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Suspended Sediment Transport Formula for the Upstream of Al-Amarah Barrage

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***Abstract*- In this study, the researcher suggest a new formula for the estimation of suspended sediment discharge for a reach of Tigris River located upstream AL-Amarah barrage, Maysan province-Iraq. For this purpose, a number of in-site observations made; many samples were taking from the river during each observation, these samples filtered and the suspended sediment concentration and the average concentration recorded. In addition, for each observation, the river discharge measured using the ADCP technology. A total number of twenty observations recorded. The formula developed by dimensional analysis and general regression among effect parameters, water density (ρ), solid particles density (ρ_s), water viscosity (ν), particles diameter (d_{50}), gravitational acceleration (g), water velocity (V), river top width (B) and hydraulic radius (R_h).A good agreement between the formula and the observed data achieved depending on the value of coefficient of determination R^2.**

Key Words-Suspended sediment, new sediment formula, ADCP, Al-Amarah Barrage.

I. INTRODUCTION

Sediment is comprised of solid particles of mineral and organic material that transported by water. In river systems, the amount of sediment transported controlled by both the transport capacity of the flow and the supply of sediment. The “suspended sediment load” refers to the fine sediment that carried in suspension and this can comprise material picked up from the bed of the river (suspended bed material) and material washed into the river from the surrounding land (wash load). The wash load is usually finer than the suspended bed material. In contrast, the “bed load” comprises larger sediment particles that transported on the bed of the river by rolling, sliding or saltation. Most rivers will transport sediment in each of these “load” forms, according to the flow conditions[1].

Since natural rivers are subject to constant erosion and sediment transport processes, the study of sediment transport mechanisms and transport capacity of stream flows is considerably important in river hydraulics and geomorphology. Sediment transport and sedimentation in rivers have serious consequences including formation of sediment bars and reduction of flood sediment transport capacity, affected dams lifetime and their reservoir capacity, severe erosion of hydro-mechanical facilities and damaging field and water structures, sedimentation at flow channels, and other hydraulic problems. In addition, considering the principles of river material extraction and transported sediments by river flow in design of river structures, the study of various methods to predict river-sediment transport rate seems to be necessary.

Therefore, there is a need to establish a certain formula that can applied to study reach, which must derived depending upon the local boundary and hydraulic conditions of the study reach.

II. REGION OF STUDY

The reach of study is a 4km part of Tigris River in Al-Amarah city (south of Iraq), Maysan province upstream Al-Amarah barrage. Its location is between latitudes 31.865°N and 31.850°N and longitudes 47.115°E and 47.155°E. Fig. 1 shows the study reach location.

Fig. 1, Study Reach Location

III. VELOCITY MEASUREMENTS AND DISTRIBUTION

Twenty cross-sections, Fig. 2, considered along the reach. At each section, bed elevation, top width, water level, area of cross sections, water velocity and discharge measured using the ADCP technology. SonTek river tracker surveyor; Fig. 3 and Fig.4; and its software version 4.3 used for this purpose. These measurements tabulated in Table 1.

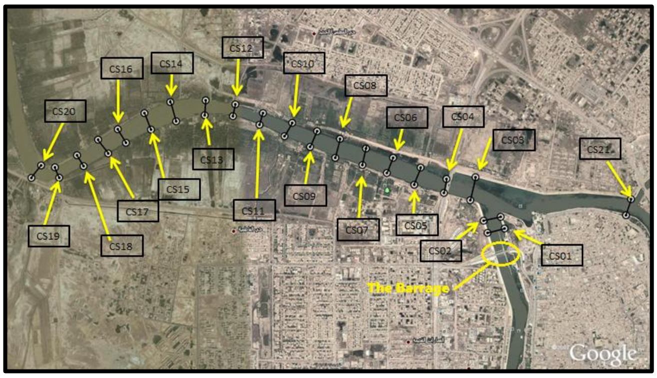

Fig. 2: Transect Sections Locations

Fig. 3: SonTek River Surveyor ADCP

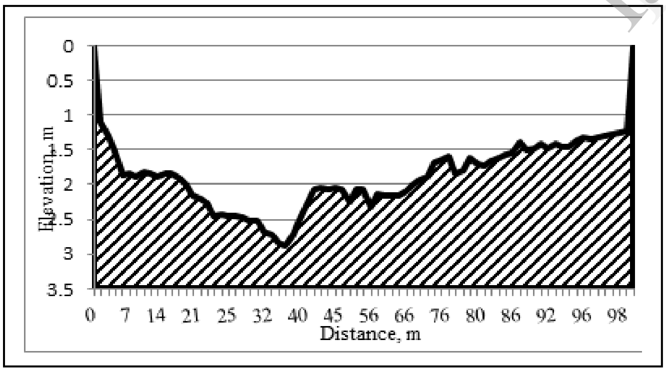

Fig. 4: Geometry of Section No.1 using the ADCP

IV. SUSPENDED SEDIMENT CONCENTRATIONS

Suspended sediment concentration measured and recorded to determine how much sediment entrained in the stream flow. Depending on the desired degree of accuracy of the measurements, the number and location of sampling verticals should selected. The common methods in use given and briefly discussed by the Interagency Committee on Water Resources [2]. In this study, the sampling verticals chosen at ¼, ½ and ¾ of the width of stream at each cross-section. This procedure was very convenient and more practical for study reach; three samples taken at each vertical at three depths *0.8d*, *0.6d* and *0.2d*, where *d* is the depth measured from water surface. Nine samples in each transect section. Every sample was marked with a sticker containing all information about the time, date and location. All field sampling conducted between (1-9-2012 to 1-9-2013).

Once suspended sediment samples collected, the samples were filtered using filter papers. The filters used had a pore size of 0.45µm and pre-dried for 15 minutes in an oven at 105 °C. The weight of the filter paper measured prior to filtering. The amount of water filtered also measured. After the sediment filtered out of the sample, the sediment and filter paper placed on a dish, placed in an oven, and baked for 24 hours at approximately 105 degrees Celsius to remove water from the sediment. After 24 hours, the filter paper with sediment removed from the oven and weighed. The mass of sediment could then be determined by subtracting the initial filter weight from the weight of the dried sediment and filter. Once the weight of the sediment and the volume of water filtered were determined, the following equation used to calculate the suspended sediment concentration[3].

$$\textbf{Sediment Concentration } (Cs) = \frac{\textbf{Mass of Sediment}(M)}{\textbf{VolumeofWater}\ (v)} \ldots(1)$$

Where *Cs* in *ppm or mg/l*; *M* in *mg* and *v* in *liter*.

V. BED MATERIALS SAMPLING

One bed material sample taken for each section in study reach. The samples taken using Van Veen's grab. For sample taking from the bottom surface the “Van Veen’s grab” is a very useful tool. It can easily handle and gives in many cases quite good samples. During the descent to the bottom, the two buckets held in open position by the means of a hook. When the grab hits the bottom, the tension on the hook released and the hook is disengaged. When the line is hoist, the buckets close automatically.

Sieve analysis and specific weight done for each bed sample, Fig. 5. The procedure listed in ASTM D_{854} and AASHTO T_{100} followed in the determination of specific gravity of bed sediments materials. The average value of specific gravity for all sections was (2.62).

VI. SEDIMENT DISCHARGE IN STUDY REACH

Suspended sediment transport rate (discharge) may computed from the following equation [3 and 4]

$$Q_s = C\,Q \qquad \ldots. (2)$$

Where: Q_s = Sediment discharge (kg/sec).
C= Average concentration of suspended sediments (mg/lit).
Q = Water discharge (m3/sec).

Average values of concentration of suspended sediments in each section (C), water discharge (Q) and sediment discharge (Q_s) listed also in Table 1.

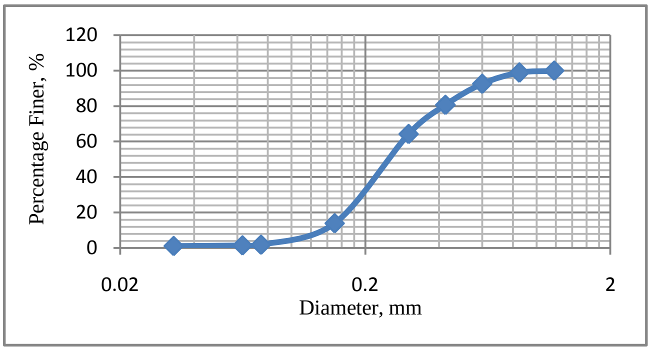

Fig. 5: Average Sieve Analysis for All Sections

TABLE (1): HYDRAULIC PROPERTIES FOR ALL SECTIONS

Sec. No.	Depth (m)	Velocity (m/sec)	Area (m^2)	Q m^3/sec	A.S.C. (ppm)	Qs kg/sec
1	2.46	0.33	204.78	67.68	95.89	6.49
2	2.78	0.39	188.59	72.79	129.78	9.45
3	7.70	0.16	577.99	95.06	160.11	15.22
4	6.50	0.36	288.57	105.24	123.78	13.03
5	3.01	0.32	303.16	96.19	118.22	11.37
6	3.04	0.43	230.33	98.91	143.89	14.23
7	2.93	0.36	285.85	103.00	132.22	13.62
8	3.19	0.33	294.43	98.61	139.55	13.76
9	3.53	0.36	284.80	101.40	126.56	12.83
10	5.39	0.31	330.68	102.94	169.11	17.41
11	7.56	0.31	357.23	106.11	119.78	12.71
12	9.13	0.25	390.43	97.00	130.89	12.70
13	9.24	0.25	392.38	97.76	122.22	11.95
14	3.19	0.35	288.13	101.15	166.77	16.86
15	3.42	0.33	296.35	96.54	137.67	13.30
16	4.84	0.32	315.91	100.74	125.78	12.67
17	5.46	0.32	308.42	97.30	113.00	11.00
18	6.62	0.30	350.54	104.60	131.44	13.75
19	9.03	0.22	433.1	96.58	126.77	12.24
20	10.33	0.24	498.03	118.01	102.11	12.05

VII. DEVELOPMENT OF A NEW FORMULA

The dimensional analysis is a good method in dealing with physical quantities and to convert them into dimensionless quantities.

Alghazali (2012) suggested a new approach in dimensional analysis, which used in this study. [5]

The dimensional expression of the sediment transport in alluvial channels and rivers can expressed as a function of water density (ρ), solid particles density (ρ_s), water viscosity (v), particles diameter (d_{50}), gravitational acceleration (g), water velocity (V), river top width (B) and hydraulic radius (R_h).

So,

$$Qs = f(\rho, \rho_s, d_{50}, \mathrm{v}, g, V, B, R_h) \quad ..... (3)$$

Alternatively, it can written as,

$$F(Qs, \rho, \rho_s, d_{50}, \mathrm{v}, g, V, B, R_h) = 0 ..... (4)$$

Additional data needed for the derivation of the formula tabulated in table 2.

TABLE (2): ADDITIONAL DATA FOR ALL SECTIONS

Sec. No.	d_{50} (m)	ρ_s(kg/m^3)	*B* (m)	R_h (m)	*v* (m^2/sec)
1	0.00025	2530	97.2	2.11	1.31E-06
2	0.00021	2600	98.9	1.91	1.31E-06
3	0.00021	2720	154	3.75	1.31E-06
4	0.00023	2650	90.6	3.19	1.31E-06
5	0.00023	2610	118	2.57	1.31E-06
6	0.0002	2630	70.3	3.28	1.31E-06
7	0.00022	2590	113.2	2.53	1.31E-06
8	0.00022	2560	103	2.86	1.31E-06
9	0.00022	2580	88.3	3.23	1.31E-06
10	0.00021	2680	78.4	4.22	1.31E-06
11	0.00027	2700	81.1	4.40	1.31E-06
12	0.0002	2570	60.6	6.44	1.31E-06
13	0.00024	2600	81.6	4.81	1.31E-06
14	0.0002	2580	114.4	2.52	1.31E-06
15	0.00023	2650	112	2.65	1.31E-06
16	0.00023	2680	84	3.76	1.31E-06
17	0.00023	2640	80.2	3.85	1.31E-06
18	0.00021	2600	77.1	4.55	1.31E-06
19	0.0002	2590	64	6.77	1.31E-06
20	0.00024	2560	76.4	6.52	1.31E-06

Choosing the repeating variables as (ρ_s, d_{50}, g), number of repeating variables equals the number of basic dimensions.

The matrix of repeating variables and nonrepeating variables can written as, table (3)

Table (3): REPEATING AND NONREPEATING VARIABLES

	R_1	R_2	R_3	U_1	U_2	U_3	U_4	U_5	U_6
	d_{50}	ρ_s	g	Q_s	ρ	v	V	B	R_h
L	**1**	**-3**	**1**	**0**	**-3**	**2**	**1**	**1**	**1**
M	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**0**	**0**
T	**0**	**0**	**-2**	**-1**	**0**	**-1**	**-1**	**0**	**0**

The method needs only to transform the repeating variables matrix into an identity (unit) matrix. This done in steps and tables below:

1- Dividing row no.3 by (-2),

Multiplying row no. 2 by 3 and adding it to row no.

	R_1	R_2	R_3	U_1	U_2	U_3	U_4	U_5	U_6
	d_{50}	ρ_s	g	Q_s	ρ	v	V	B	R_h
L	**1**	**0**	**1**	**3**	**0**	**2**	**1**	**1**	**1**
M	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**0**	**0**
T	**0**	**0**	**1**	**1/2**	**0**	**1/2**	**1/2**	**0**	**0**

2- Subtracting row no. 3 from row no. 1

	R_1	R_2	R_3	U_1	U_2	U_3	U_4	U_5	U_6
	d_{50}	ρ_s	g	Q_s	ρ	v	V	B	R_h
L	**1**	**0**	**0**	**2.5**	**0**	**1.5**	**0.5**	**1**	**1**
M	**0**	**1**	**0**	**1**	**1**	**0**	**0**	**0**	**0**
T	**0**	**0**	**1**	**1/2**	**0**	**1/2**	**1/2**	**0**	**0**

Therefore, the dimensional expression will be

$$Qs = \rho_s {d_{50}}^{2.5} g^{0.5} f\left(\frac{\rho_s}{\rho}, \frac{v}{{d_{50}}^{1.5} g^{0.5}}, \frac{V}{{d_{50}}^{0.5} g^{0.5}}, \frac{B}{d_{50}}, \frac{R_h}{d_{50}}\right) \ldots (5)$$

The regression is the most commonly method used by investigators to formulate a relationship among physical quantities [6, 7]. Minitab15 (figure 6), 30days trial demo version, conducts this regression on the observed data.
These data divided into two groups; the first group consist of thirteen sections used to derive the equation, the second group consist of seven sections used for testing the equation.

The final form of the equation can written as

$$Qs = 9.36 * 10^{-19} \frac{{\rho_s}^{2.57} V^{1.2} B^{1.38} {R_h}^{1.18}}{v^{.36} {d_{50}}^{1.5}} \quad \ldots. (6)$$

Where:

Q_s = sediment transport rate (discharge), kg/sec
ρ_s = sediment particles density, kg/m^3
V = average water velocity, m/sec
B = top river width, m
R_h = hydraulic radius, m
v = water viscosity, kg.sec/m^2
d_{50} = mean particle diameter, m

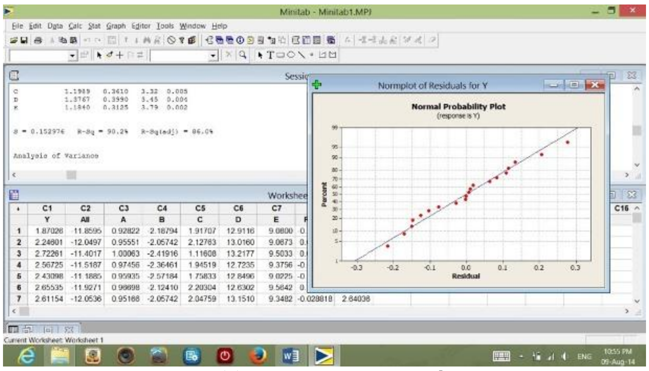

Fig. (6): Main Menu in Minitab 15

Table (4) showed the observed and calculated sediment transport rates for the thirteen sections, figure (7) showed a good agreement between observed and calculated sediment discharges.

Table (4): OBSERVED AND CALCULATED SEDIMENT FOR DERIVATION

Section No.	Observed Sed. Dis. (kg/sec)	Calculated Sed. Dis. (kg/sec)
1	6.49	6.11
2	9.45	9.46
4	13.03	12.79
5	11.37	11.93
7	13.62	13.32
8	13.76	11.84
10	17.41	14.39
11	12.71	11.09
13	11.95	10.38
14	16.86	14.88
16	12.67	12.52
17	11.00	11.61
19	12.24	12.40

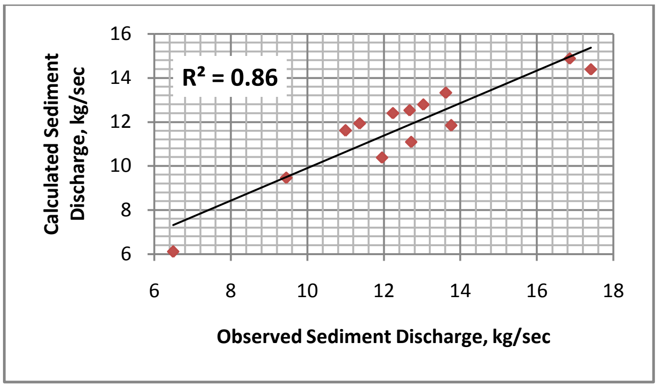

Fig. (7): Observed and Calculated Sediment for Derivation of Equation

VIII. VERIFICATION OF THE FORMULA

Table (5) and figures (8 and 9) represent the verification of the proposed equation. Depending upon the coefficient of determination, a good agreement achieved between observed and calculated sediment discharges. [8]

Table (5): OBSERVED AND CALCULATED SEDIMENT FOR VERIFICATION

Section No.	Observed Sed. Dis. (kg/sec)	Calculated Sed. Dis. (kg/sec)
3	15.22	14.95
6	14.23	13.94
9	12.83	12.50
12	12.70	12.40
15	13.3	12.40
18	13.75	13.66
20	12.05	12.42
3	15.22	14.95
6	14.23	13.94

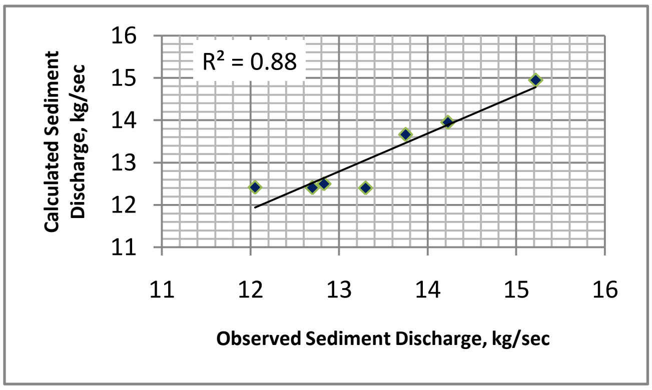

Fig. (8): Observed and Calculated Sediment for Verification of Equation

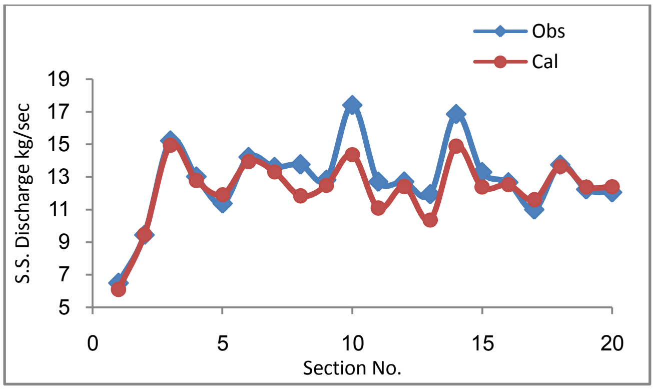

Fig. (9): Longitudinal S.S. Discharge Profile for All Sections

IX. CONCLUSIONS

This study presents the development and comparison performed to suggest a new sediment transport formula for the upstream of Al-Amarah barrage.

According to the results obtained by this study, the following points concluded:

1- The particle size distribution of sediment samples 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 (0.20 to 0.27) mm.

2- The observed suspended sediment discharge range in the study region was from (6.49) to (16.86) kg/sec. While the computed suspended sediment discharge by the SSIIM in the study region ranged between (7.43) to (16.75) kg/sec at the same conditions, and by the new formula was (6.11) to (14.95) kg/sec.

3- A new sediment transport formula developed in terms of dimensionless parameters.

4- The new formula exhibited a good correlation between observed and calculated sediment discharge (R^2=0.88).

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