Journal of Engineering Science and Technology
Special Issue on DMPCE2021, February (2021) 1 - 9

EMPIRICAL FORMULA DEVELOPMENT FOR PREDICTING THE AVERAGE SUSPENDED LOAD DISCHARGE IN THE DOWNSTREAM AL-AMARAH BARRAGE, IRAQ

ABAAS J. ISMAEEL*, WISAM S. AL-REKABI, SARMAD A. ABBAS

Civil Engineering Department, College of Engineering, University of Basrah, Basrah, Iraq
*Corresponding Author: jabbaas@yahoo.com

Abstract

This research entails the development of a new formula for calculating the quantities of suspended sediments discharge by using dimensional analysis. Twenty cross-sections have been identified from the Tigris River of approximately 5 km at the downstream Al-Amarah barrage in southern Iraq. The study involved two phases: the first entails the field and laboratory works i.e., taking samples from the river and filtering them to determine the concentration and average of suspended sediments, as well as taking samples from the river bed and analysing them in the laboratory using the sieve analysis method and the hydrometer test to obtain the distribution of grain sizes for the river bed, where the hydraulic parameters were represented by the water discharge and flow velocity using the Acoustic Doppler Current Profiler (ADCP) technique. The second part of the study entails the statistical analysis using the *SPSS* program and the method of dimensional analysis to obtain the required formula for calculating the suspended sediment discharge. The formula was developed using the method of linear regression and it gave results close to the field measurements, where the coefficient of the determination reached (R^2 = 0.89). There was also a good agreement between the results of the proposed formula and the field measurements of suspended sediment discharge using statistical parameters. The annual sediment quantities calculated by the proposed formula were also compared with the annual sediment quantities from the field measurements, and the results showed a good agreement as these quantities reached (362900) tons and (366480) tons, respectively.

Keywords: A new sediment formula, Al-Amarah barrage, Dimensional analysis, SPSS program, Suspended sediment discharge.

1. Introduction

Sediments are transported in rivers as bed-material load and washing load. Wash load is very fine particles that remain suspended in the water and of which do not contribute to the morphological changes. As for the bed-material load, it is divided into two parts namely the bed load and the suspended load. The bed load is the sediment particles that move near the bed of the river by jumping, rolling, or sliding. The suspended load is a load of sediments that remains suspended in the water due to turbulence in the water [1, 2].

Al-Saadi et al. [3] studied the amount of total sediment load at the upstream of the Al-Shamia barrage through 24 cross-sections along the 6 km study area in order to collect the sediments characteristics and hydraulic parameters, from this data a new formula developed to calculate the total sediment load.

Mizuyama et al. [4] monitored the suspended sediments transport and the wash load in mountain torrents using turbidometry or direct sampling and in regard to the bed load, they developed a device to monitor the movement of bed materials by installing a steel pipe connected to a microphone, where the number of transported gravels is recorded through a hit of this pipe.

Mouhammed and Khayyun [5] developed a new formula to calculate the sediment transport in the upstream of Al-Betera regulator using regression analysis and the dimensional analysis method through 17 cross-sections. Also, suspended sediment concentration was obtained through water samples taken from the cross sections. The process of transporting sediments in natural channels and rivers is very important, thus rendering the need to develop equations to calculate these sediments. These equations were developed and concluded through special conditions for each study area according to the characteristics of the flow and the properties of the sediments in these areas, as these equations gave good results when used under the same conditions from which they were derived. But on the other hand, these equations gave bad results when used in different conditions.

The objective of this study to develop a new formula used to calculate the discharge of suspended sediments at the downstream of the Al-Amarah barrage located within the Maysan Governorate, southern Iraq. Among the significant reasons for selecting this study area was the accumulation of large amounts of sediments at the downstream of this barrage and the lack of data related to sediment in this study area.

2. Description of Study Reach

The study area is located at the downstream of the Al-Amarah barrage, which is considered as one of the modern irrigation projects in Iraq, specifically in the Maysan province. The project was implemented by the employees of the Iraqi Ministry of Water Resources and subsequently opened on 30/5/2005. This barrage consists of six gates with a width of 8 m and a height of 6 m, a design discharge of 350 m^3/s, an operational level of 7.8 m in the upstream of the barrage. The length of the reach towards the downstream of this barrage is approximately 5 km. This study area is located between longitude (47°09'18" E) to (47°08'42" E) and latitude (31°51'00" N) to (31°48'18" N) as shown in Fig. 1.

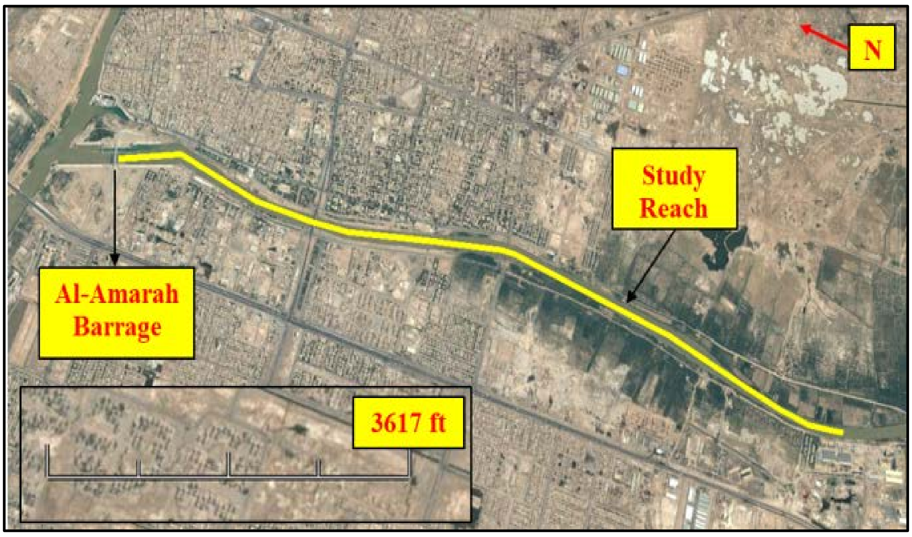

Fig. 1. Study reach location.

3. Data Field Measurements

The field measurement includes the collection of all data required to complete this study, which entail the distribution of twenty cross-sections with a distance of approximately 250 m between the cross-sections along the study area.

3.1. Hydraulic and geometric data measurements

The ADCP is a widely used device in river applications and with the associated software packages, flow velocity, water discharge, and bathymetry can be measured [6]. The ADCP device was used to draw 20 cross-sections as shown in Fig. 2 for cross-section No. 1, and then obtained the required measurement such as discharge and velocity of water, area and top width for each cross-section. The program of the SonTek river tracker surveyor was from version 4.3, was used to collect information after contacting with the ADCP device [7].

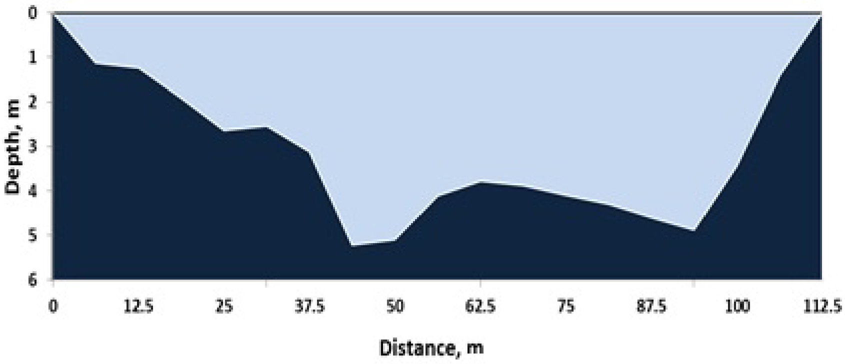

Fig. 2. Geometry of cross section No. 1.

3.2. Bed materials sampling

At each cross-section, three samples were taken at 1/4, 1/2, and 3/4 from width of each cross-section. Next, the three samples were mixed well to obtain a homogeneous sample representing the cross-section and a part of it was taken to the laboratory for analysis [8]. The device that was used to obtain the bed samples is called the Van Veen Grab sampler. This device is made of stainless steel and is an effective tool for taking samples from the bed of the river, lakes, etc. [9].

3.3. Sampling of suspended load

There are different methods for taking samples of suspended sediments in streams and rivers such as using the depth-integrating sampler, the point-integrating sampler, and pumping samplers; the method of sampling mainly depends on several factors such as type of study, time and cost [10]. In this study, the method (point-integrating sampler) was used. The number and locations of vertical sampling required were determined according to the recommendations of the Inter-agency Committee on Water Resources [11]. Through this method used, samples of suspended sediments were taken at 1/4, 1/2, and 3/4 from the width of the river cross-section and at three depths (i.e., 0.2 d, 0.6 d, and 0.8 d) for each vertical column, where *d* is the depth of the water measured from the surface. The total number of samples for each cross-section was nine. The device used to take samples was homemade and operated according to the point integration sampler.

4. Laboratory Tests

In the laboratory, to obtain the sediment distribution curve and specific gravity for the bed materials, and the concentration of the suspended sediments.

4.1. Specific gravity and distribution of grain sizes of bed materials

The procedure using a pycnometer test was used to determine the values of specific gravity of bed materials according to ASTM D854-02 [12]. From this test, the average value of specific gravity for all the sections was 2.69. The sieve analysis and hydrometer test were used to determine the gradation curve for the riverbed samples [13]. In this study, the sieve analysis and hydrometer test of riverbed samples were carried out according to ASTM D422 [14]. Figure 3 shows the average of bed material size distribution in the study reach.

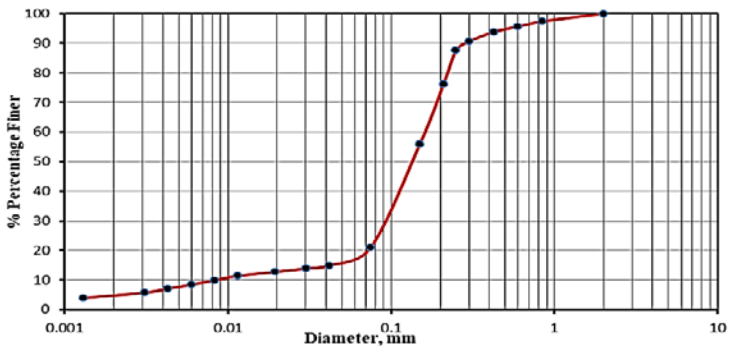

Fig. 3. Average sieve analysis for all sections.

4.2. Suspended sediment concentration in study reach

The filtration method was utilized to obtain the concentration of suspended sediments according to the specific sites for taking samples. This method entails filtering a litre of water for each sample using suitable filter paper and using Eq. (1) to calculate the concentration of the suspended sediment [15].

$$SSC = \frac{w_2 - w_1}{V} = \frac{Mass\ of\ sediment\ (M)}{Volume\ of\ water\ (V)} \quad (1)$$

where SSC is the suspended sediment concentration, W_1 is the weight of dry filter paper, W_2 is the weight of dry filter paper + suspended sediment, and V is the volume of sample.

4.3. Estimation of sediment discharge in study reach

The suspended sediments rate (discharge) can be calculated by multiplying the concentration of suspended sediment in the water discharge through using the Eq. (2) [15]:

$$Qs = C \times Q \times 0.001 \quad (2)$$

where Qs is the suspended sediments discharge, Q is the water discharge, and C is the suspended sediment concentration.

Table 1 shows the values of suspended sediment discharge Qs calculated in each cross-section from the study reach.

Table 1. Suspended sediment discharge for each cross-section.

Section No.	Water discharge (m^3/s)	Average suspended sediment concentration (ppm)	Suspended sediment discharge (kg/s)
1	123.95	113.72	14.10
2	124.87	98.13	12.25
3	127.33	102.81	13.09
4	126.02	96.07	12.11
5	123.60	72.78	9.00
6	124.72	94.08	11.73
7	124.12	104.52	12.97
8	122.65	91.99	11.28
9	120.30	90.55	10.89
10	117.10	83.69	9.80
11	117.94	99.53	11.74
12	116.23	101.88	11.84
13	116.63	98.77	11.52
14	113.63	110.81	12.59
15	112.05	99.78	11.18
16	114.77	110.85	12.72
17	111.18	99.89	11.11
18	110.89	99.73	11.06
19	108.00	90.83	9.81
20	104.92	110.83	11.63

5. Development of a New Formula

The Buckingham π theorem is one of the common ways used to reduce the number of a dimensional variable into a smaller number of groups of variables; this theorem was suggested by Buckingham in 1914 and called Buckingham's *pi* theorem [16]. By using Buckingham's π theorem procedure, the dimensional expression of the sediment motion can be expressed as in Eq. (3):

$$F(Q_s, d_{50}, W_s, \rho_s, B, R_h, V, \rho_w, h, \upsilon) = constant \quad (3)$$

The repeating variables are selected (ρ_w, W_s, h) and the results of the analysis of this parameter appears as in Eq. (4):

$$\frac{Q_s}{\rho_w \times W_s \times h^2} = F\left(\frac{V}{W_s}\right)\left(\frac{R_h}{h}\right)\left(\frac{B}{h}\right)\left(\frac{d_{50}}{h}\right)\left(\frac{\rho_s}{\rho_w}\right)\left(\frac{\upsilon}{w_s \times h}\right) \quad (4)$$

To obtain the final form of the formula, regression analysis was conducted using the SPSS version 22 software on the observed data for (13 sections) to derive a new formula, whereas the other (7 sections) was utilized to verify the new formula. The result of the regression analysis gives in the Eq. (5):

$$Q_s = 0.14\rho_w \times W_s \times h^2 \left(\frac{V \times \upsilon}{W_s^2 \times h}\right)^{0.451}\left(\frac{R_h}{h}\right)^{0.862}\left(\frac{B}{h}\right)^{0.725}\left(\frac{d_{50}}{h}\right)^{-0.128}\left(\frac{\rho_s}{\rho_w}\right)^{-1.055} \quad (5)$$

This formula is applicable only under the following conditions, average velocity of water (0.32 - 0.49) m/s, discharge of water (104.92 - 127.33) m^3/s, average of suspended sediment concentration (72.78 - 113.72) p.p.m, sediment discharge (9.0 - 14.1) kg/s, and median grain size (0.095 - 0.198) mm.

6. Verification of the Proposed Formula Using the Graph Method

In order to verify the results of the proposed formula developed for this study reach, seven cross sections for this purpose were used as listed in Table 2 and depending on the coefficient of determination (R^2=0.89) that was obtained, this formula demonstrated a good agreement between the calculated and observed suspended sediment discharge as shown in Fig. 4.

Verification of the proposed formula using statistical relations

This study used three statistical methods to assess the viability of the proposed formula for calculating the suspended sediment discharge by comparing it with the observed values.

These statistical methods**:** (i) Mean Standard Error (MSE) was used to assess the extent of convergence between the calculated and measured values [17]; (ii) Discrepancy Ratio (R) this method represented the ratio between the suspended sediment discharge computed and observed [18]; and (iii) Root Mean Squared Error (RMSE) was used for error analysis and calculates the magnitude of deviations of an estimated (observed or calculated) value from the actual value sought [16]. The results of statistical parameters used for the seven cross-sections it was (MSE = 2.29%), (RMSE = 0.328) and (R = 100%) for all ranges at (0.75-1.25), (0.5-1.5), and (0.25- 1.75)).

Table 2. The values of the sediment discharge for the seven sections.

Section No.	Observed values (kg/s)	Calculated values (kg/s)
2	12.25	12.49984
4	12.11	12.05108
8	11.28	11.06054
11	11.74	11.14536
12	11.84	11.79235
15	11.18	11.009
17	11.11	10.60303

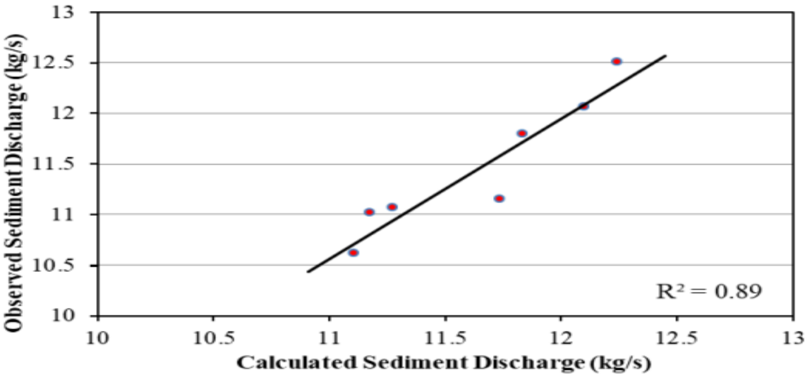

Fig. 4. Comparison between observed and computed sediment load for seven cross sections.

7. Conclusions

According to the results obtained from this study, the following points can be deduced:

- The newly developed formula gave a good correlation between the calculated and observed suspended sediment discharges (R^2=0.89).
- Depending on statistical parameters, a good agreement between the observed and calculated suspended sediment discharges as the discrepancy ratio (*R*) is equal to 100% for all ranges, (MSE) is equal to 2.29%, and (RMSE) is equal to 0.328.
- A good acceptance between the annual suspended sediment discharges compared to the field measurements, where the annual sediment quantities from field measurements reached 366,480 tons while the annual sediment quantities calculated by the developed formula reached 362,900 tons.

Nomenclatures

B	Top width of river, m
C	Concentration of suspended sediment, p.p.m
d	Depth of the water, m
d_{50}	Median grain size, mm
Gs	Specific gravity

h	Max depth of water, m
M	Mass of sediment, mg
Q	Water discharge, m^3/sec
Qs	Suspended sediment load, kg/sec
R_h	Hydraulic radius, m
R	Discrepancy ratio
R^2	Coefficient of correlation
SSC	Suspended sediment concentration, mg/l
V	Volume of sample, L
W_1	Weight of dry filter paper, mg
W_2	Weight of dry filter and suspended sediment, mg
W_s	Fall velocity, m/sec
Greek Symbols	
pi	Buckingham's theorem
ρ_s	Density of sediment, kg/m^3
ρ_w	Density of water, kg/m^3
ϑ	Kinematics viscosity of water, m^2/s
π	Number of terms
Abbreviations	
ADCP	Acoustic Doppler Current Profilers
ASTM	American Society for Testing and Materials
MSE	Mean Standard Error
RMSE	Root Means Square Error
SPSS	Statistical Package for the Social Sciences

References

1. Naqshband, S.; Ribberink, J.S.; and Hulscher, S.J.M.H. (2014). Bed load and suspended load contributions to migrating sand dunes in equilibrium. *Journal of Geophysical Research: Earth Surface*, 119(5), 1043-1063.
2. Shamkhi, M.S.; and Noori, A.F. (2018). Study of suspended sediment transport at Tigirs river- upstream Kut barrage (Iraq). *Proceedings of the International Conference on Civil Engineering, Architecture and Urban Development Management in Iran*. Tehran, Iran, 712-723.
3. Al-Saadi, S.I.K.; AAL-Khalaf, S.K.H.; and Sharba, N.M. (2013). Optimal formula to estimate the quantity of sediment transport upstream of Al- Shamia barrage. *International Journal of Engineering Research and Technology*, 2(12), 3819- 3829.
4. Mizuyama, T.; Satofuka, Y.; Laronne, J.; Nonaka, M.; and Matsuoka, M. (2008). Monitoring sediment transport in mountain torrents. *Proceedings of the 11th Congress INTERPRAEVENT 2008*. Dornbirn, Austria, 425-431.
5. Mouhammed, N.H.; and Khayyun, T.S. (2015). Suspended sediment transport formula for the upstream of Al-Betera regulator. *International Journal for Management Science and Technology*, 3(6), 1-12.
6. Yorke, T.H.; and Oberg, K.A. (2002). Measuring river velocity and discharge with acoustic doppler profilers. *Flow Measurement and Instrumentation*, 13(5-6), 191-195.

7. SonTek. (2005). Riversurveyor system manual, software version 4.30, SonTek/YSI, Inc, San Diego, USA.
8. Adegbola, A.A.; and Olaniyan, O.S. (2012). Estimation of bed load transport in river Omi, south western Nigeria using grain size distribution data. *International Journal of Engineering and Technology*, 2(9), 1587-1592.
9. Eijkelkamp Soil and Water. (2018). *Van veen grabs manual*, Giesbeek, the Netherlands.
10. Community based flood and glacial lake outburst risk reduction project. (2015). *Sediment monitoring protocols for Churia originating river systems*, Department of Hydrology and Meteorology, Ministry of Science Technology and Environment, Government of Nepal, Nepal.
11. University of California. (1963). *A study of methods used in measurement and analysis of sediment loads in streams*, Federal Inter-Agency Sedimentation Project, Minnesota, US.
12. ASTM Standards, D854-02. (2002). *Standard test methods for specific gravity of soil solids by water pycnometer*, ASTM International Committee on Soil and Rock, United States.
13. Kalinski, M.E. (2011). *Soil mechanics lab manual* (2th ed.). New York: John Wiley and Sons Inc.
14. ASTM Standards, D422-63. (2007). *Standard test method for particle-size analysis of soils*, ASTM International Committee on Soil and Rock, United States.
15. Maidment, D.R. (1993). *Handbook of hydrology*. New York: McGraw-Hill Inc.
16. White, F.M. (2011). *Fluid mechanics* (7th ed.). New York: McGraw-Hill Inc.
17. Scheaffer, R.L.; Mulekar, M.; and McClave, J.T. (2001). *Probability and statistics for engineers* (5th ed.). USA: Cengage Learning.
18. Bureau of Reclamation. (2006). *Erosion and sedimentation manual*, US Department of the Interior, Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulics Group, Denver, Colorado.