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An Empirical Formula for Estimating of Suspended Sediment Transport in Upstream of Al-Amarah Barrage using Pi Theorem

Ali H. Al-Aboodi, Husham T. Ibrahim and Sarmad A. Abbas
Department of Civil Engineering, College of Engineering, University of Basrah, Basrah, Iraq
drhushamibrahim@gmail.com, 009647725519687

Abstract: A new formula have been suggested for estimating of suspended sediment load for a reach of Tigris River. This reach is located in upstream of Al-Amarah barrage, Maysan Province, South of Iraq. The total number of the observations was fifty-six these observation have been obtained from pervious study. Pi theorem and general regression among effective parameters are used for developing empirical formula. The effective parameters represent the characteristics of both flow and sediment. These parameters include density of water (ρ) solid particles (ρs), viscosity of water (ν), mean diameter of particles (d50), acceleration due to gravity (g), river flow velocity (V), river width (B), particles settling (fall) velocity (w-s) and maximum flow depth (h). Based on the magnitude of determination coefficient (R^2) a good agreement between the loads calculated by the suggested formula and the observed data have been achieved.

Key words: Sediment transport formula, Al-Amarah barrage, Maysan Province, Iraq , Pi theorem, viscosity of water

INTRODUCTION

The estimating amounts of sediments load is an important issue in hydraulic and engineering practices. Sediment load is a solid particles of minerals and organic materials that carried by water. In rivers and irrigation systems, the yield of transported sediment is controlled by both the transport capacity of the flow and the availability of sediment. Sediment loads may be classify into two major categories: bed load and suspended load. The "suspended sediment load" is the sediment that carried by water column as suspension load while the "bed load" consists of larger particle sizes that transported within a thin layer on the bed of the river by either rolling, sliding or saltation. According to the flow conditions, rivers carry sediment in each of these forms.

The transportation of sediment in natural revers is a continuous process the predicting of sediment amount load is a serious issue for planning and operation of water resources projects. Forecasting of sediment transport load should be established on the accommodating of the influence of hydraulic characteristics and sediment characteristics for any irrigation or river channel.

Sedimentation in rivers have serious effects, the transported sediment load by the river may lead to a decrease in the beneficial dam storage. Also, the ecologic and hydraulic equilibrium of the riverbed may be changed by the transportation of sediment. Furthermore, sedimentation in rivers have significant results including sediment bars formation and reduction for capacity of flood sediment transport. Sediments in water may cause acute erosion of hydro-mechanical facilities and destructive for the field and water structures (Pektas and Dogan, 2015). It is necessary to study various methods for estimating the rate of sediment transported in rivers. In the literature there are many equations and formulas to estimate sediment transport rates. These formulas are submitted in different forms for considerable parameters as a function of river and sediment characteristics. Some of them have been achieved in a laboratory environment while others have been discovered through site data or theoretical approaches. On the other hand, most of the equations and formulas of sediment transport need inclusive information on the characteristics of river, flow and sediment (Ozturk *et al*., 2001).

There is no global methodology is presently usable to any type of river or irrigation channel. Therefore, adopting a suitable method requires careful consideration of the theory and the data availability. Accordingly, there is a necessity to obtain a formula can be applied for studying the river's reach. This formula must be based on local boundaries and hydraulic conditions of studied river reach.

Corresponding Author: Husham T. Ibrahim, Department of Civil Engineering, College of Engineering, University of Basrah, Basrah, Iraq, drhushamibrahim@gmail.com, 009647725519687

MATERIALS AND METHODS

The studied reach: The studied reach is a segment of Tigris River. Its length is 4 km it is located in Al-Amarah city, Maysan Province, South of Iraq. This reach lies in upstream of Al-Amarah barrage. It is located between latitude lines (31.865 and 31.850°) and longitude lines (47.115 and 47.155°). The location of study reach showed in Fig. 1.

Measured data: Khassaf and Hassan (2014) and Hassan (2014) collected the field and laboratory data which are necessary for the derivation of an empirical formula. The total number of cross sections that considered along the reach was twenty cross-sections, Fig. 2. Measured field data includes average current velocity (V), top width (B), maximum flow depth (h), cross section area (A), flow discharge (Q). While the laboratory work includes the determination of particles diameter (d_{50}), solid particles

Fig. 1: Location of study area in references to Iraq map

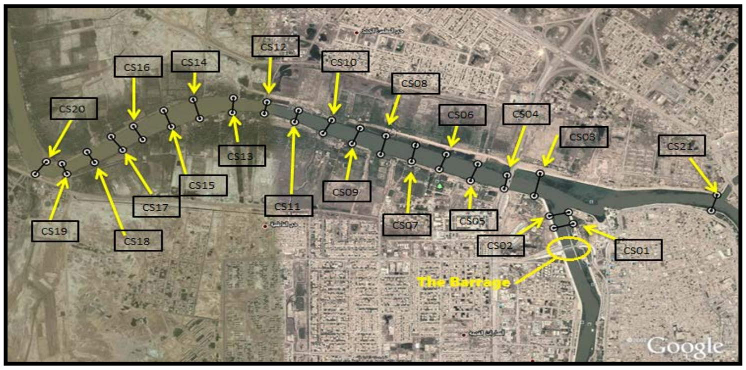

Fig. 2: Transect sections locations

density (ρ_s) and concentration of suspended sediments (C). The Acoustic Doppler Current Profile (ADCP) technology and Van Veen's grab are used in the field measurement and sampling. All field sampling are carried out during the period (1-9-2012-1-9-2013) (Khassaf and Hassan, 2014; Hassan, 2014). The rate of suspended sediment transport (discharge) could be calculated by the following Eq. 5 and 6 (Maidment, 1993; Chanson, 2004):

(1)

Where:

Q_s = Sediment transport rate
C = Suspended sediments concentration
Q = River discharge

Based on the literatures of the sediment transport mechanism and due to the complexity of combining the effects of flow and sediment characteristics in a simple equation or formula it is useful to use numerical technique or dimensional analysis method to obtain an appropriate formula that links the sediment discharge to the effective parameters that represent these characteristics, Pi theorem is one of the most important and effective method.

RESULTS AND DISCUSSION

The new formula development

Pi theorem: The reducing a number of dimensional variable into a smaller number of dimensionless group of variables can be done using Pi theorem. It is suggested by Buckingham in 1914, It is called Buckingham's Pi theorem (White, 2016; Young and Huebsch, 2009). The method is typically involves five steps illustrated in the flow chart of Fig. 3.

Determination of Pi terms: In rivers, the dimensional expression of sediment transportation can expressed as a function of the variables water and solid particles density (ρ and ρ_s), mean diameter of particles (d_{50}), water kinematic viscosity (V), acceleration due to gravity (g), water velocity (V), particles fall velocity (w_s), river width (B) and maximum flow depth (h). Accordingly:

$$Q_s = f(\rho, \rho_s, d_{50}, \nu, g, V, w_s, B, h) \quad (2)$$

Alternatively, it can be written as:

$$F(Q_s, \rho, \rho_s, d_{50}, \nu, g, V, w_s, B, h) = 0 \quad (3)$$

Where:

$$w_s = \frac{g(S\text{-}1)d^2}{18\nu} \quad (4)$$

where, S = relative density = ρ_s/ρ. The units and dimensions of each variable according to, MLT system are listed in Table 1. Choosing the repeating variables that do not compose Pi terms as (ρ_s, d_{50}, V), number of repeating variables may be equal or less than the number of basic dimensions. According to, procedure of Pi determination terms and by regression analysis the following empirical formula (expression) is obtained (Fig. 4 and 5):

Table 1: Dimensional variables

Variables	d_{50}	ρ	ρ_s	g	Q_s
Unit	m	Kg/m^3	Kg/m^3	m/s^2	kg/sec
MLT	L	ML^{-3}	ML^{-3}	MT^{-2}	MT^{-1}
Variable	v	V	W_s	B	h
Unit	m^2/sec	m/sec	m/sec	m	m
MLT	L^{2}T^{-1}	LT^{-1}	LT^{-1}	L	L

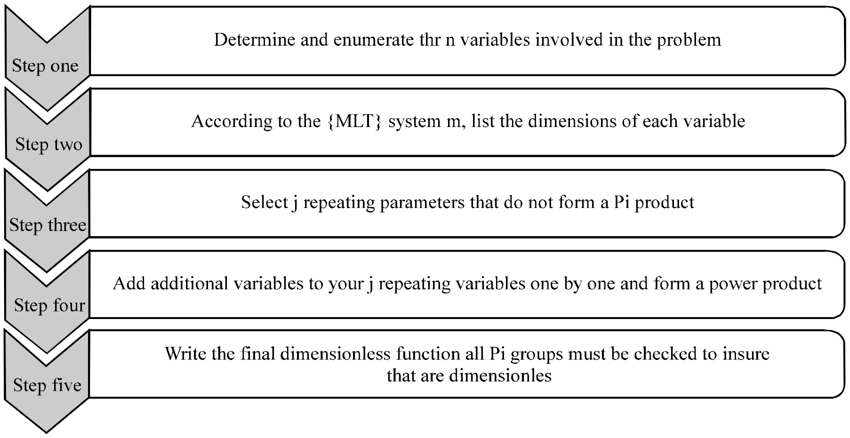

Fig. 3: Flow chart of Pi theorem

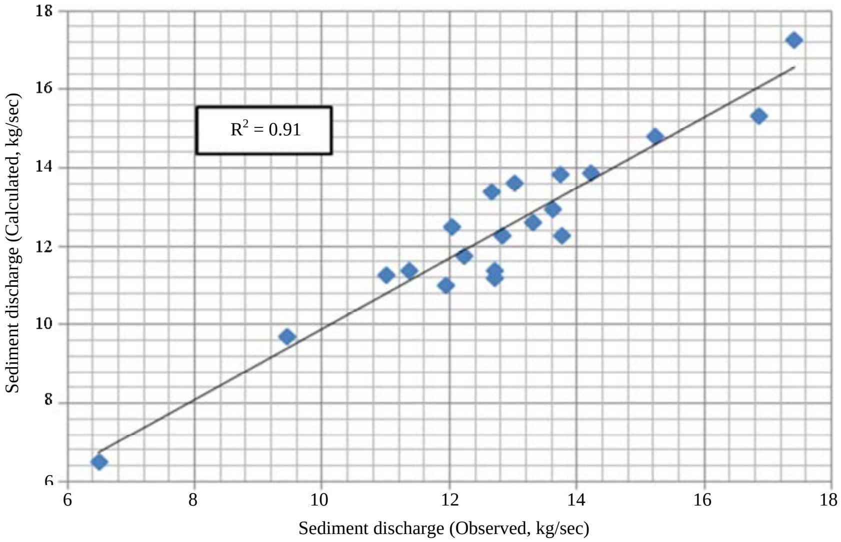

Fig. 4: Scatter plot of obsrved and calculated sediment transport rate

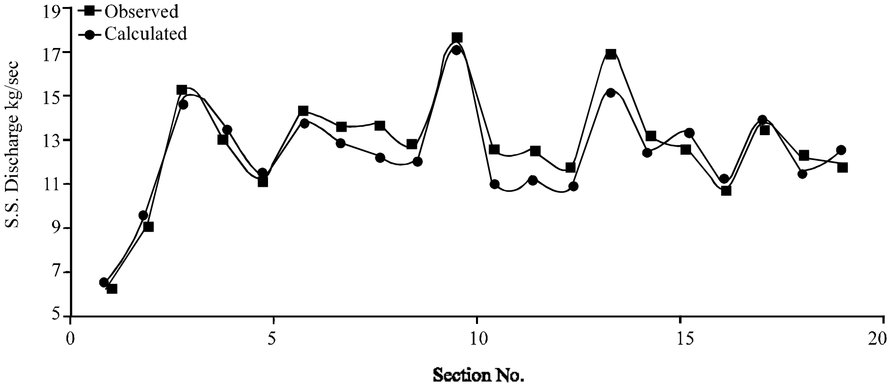

Fig. 5: Comparative plot of observedand calculated sediment transport rate along river reach sections

$$Q_s = 1.26 * 10^{-4} \frac{\rho_s^2 \nu V B h}{\rho \sqrt{g d_{50}^3}} \tag{5}$$

Where:

Q_s = Sediment transport rate (kg/sec)
ρ_s = Density of sediment particles (kg/m^3)
ρ = Water density (kg/m^3)
V = Average velocity (m/sec)
B = River top width (m)
h = Maximum flow depth (m)
ν = Water kinematic viscosity (m^2/sec)
d_{50} = Mean diameter of particles (m)

Evaluation of the formula: In order to check the applicability of the empirical formula for estimating suspended sediment transport rate in Tigris River it was checked against observed data which are published by Khassaf and Hassan (2014). The results of this evaluation were listed in Table 2 and 3, Fig. 5 and 6, it can be noted that an acceptable agreement between calculated and observed sediment transport rates.

Verification of the formula: After deriving the empirical formula and checking its efficiency through evaluating this formula, there is a need to verify it versus another set of observed data. This set of data consists of thirty-six measurements; these field measurements have been achieved by Khassaf and Hassan (2014). These data were measured at section No.1 near the Barrage at different times during the same period which is mentioned above. The verification of the new sediment transport formula was represented in Table 5 and Fig. 6. It can be clearly a good similarity between observed and calculated sediment transport rates depending upon the coefficient of determination (McDonald, 2008).

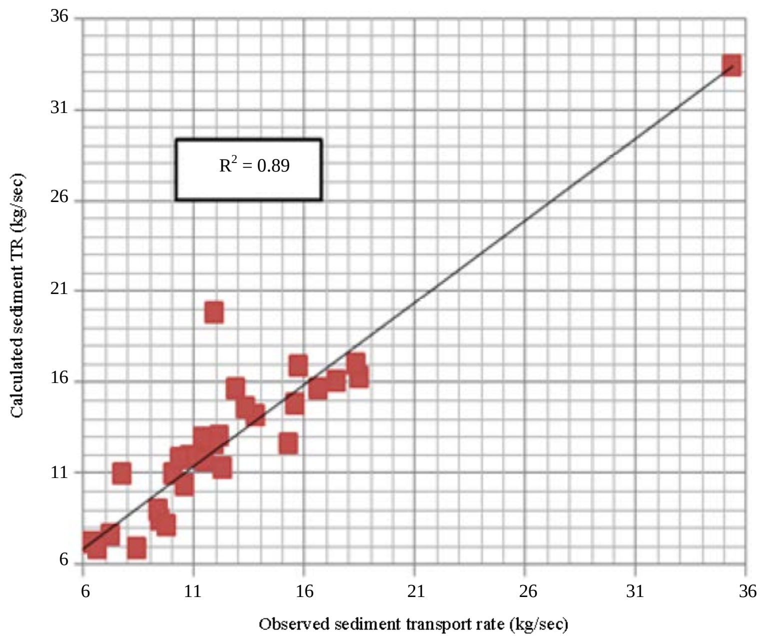

Fig. 6: Scatter plot of observed and calculated sediment transport rate for verification stage

Table 2: observed and calculated sediment transport rate

No. of section	Sediment transport rate (Calculated, kg/sec)	Sediment transport rate (Observed, kg/sec)
1	6.49	6.50
2	9.45	9.70
3	15.22	14.82
4	13.03	13.62
5	11.37	11.39
6	14.23	13.86
7	13.62	12.94
8	13.76	12.28
9	12.83	12.25
10	17.41	17.26
11	12.71	11.19
12	12.70	11.39
13	11.95	11.01
14	16.86	15.33
15	13.30	12.62
16	12.67	13.41
17	11.00	11.25
18	13.75	13.82
19	12.24	11.76
20	12.05	12.50

Table 3: Observed and calculated sediment for verification stage

Record No.	Observed SD (kg/sec)	Calculated SD (kg/sec)
1	6.35	7.19
2	7.19	7.69
3	6.57	6.91
4	5.63	6.59
5	5.12	3.66
6	3.90	6.80
7	5.89	5.82
8	4.96	6.60
9	4.69	3.60
10	4.72	5.60
11	10.05	11.01
12	18.48	16.33
13	17.43	16.10
14	13.76	14.20
15	15.29	12.69
16	10.79	11.97
17	12.10	13.08
18	13.32	14.66
19	7.75	11.00
20	10.30	11.85
21	9.44	8.49
22	11.91	12.64
23	12.87	15.66
24	11.90	19.90
25	9.36	9.00
26	35.36	33.41
27	12.24	11.26
28	10.55	10.36
29	8.40	6.94
30	18.34	16.99
31	15.68	16.90
32	16.60	15.69
33	15.56	14.88
34	9.76	8.16
35	11.46	11.71
36	11.39	13.00

CONCLUSION

In this study, a new formula was suggested for the sediment transport in the studied reach (Tigris River, upstream of Al-Amarah barrage). The results can be summarized by the following points. Pi theorem is a good and effective method for obtaining empirical formula for estimating suspended sediment load. The observed suspended sediment transport rates were ranged from (6.49-17.41 kg/sec) while the calculated values by the new empirical formula were ranged between (6.50-17.26 kg/sec). The verification test of the new empirical formula showed a good matching between calculated and observed sediment transport rate ($R^2 = 0.89$).

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