	438.78	2.39
12-07-91	3.23	131.0	1003.36	422.94	2.35
20-07-91	2.83	123.5	768.16	349.10	2.20

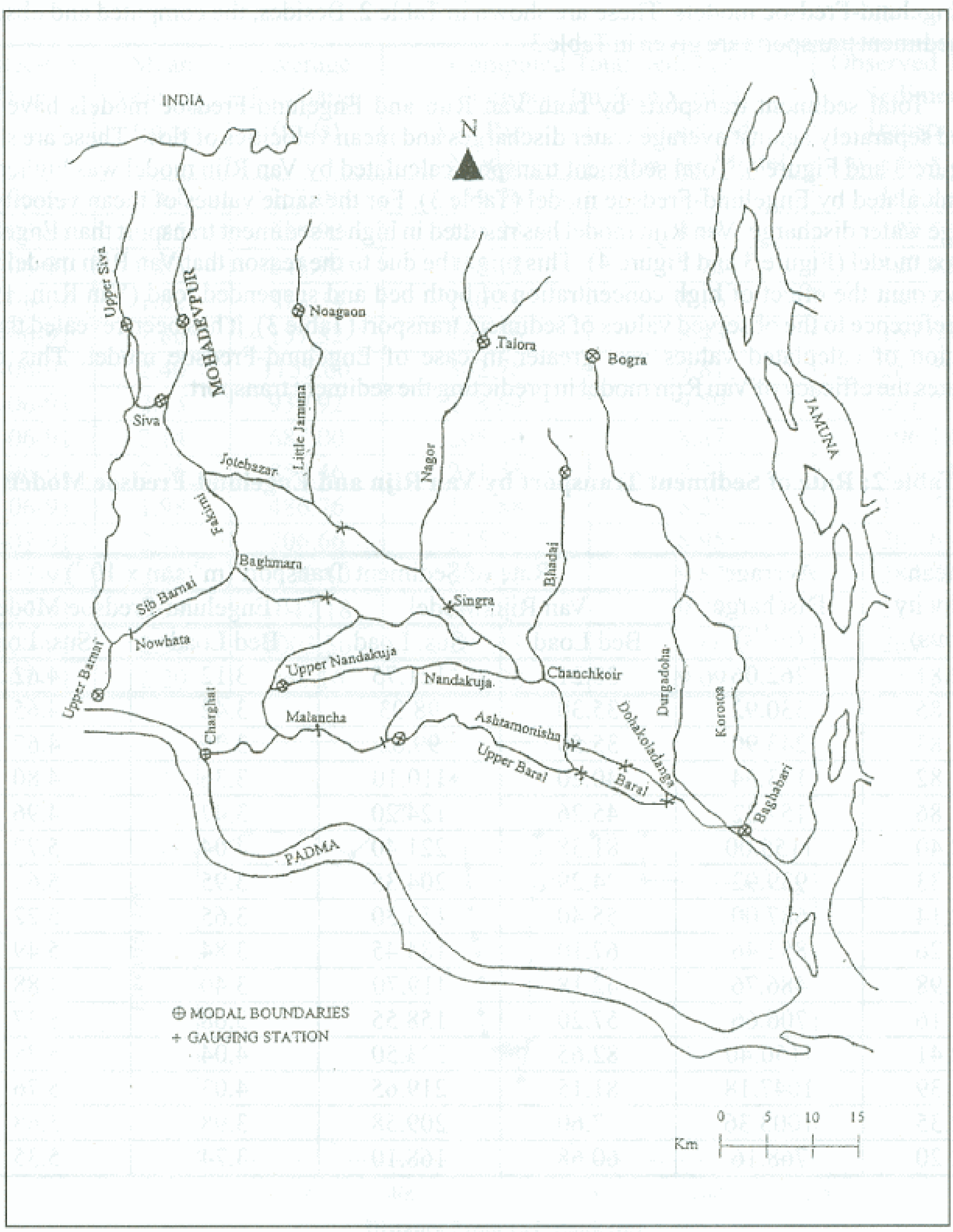

Figure 1: The River System of Atrai Basin and the Location of Study Area

Sediment transport rate for both bed and suspended loads were determined by Van Rijn and Engelund-Fredsoe models. These are shown in Table 2. Besides, the computed and observed total sediment transports are given in Table 3.

Total sediment transports by both Van Rijn and Engelund-Fredsoe models have been plotted separately against average water discharges and mean velocities of flow. These are shown in Figure 3 and Figure 4. Total sediment transport calculated by Van Rijn model was higher than that calculated by Engelund-Fredsoe model (Table 3). For the same values of mean velocity and average water discharge, Van Rijn model has resulted in higher sediment transport than Engelund-Fredsoe model (Figure 3 and Figure 4). This might be due to the reason that Van Rijn model takes into account the effect of high concentration of both bed and suspended load (Van Rijn, 1984). With reference to the observed values of sediment transport (Table 3), it has been revealed that the deviation of calculated values was greater in case of Engelund-Fredsoe model. This result indicates the efficacy of Van Rijn model in predicting the sediment transport.

Table 2: Rate of Sediment Transport by Van Rijn and Engelund-Fredsoe Models

Mean Velocity (m/s)	Average Discharge (m^3/s)	Rate of Sediment Transport ($m^3/s/m \times 10^{-5}$)			
		Van Rijn Model		Engelund-Fredsoe Model	
		Bed Load	Sus. Load	Bed Load	Sus. Load
1.81	262.06	38.21	121.75	3.12	4.62
1.85	330.92	35.30	98.93	3.42	4.65
1.83	243.90	35.50	99.62	3.25	4.67
1.82	173.34	40.20	110.10	3.36	4.80
1.86	157.32	45.26	124.20	3.47	4.96
2.40	1155.00	81.38	221.40	4.04	5.77
2.33	939.92	74.29	204.35	3.95	5.64
2.14	687.00	55.40	153.30	3.65	5.22
2.26	852.46	67.10	184.45	3.84	5.49
1.98	486.76	42.18	119.70	3.40	4.88
2.16	706.66	57.20	158.55	3.68	5.27
2.41	1150.40	82.65	223.50	4.04	5.78
2.39	1047.18	81.15	219.65	4.03	5.76
2.35	1003.36	77.60	209.58	3.98	5.68
2.20	768.16	60.68	168.10	3.74	5.35

Table 3: Rate of Computed and Observed Total Sediment Transport

Collection Date	Mean Velocity (m/s)	Average Discharge (m^3/s)	Computed Total Sediment Transport ($m^3/s/m \times 10^{-5}$)		Observed Total Sediment Transport ($m^3/s/m \times 10^{-5}$)
			Van Rijn Model	Engelund-Fredsoe Model	
01-06-91	1.81	262.06	159.96	7.74	151.96
02-06-91	1.85	330.92	134.23	8.07	127.52
06-06-91	1.83	243.90	135.12	7.92	127.02
10-06-91	1.82	173.34	150.30	8.16	141.28
13-06-91	1.86	157.32	169.46	8.43	157.60
16-06-91	2.40	1155.00	302.78	9.81	281.58
20-06-91	2.33	939.92	278.64	9.59	261.92
23-06-91	2.14	687.00	208.70	8.87	196.18
26-06-91	2.26	852.46	251.55	9.33	233.94
30-06-91	1.98	486.76	161.88	8.28	153.79
03-07-91	2.16	706.66	215.75	8.95	200.65
06-07-91	2.41	1150.40	306.15	9.82	284.72
10-07-91	2.39	1047.18	300.80	9.79	279.75
12-07-91	2.35	1003.36	287.18	9.66	269.95
20-07-91	2.20	768.16	228.78	9.09	217.34

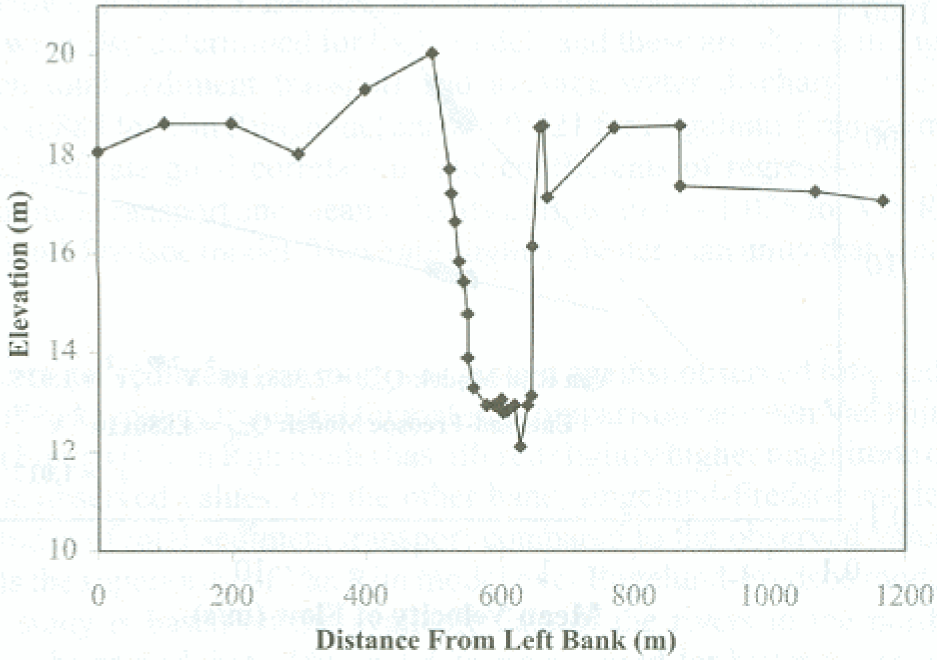

Figure 2: Cross Sectional Profile of the Atrai Basin at Mohadevpur Station

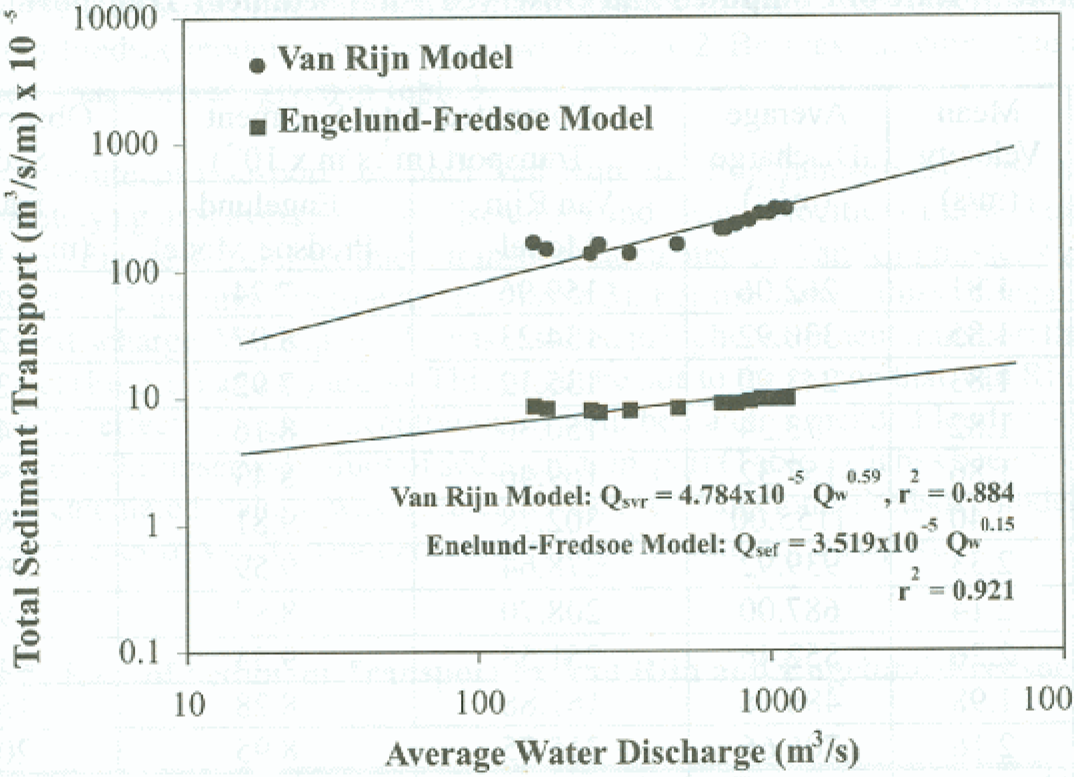

Figure 3: Total Sediment Transport with Average Water Discharge

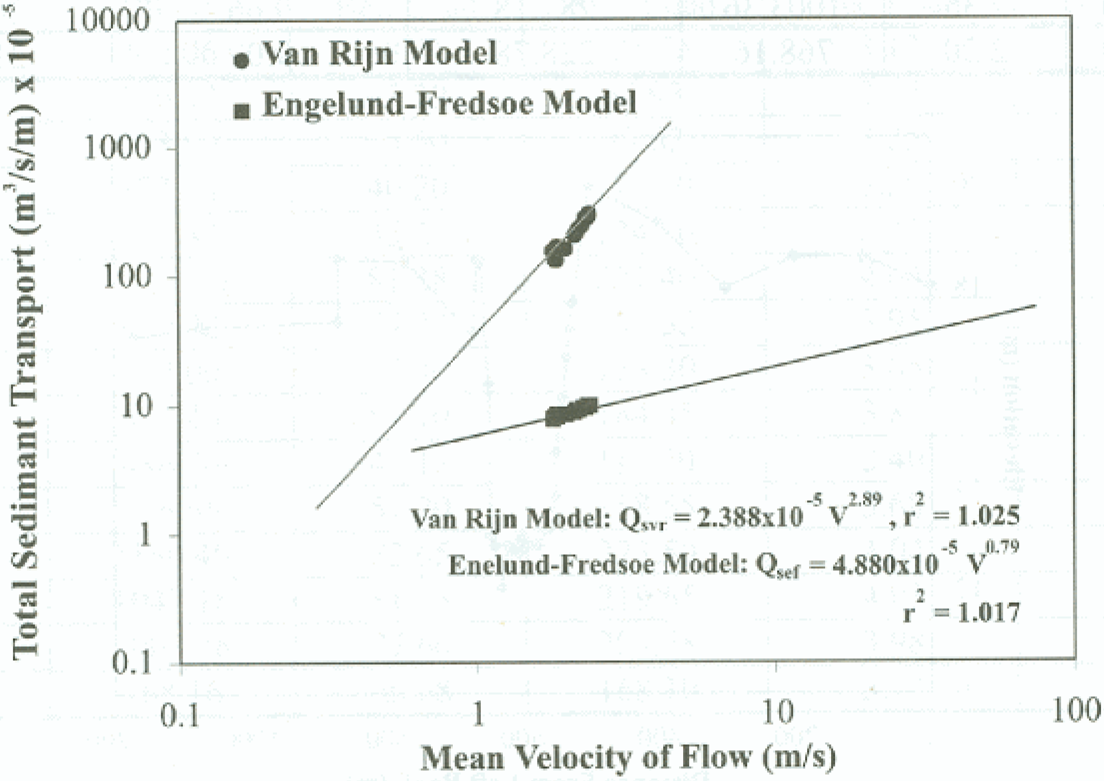

Figure 4: Total Sediment Transport with Mean Velocity of Flow

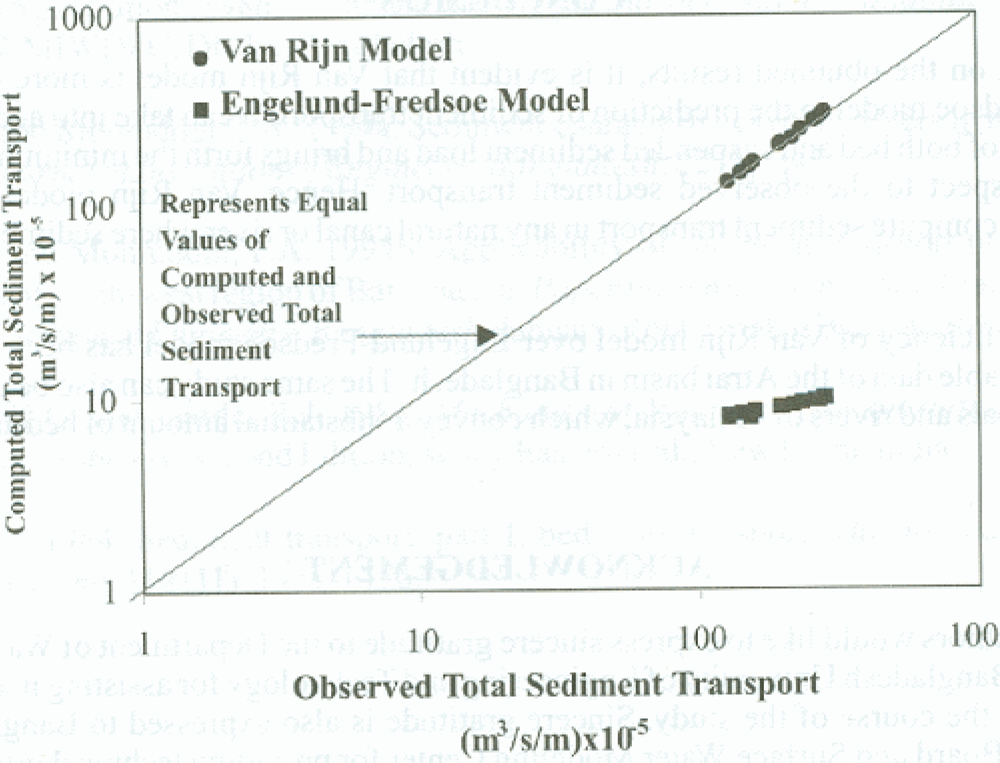

Figure 5: Comparison between Van Rijn and Engelund-Fredsoe Models

Power relations for water discharge and total sediment transport were established for both models and are shown in Figure 3. Besides, power relations for total sediment transport and mean velocity of flow were also determined for both models and these are shown in Figure 4. In power relations between total sediment transport and average water discharge, the coefficients of regression are $r^2 = 0.884$ for Van Rijn model and $r^2 = 0.921$ for Engelund-Fredsoe model. These are near to unity and indicate good correlation. The coefficients of regression in power relations between total sediment transport and mean velocity of flow are $r^2 = 1.025$ for Van Rijn model and $r^2 = 1.017$ for Engelund-Fredsoe model. These are slightly greater than unity that seems tolerable.

Computed total sediment transport was plotted against observed total sediment transport in order to identify discrepancy trend and for making comparison between Van Rijn and Engelund-Fredsoe models (Figure 5). Van Rijn model has offered slightly higher magnitude of total sediment transport than the observed values. On the other hand, Engelund-Fredsoe model has computed very low magnitudes of total sediment transport compared to the observed values. This finding obviously reveals the superiority of Van Rijn model over Engelund-Fredsoe model. However, the outcome of this study is based on the available data of the rivers in the northwest region of Bangladesh. It can be argued that additional data are required for better interpretation of results and thus for emphasizing the efficiency of Van Rijn model.

CONCLUSION

Based on the obtained results, it is evident that Van Rijn model is more efficient than Engelund-Fredsoe model in the prediction of sediment transport. It can take into account the high concentration of both bed and suspended sediment load and brings forth the minimum discrepancy trend with respect to the observed sediment transport. Hence, Van Rijn model can be used confidently to compute sediment transport in any natural canal or river where sediment transport is predominant.

The efficiency of Van Rijn model over Engelund-Fredsoe model has been examined by using the available data of the Atrai basin in Bangladesh. The same study can also be carried out for the natural canals and rivers of Malaysia, which convey a substantial amount of bed and suspended loads.

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