Optimal formula to estimate the quantity of sediment transport upstream of Al- Shamia Barrage

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Abstract

This research was conducted to estimate the total amount of Sediment Load at the up-stream of Al-Shamia Barrage in middle of Iraq. For the analysis of the applicability of sediment transport formulas to the study site, eight equations were chosen for that purpose, namely:

(Engelund-Hansen, Inglis-Lacey, Ackers-White, Van Rijn, Yang, Fazle, Ariffin and Jasem)

The applicability of each formula was tested using data taken from field measurements of twenty-four sections along the study area (6 km) to measure all the hydraulic variables and characteristics of sediments transported. The bottom samples were obtained using a device (Van Veen Sample), which was manufactured by the researcher in addition to sampling the mixture (Water-Sediment) by using a factory device. Also, the hydraulic variables were found using (Acoustic Doppler Current Profile) device.

From the analysis, the equations (Engelund-Hansen and Fazle) are the closest to the true estimate in order to get the sediment discharge among other equations selected in the search within the hydraulic conditions of the site.

Key words: Sediment Transport, River Bed Degradation, Measurements.

List of symbols

A_1 = Critical particle mobility factor
B, W = Width of the river
C_s = Concentration coefficient in the sediment transport function
C_t, C_v = Total sediment concentration
D_{50} = Particle size for which 50 percent by weight of the sediments is finer
d_{50} = Median grain size
d_{gr}, d_* = Dimensionless particle diameter
F_{gr} = Particle mobility parameter
g = Acceleration of gravity
D_s, S_g = Specific gravity
H = Average depth of flow
h = Water depth
m = Exponent in the sediment transport function
n' = Manning roughness coefficient
q_b = Volume rate of transport per unit length of surface
q_s = Suspended sediment transport
Q_t = Total sediment discharge
R, R_h = Hydraulic radius
S = Water surface slope
U_*, u_* = Shear velocity
V = Mean flow velocity
V_{cr} = Critical velocity for start of suspension
W_s = Fall velocity of particle
ρ, ρ_w = Specific density of water
τ_o = Shear stress along the bed
ν = Kinematic viscosity

1-Introduction

Rivers and channels are considered to be important resources for water supply, irrigation, navigation, water power generation and other public uses. The presence and movement of sediment causes many problems. The deposition and erosion of solid material of the beds and banks of channel increases bed deformation, which in turn will reduce the depth of water in some places and reduce the ability of the water way for navigation or hydraulic purposes. However, the raising of the river bed by the deposited materials increases the flood range to a great extent. As a result, large sums of money have to be spent to maintain the course of the river necessary for the hydraulic requirements. [(7)]

There is a number of equations to compute the total sediment load. Most of these equations have some theoretical and empirical bases. They were derived under very limited conditions of flow and sediment characteristics. All of them have shown good results when used to compute the sediment load for conditions similar to those under which they were derived. On the other hand, very poor results are obtained when they were applied for different conditions.

The most important reason for choosing this site to study is the accumulation of sediment in the up-stream of Al-shamia Barrage. The sediment was amounted to about three meters, which led to the closure of four out of six gates. There was no direct study of this region by the researchers to estimate the amount of sediment.

2-Description of the Study Region

The region of this study in the Euphrates basin is located between the towns of Kifil and Shinafiya, extending between latitudes 31^{o} 55' and 32^{o} 15' N and longitudes 43^{o} 55' and 44^{o} 45' E. Al-shamia Barrage is located on the Euphrates river at Al-Diwaniya city in Iraq.

The maximum design discharge is 1100 m^3/sec with the highest level of water by 22.5 m above sea level. It has six radial gates for water drainage is run electrically. Al-Shamia Barrage was constructed during 1986 to control the flow in the middle Euphrates region. Figure (1) shows reach study location.

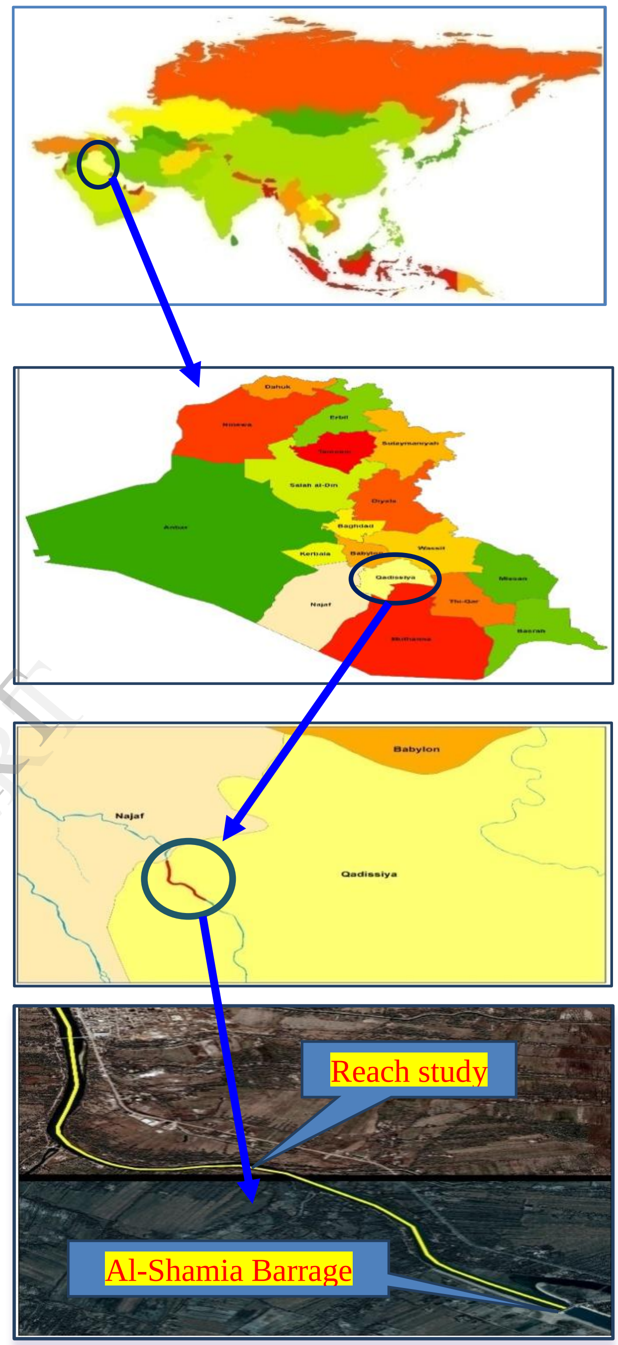

Figure (1): Reach study location

3-Field Measurement

In this research, the data used for hydraulic and sediment characteristics were collected from 24 sections in the Euphrates River distributed along the study area upstream of Al-shamia Barrage. The collected data were discharge, velocity, width, cross-sectional area, and observed suspended sediment load from the field measurements. The flow depth in study reach ranged from (1 to 5) meters, with flow ranging from (28.5 to 62) m^3/sec. The flow velocities ranges from (0.145 to 0.584) m/sec and the median sediment size (0.177) mm for the bed material composition was observed. Figure (2) shows the distribution of the sections along the search area.

A summary of data used in the study is presented in Table (1).

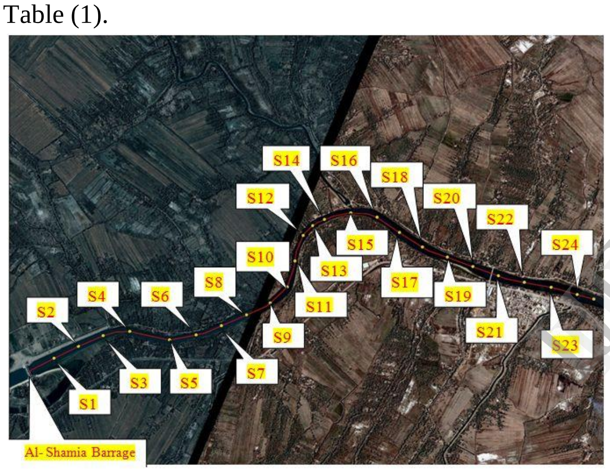

Figure (2): The position of cross sections in the reach study

Table (1): Primary data and parameters

Sec. No	**1**	**2**	**3**
Q_w (m^3/sec)	31.14	55.4	32.29
V (m/sec)	0.233	0.28	0.276
G_s	2.67	2.65	2.65
d_{50} (mm)	0.148	0.167	0.178
A (m^2)	133.5	197.8	117
B (m)	109.28	111.95	77.75
R_h (m)	1.22	1.77	1.5
ν (m^2/sec)	1.25×10^{-6}	1.21×10^{-6}	1.21×10^{-6}
W_s (m/sec)	0.013306	0.016724	0.018839
U_* (m/sec)	0.0424	0.051	0.047
Sec. No	**4**	**5**	**6**
Q_w (m^3/sec)	57.94	33.14	31.33
V (m/sec)	0.459	0.489	0.326
G_s	2.69	2.68	2.68
d_{50} (mm)	0.173	0.18	0.182
A (m^2)	126.2	67.8	96.2
B (m)	61.73	59.1	48.78
R_h (m)	2.04	1.15	1.97
ν (m^2/sec)	1.15×10^{-6}	1.15×10^{-6}	1.16×10^{-6}
W_s (m/sec)	0.01889	0.020065	0.020298
U_* (m/sec)	0.0548	0.0411	0.0538
Sec. No	**7**	**8**	**9**
Q_w (m^3/sec)	33.99	40.92	36
V (m/sec)	0.358	0.478	0.204
G_s	2.6	2.69	2.67
d_{50} (mm)	0.191	0.182	0.175
A (m^2)	95	85.6	176.1
B (m)	90.33	52.21	77.64
R_h (m)	1.05	1.64	2.27
ν (m^2/sec)	1.17×10^{-6}	1.15×10^{-6}	1.16×10^{-6}
W_s (m/sec)	0.020904	0.020539	0.018924
U_* (m/sec)	0.0393	0.0491	0.0578

Sec. No	10	11	12
Q_w (m^3/sec)	28.58	38.61	34.48
V (m/sec)	0.306	0.352	0.386
G_s	2.65	2.72	2.68
d_{50} (mm)	0.181	0.18	0.17
A (m^2)	93.4	109.7	89.4
B (m)	41.22	75.33	49.45
R_h (m)	2.27	1.46	1.81
ν (m^2/sec)	1.21×10^{-6}	1.25×10^{-6}	1.12×10^{-6}
W_s (m/sec)	0.019165	0.019211	0.018629
U_* (m/sec)	0.0578	0.0464	0.0516

Sec. No	13	14	15
Q_w (m^3/sec)	30	44.34	39.7
V (m/sec)	0.145	0.484	0.584
G_s	2.69	2.6	2.71
d_{50} (mm)	0.172	0.156	0.164
A (m^2)	206.7	91.6	68
B (m)	83.98	79.56	58.86
R_h (m)	2.46	1.15	1.16
ν (m^2/sec)	1.07×10^{-6}	1.15×10^{-6}	1.02×10^{-6}
W_s (m/sec)	0.019776	0.015068	0.019164
U_* (m/sec)	0.0602	0.0411	0.0413

Sec. No	16	17	18
Q_w (m^3/sec)	53.85	33.98	33.8
V (m/sec)	0.251	0.393	0.262
G_s	2.69	2.68	2.68
d_{50} (mm)	0.162	0.176	0.186
A (m^2)	214.6	86.4	129
B (m)	93.71	62.24	82.65
R_h (m)	2.29	1.39	1.56
ν (m^2/sec)	1.12×10^{-6}	1.04×10^{-6}	1.05×10^{-6}
W_s (m/sec)	0.017268	0.020861	0.022619
U_* (m/sec)	0.058	0.0452	0.0479

Sec. No	19	20	21
Q_w (m^3/sec)	62.03	34.99	50.45
V (m/sec)	0.253	0.378	0.382
G_s	2.66	2.65	2.66
d_{50} (mm)	0.189	0.179	0.186
A (m^2)	245.1	92.5	132
B (m)	71.88	79.23	59.82
R_h (m)	3.41	1.17	2.21
ν (m^2/sec)	1.02×10^{-6}	1×10^{-6}	1×10^{-6}
W_s (m/sec)	0.023429	0.021712	0.023174
U_* (m/sec)	0.0708	0.0415	0.057

Sec. No	22	23	24
Q_w (m^3/sec)	33.89	33.96	57
V (m/sec)	0.406	0.405	0.234
G_s	2.65	2.65	2.67
d_{50} (mm)	0.183	0.208	0.185
A (m^2)	83.4	83.8	244.1
B (m)	68.82	69.53	86.34
R_h (m)	1.21	1.21	2.83

ν (m^2/sec)	1×10^{-6}	1×10^{-6}	1×10^{-6}
W_s (m/sec)	0.02248	0.025745	0.023099
U_* (m/sec)	0.0422	0.0422	0.0645

4-Sediment Transport Formulas

There are two general categories of sediment transport model equations used to simulate the movement of sediment in natural rivers. One set of transport model equations separates the total sediment load into suspended and bed load, whereas the other combines the two modes of transport and tracks only the total load [10]. The formulas used in testing were Engelund-Hansen, Inglis-Lacey, Yang, Van Rijn, Ackers-White, Fazle, Ariffin, and Jasem. Table (2) is showing summary of the sediment discharge variables by the investigators.

Table (2): Summary of sediment parameters

Author	Input parameters used
Engelund-Hansen(1967)	γ_s , V, $\frac{d_{50}}{(G_s-1)\,g}$, $\frac{\gamma\, D_m\, S}{(\gamma_s-\gamma)\, d_{50}}$
Inglis-Lacey(1968)	$\nu\, g/W_s$, $V/g\, h$, $\rho_w\, V/g$
Ackers-White(1973)	d_{50}/h , V/U_* , γ_s/γ , C_s , ν
Van Rijn(1984)	$\frac{(V-V_{cr})}{(G_s-1)\,g\,D_{50}}$, $\frac{D_{50}}{H}$, $\frac{d\,(G_s-1)\,g}{\nu}$
Yang(1973)	$V\,S/W_s$, V/u_* , $W_s\, d_{50}/\nu$
Fazle(1998)	$V/g(G_s-1)d_{50}$, U_*/w_s
Ariffin(2004)	R_h/d_{50} , U_*/W , U_*/V , $V/g\,D$
Jasem(2012)	$\rho\, W\, R_h$, V/W , R_h/d_{50} , $\nu/w\, R_h$, $Gs\, B/R_h$

The meanings of each symbol are presented in list of symbol.

- **Inglis-Lacey formula**

The Inglis-Lacey formula was developed by Lacey (1947) [5] and Inglis (1968) by introducing the mean size and fall velocity of the bed sediment. The original Lacey regime relations were based on data from large stable irrigation canals. The formula itself is dimensionally homogeneous and it can be use with any consistent set of units.

The actual expression used with the Inglis-Lacey approach to predict sediment transport is:

$$Q_t = 0.562\left(\frac{\sqrt[3]{\nu\, g}}{W_s}\right)\left(\frac{V^2}{g\, h}\right)\left(\frac{\rho_w\, V^3}{g}\right) \quad \ldots(1)$$

- **Ackers - White Formula**

Ackers and White (1973) [1] used dimensional analysis based on flow power concept, as explained by Bagnold, in order to express sediment transport rate by several dimensionless parameters. Their proposed formula was as follows.

$$C_t = C_s G_S\left(\frac{d_{50}}{h}\right)\left(\frac{V}{U_*}\right)^{n'}\left[\left(\frac{F_{gr}}{A_1}\right) - 1\right]^m \quad \ldots(2)$$

The dimensionless particle d_{gr} is calculated by:

$$d_{gr} = d_{50}\sqrt[3]{\frac{g\,(G_S-1)}{\nu^2}} \quad \ldots(3)$$

The particle mobility factor F_{gr} is calculated by:

$$F_{gr} = \sqrt{\frac{U_*^{n'}}{(G_S-1)g\, d_{50}}}\left[\frac{V}{5.66\,\log\left(\frac{10\, h}{d_{50}}\right)}\right]^{1-n'} \quad \ldots(4)$$

- **Engelund-Hansen Formula**

The dimensionally homogeneous equation for prediction of total sediment discharge rates in the Engelund-Hansen method is[4].

$$Q_t = 0.05\,\gamma_s\, V^2\sqrt{\frac{d_{50}}{(G_s-1)\,g}}\left(\frac{\tau_o}{(\gamma_s-\gamma)\, d_{50}}\right)^{3/2} \quad \ldots(5)$$

- **Yang's equation**

Yang (1973) [11] proposed a sediment transport formula based on the concept of unit stream power, which can be utilized for the prediction of total bed material concentration transported in sand bed flumes and rivers. The formula is as follows:

$$\log C_t = 5.435 - 0.286\,\log\left(\frac{w_s\, d_{50}}{\nu}\right) - 0.457\,\log\left(\frac{u_*}{w_s}\right) +$$

$$[1.799 - 0.409 \log(\frac{w_s\, d_{50}}{\nu}) - 0.314 \log(\frac{u_*}{w_s})] \log(\frac{V\,S}{w_s} - \frac{V_{cr}\,S}{w_s}) \quad ...(6)$$

The value $\frac{V_{cr}}{w_s}$ is given by:

$$\frac{V_{cr}}{w_s} = (\frac{2.5}{\log\,(u_*\,d_{50}/\nu)}) + 0.66 \quad 0 < \frac{u_*\,d_{50}}{\nu} < 70 \quad ......(7)$$

$$\frac{V_{cr}}{w_s} = 2.05 \qquad 70 < \frac{u_*\,d_{50}}{\nu} \quad ..(8)$$

- **Van Rijn formula**

Van Rijn (1984) cited in [8] developed an analytical relationship for sediment load transport in terms of the saltation height, particle velocity and bed load concentration. The transport equation can be expressed in a simplified form when only the mean velocity, flow depth and particle size are known was given as:

$$\frac{q_b}{V\,H} = 0.005(\frac{(V - V_{cr})}{\sqrt{(G_s - 1)\,g\,D_{50}}})^{2.4}(\frac{D_{50}}{H})^{1.2} \quad ...(9)$$

$$\frac{q_s}{V\,H} = 0.012\,(\frac{(V - V_{cr})}{\sqrt{(G_s - 1)\,g\,D_{50}}})^{2.4}(\frac{D_{50}}{H})(D_*)^{-0.6} \quad ...(10)$$

$$D_* = d\,\sqrt[3]{\frac{(G_s - 1)\,g}{\nu^2}} \quad ...(11)$$

- **Fazle Karim Formula**

Fazle Karim (1998)[3] in this analysis for developing the relation for total sediment discharge per unit width. The equation is:

$$\frac{Q_t}{\sqrt{g(G_s - 1)\,d_{50}^3}} = 0.00139[\frac{V}{\sqrt{g(G_s - 1)d_{50}}}]^{2.97} (\frac{U_*}{w_s})^{1.47} \quad ...(12)$$

- **Ariffin Formula**

Ariffin (2004) [2] had derived her sediment transport equation based on regression. She had conducted tests on the robustness on the variables used in her equation. Her proposed equation is:

$$C_v = 1.156 \times 10^{-5} (\frac{R_h}{d_{50}})^{0.716} (\frac{u_*}{w_s})^{-0.975} (\frac{u_*}{V})^{0.507} (\frac{V^2}{g\,H})^{0.524} \quad .(13)$$

- **Jasem Formula**

Jasem (2012) [6] was studied the transportation of bed load and its entrapment have been estimated of up-stream Al-Abassiya Barrage. The equation is:

$$Qs = \rho\, W_s\, R_h (\frac{V}{Ws})^{1.5} (\frac{R_h}{d_{50}})^{-0.5} (\frac{\nu}{W_s\,R_h})^{0.43} (\frac{S_g\,B}{R_h})^{0.67} \quad ...(14)$$

Table (4-3) is showing the predicted and observed values of sediment discharge.

***Table (3): Predicted and observed values of sediment discharge in (kg/sec)*.**

Sec. No	1	2	3
Ackers	0.44	0.88	0.55
Engelund	1.54	3.71	1.96
Inglis	0.47	0.77	0.48
Yang	0.26	0.61	0.29
Van Rijn	1.37	2.63	1.48
Fazle	1.64	2.74	1.35
Ariffin	4.89	10.15	6.19
Jasem	10.68	13.98	9.32
Observed	3.05	5.37	3.07
Sec. No	**4**	**5**	**6**
Ackers	3.27	2.21	2.1
Engelund	6.41	3.62	0.79
Inglis	2.91	4.49	0.55
Yang	1.5	0.8	0.41
Van Rijn	9.31	10.41	1.83
Fazle	6.04	4.2	1.52
Ariffin	16.06	9.21	9.86
Jasem	18.72	15.29	9.07
Observed	5.39	2.82	2.88
Sec. No	**7**	**8**	**9**

Ackers	0.98	4.35	0.41
Engelund	1.81	2.47	1.19
Inglis	2.2	4.05	0.06
Yang	0.44	1.01	0.21
Van Rijn	4.51	8.61	0.43
Fazle	1.71	5.2	0.74
Ariffin	8.38	14.54	6.86
Jasem	12.02	15.46	6.77
Observed	3.33	3.54	2.59
Sec. No	**10**	**11**	**12**
Ackers	1.42	0.67	3.4
Engelund	1.58	1.69	1.2
Inglis	0.24	0.93	1.38
Yang	0.36	0.56	0.66
Van Rijn	1.27	3.73	3.89
Fazle	1.29	2.55	2.71
Ariffin	6.88	7.58	10.88
Jasem	8.29	12.86	11.75
Observed	2.43	3.63	2.79
Sec. No	**13**	**14**	**15**
Ackers	0.12	4.62	5.43
Engelund	0.54	3.56	4.1
Inglis	0.01	11.7	16.41
Yang	0.08	1.38	1.43
Van Rijn	0.08	17.04	21.25
Fazle	0.29	8.48	7.57
Ariffin	4.5	11.89	13.98
Jasem	4.08	21.88	19.04
Observed	2.64	4.48	4.17
Sec. No	**16**	**17**	**18**
Ackers	0.85	2.04	0.56
Engelund	3.24	2.07	1.12
Inglis	0.25	2.51	0.39
Yang	0.52	0.59	0.26
Van Rijn	1.41	5.16	1.06
Fazle	1.89	2.51	0.97
Ariffin	10.77	10.38	8.61
Jasem	10.91	11.24	7.42
Observed	4.2	3.16	2.94
Sec. No	**19**	**20**	**21**
Ackers	0.71	1.65	2.71
Engelund	1.48	1.97	1.03
Inglis	0.08	3.63	0.87
Yang	0.57	0.75	0.89
Van Rijn	0.86	5.6	3.88
Fazle	1.28	3.38	2.68
Ariffin	15.04	8.39	17.65
Jasem	8.4	13.76	11.52
Observed	6.51	2.9	5.25
Sec. No	**22**	**23**	**24**
Ackers	2.23	1.62	0.55
Engelund	1.8	1.67	1.73
Inglis	3.02	2.04	0.08
Yang	0.58	0.55	0.43
Van Rijn	5.53	4.8	0.73
Fazle	2.49	2.05	1.09
Ariffin	11.31	11.16	13.47
Jasem	11.09	10.45	7.82
Observed	2.54	2.89	5.07

- **Comparison of Formulas precision**

With the intention of selecting the best formulas; there are two types of comparisons which are statistical relations and graphical comparison.

- **Comparison Using Statistical Relations**

Two methods are used in this research to evaluate the performance of each formula through comparing the measured sediment discharge with predicted sediment discharge.

- **Discrepancy Ratio**

To evaluate the difference between the measured and the predicted values, the discrepancy ratio was used as an error measure that is defined as: [11]

$$\text{Discrepancy Ratio} = \frac{\text{computed} \quad qs}{\text{measured} \quad qs} \qquad \ldots(15)$$

If the discrepancy ratio is equal to one, then the predicted value is identical to the measured value. If the discrepancy ratio is larger than one, then the predicted value will be overestimating, and if the discrepancy ratio is smaller than one, it will be underestimating. The discrepancy ratio is scheduled with the ranges (0.75-1.25), (0.5-1.5), and (0.25-1.75). The results are shown in table (4).

Table (4): Comparison between the computed and the measured values.

Formula	Discrepancy ratio			N0. data
	Percentage of data in the range			
	0.75-1.25	**0.5-1.5**	**0.25-1.75**	
Engelund -Hansen	16.6%	58.3%	87.5%	24
Inglis-Lacey	12.5%	33.3%	41.6%	24
Van Rijn	4%	29%	58.3%	24
Ackers-White	29%	54%	58.3%	24
Yang	…….	…….	25%	24
Fazle	25%	62.5%	79%	24
Ariffin	…….	…….	8.3%	24
Jasem	……	4%	12.5%	24

- **Root Mean Squared Error**

The root mean squared error (RMSE) [9] value is a commonly used error measure. The sum of squares gives more weight to higher error values, and consequently higher error variances. The RMSE has the same units as the measured and calculated data. Smaller values indicate better agreement between the measured and the calculated values.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(S_o - S_c)^2}{N}} \quad ...(16)$$

In which: S_o observed sediment rate, S_c is predicted sediment load and N is the number of predicted values. The results are shown in table (5).

Table (5): Comparison using Root Mean Squared Error

Formula	**Engelund-Hansen**	**Inglis-Lacey**	**Van Rijn**
RMSE	1.96	4	5.25
Formula	**Ackers-White**	**Yang**	**Fazle**
RMSE	2.5	3.18	2.24
Formula	**Ariffin**	**Jasem**	
RMSE	7.2	9	

- **Graphical Comparison**

A graphical comparison is conducted on the formulas by calculating the deviation of predicted sediment discharges from measured or by means of discrepancy ratio. Cited in [6]

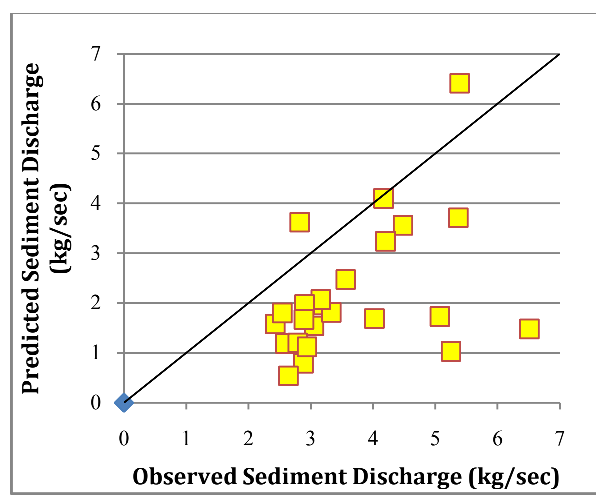

Figure (3): Comparison between measured and computed sediment load by using Engelund - Hansen Formula

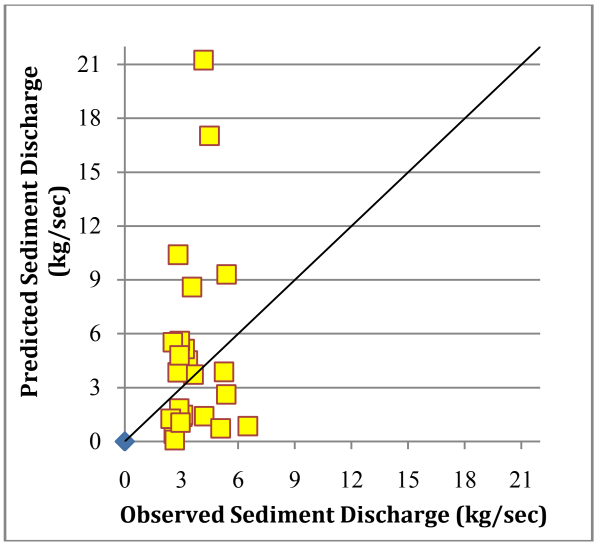

Figure (4): Comparison between measured and computed sediment load by using Van Rijn Formula

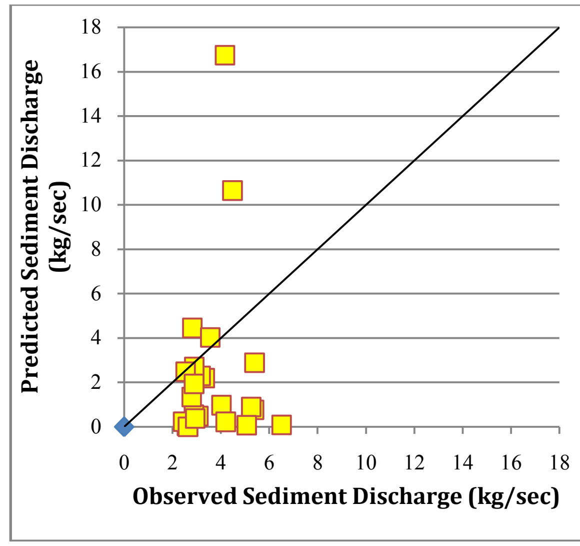

Figure (6): Comparison between measured and computed sediment load by using Inglis-Lacey Formula.

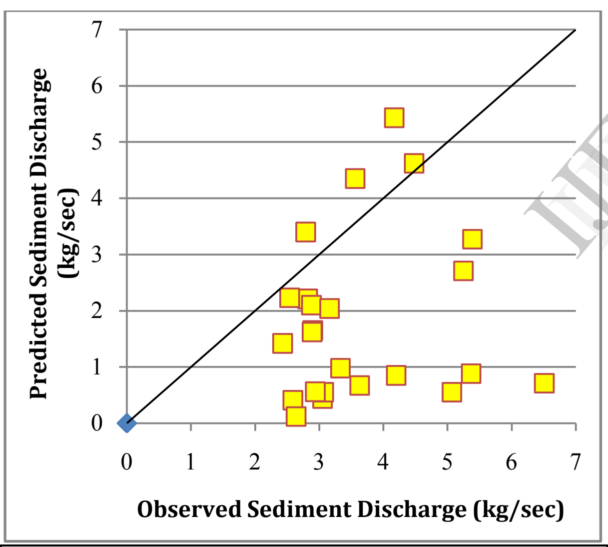

Figure (5): Comparison between measured and computed sediment load by using Ackers-White Formula

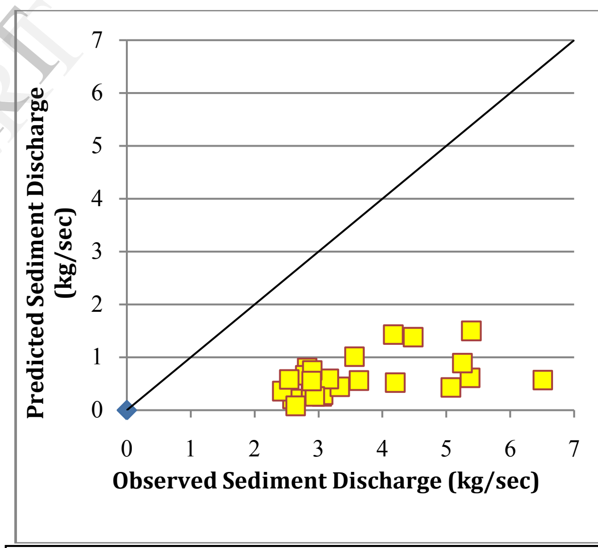

Figure (7): Comparison between measured and computed sediment load by using Yang Formula.

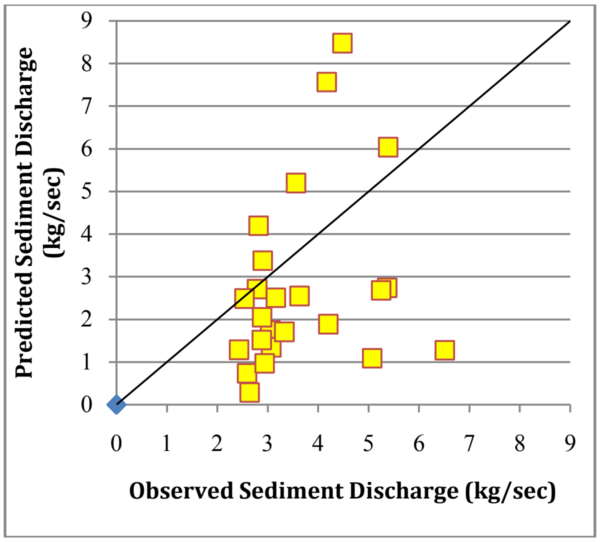

Figure (8): Comparison between measured and computed sediment load by using Fazle Karim Formula.

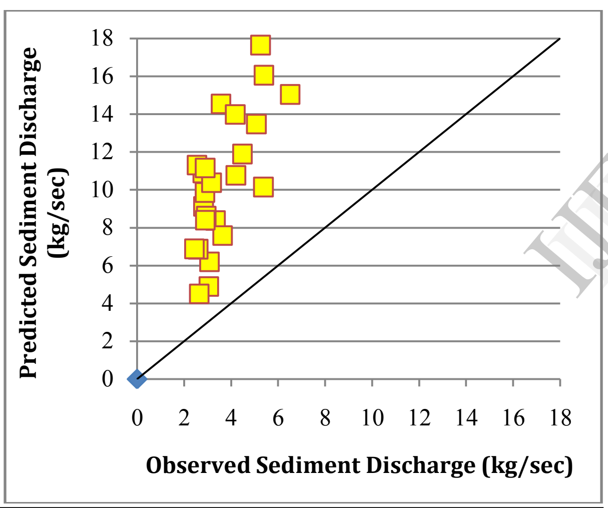

Figure (9): Comparison between measured and computed sediment load by using Ariffin Formula.

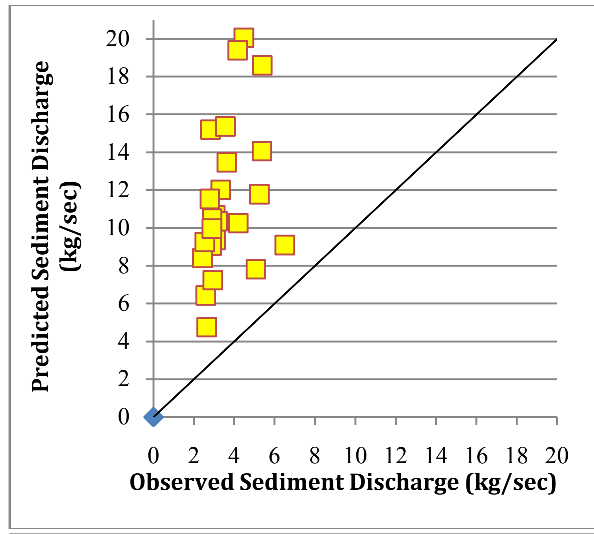

Figure (10): Comparison between measured and computed sediment load by using Jasem Formula.

• Conclusions

Based on the results obtained in this study (Euphrates river up-stream of Al-shamia Barrage), The following conclusions can be made:

1- The sediment particle size analysis showed that the bed material river is composed of Sand, Silt and Clay. The large portion of bed material is sandy material, with median grain size from (0.148 to 0.2) mm.

2- Eight formulas used in the search to predict the total sediment load, the best performance were produced by Engelund formula followed by Fazle formula. The first one gave discrepancy ratio equal to 87.5% within the ranges (0.25-1.75) and RMSE equal to 1.96. While the second one gave 79% for the same ranges, and RMSE equal to 2.24.

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