Development of an Empirical Formula for Computing Sediment Loads in Upstream of Al-Hafar Regulator

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Abstract:- **In this research, the sediments transport and estimating their amount have been studied in upstream of Al- Hafar regulator on Euphrates river which is located in the south of Iraq within Dhi-Qar governorate. Twenty one cross section were selected along the study reach (5 km) in order to study the hydraulic parameters and characteristics of sediments transported.**

The study was divided into two parts :the practical part (field and laboratory works) and the statistical part. Samples of water sediment and bed material have been taken at each section using homemade Sampler, while the hydraulic parameters were measured using (Acoustic Doppler Current Profile) ADCP device .

The Empirical Formula for estimating amount of total sediment discharge in study area was developed using dimensional analysis technical and by help SPSS program , the determination coefficient of the Empirical Formula is (R^2=0.9946) .

Finally, The average predicted annual total sediment discharge has been estimated through field measurements ,it were (120783) ton ,While The Empirical Formula gave the average annual sediment discharge was (126144) ton.

Keywords: Sediment Transport, Empirical Formula, Al-Hafar regulator, Euphrates river

1. INTRODUCTION

Sediments are small particles like sand, gravel, clay and silt. The water in a river has a natural capacity of transporting sediments. Man – made structures in a river may change the sediment transport capacity over a longer part of the river, or locally .Sediment can be classified as deposited or suspended, deposited sediment is that found on the bed of the river or lake, suspended sediment is that found in the water column where it is being transported by water movements, so the material transported by water is in suspensions, rolling or sliding on the bed. The border line between bed load and suspension is certainly not well defined, because it is hard to imagine a particle rolling or sliding on the bed without at some time loosing contact with the bed, executing short jump**[1]**.

WhereSediment transport is important in the fields of sedimentary geology, geomorphology, civil engineering and environmental engineering. Knowledge of sediment transport is most often used to determine whether erosion or deposition will occur, the magnitude of this erosion or deposition, and the time and distance over which it will occur. . In a channel the water flow erodes the available material in the banks and /or the stream bed until the flow is "loaded" with as much sediment particles as the energy of the stream will allow it to carry**[2]**.A derived of formula under the condition of the study reach is very important to estimate the quantity of sediment transport ,so in this paper a development of anew formula for estimation the sediment transport of the study reach.

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DESCRIPTION OF AL-HAFAR REGULATOR

Al-Hafar regulator channel is considered as one of the most important projects of irrigation in the region for the large areas that benefited from it and the technical applets and performance.

It is located in Suq Al- Shuyukh area(AL-Karma) (south-east) in Dhi-Qar governorate on Euphrates River. The regulator is constructed in1957and it is consists of seven steel sliding gates in addition to the navigation lock, each gate with a dimension (7x7)m. The designed flood discharge of the regulator is 500 m^3/sec . The reach of study upstream of the regulator with length 5 Km .It is located between longitude E 46°34'19.77" to E 46°32'1.62" and latitude N 30°52'52.22" to N 30°52' 9.46

3. FIELD MEASUREMENT

Twenty one cross sections all located up stream of regulator were selected downward the water flow direction with different distance range(100-300)m between section and another as required by the nature of the study area and hydraulic conditions as shown in Fig. 1.The cross sections of river were observed by

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taking reference point on the right side bank (with respect to the flow direction) from the reference point at each cross section transect sampling .Cross- section area , velocity ,width ,depth , and other hydraulic properties are determined by passing Acoustic Doppler Current profile ADCP(M9) device along the path of each section which was operated from an anchored boat see Fig. 2. Son Tek River Surveyor (SNR) program starts recording all information after interconnecting with ADCP device. A summary of data used in the study is shows in Table 1.Three samples of bed material were taken at ¼, ½ and ¾ of the width of stream at each cross section in order to conduct the size analysis distribution. The obtained samples were mixed together and part of the mixture was taken to the laboratory for analysis **[3]**.The home-made sampler is called (Van- Veen grab sampler) as shown in Fig. 3.

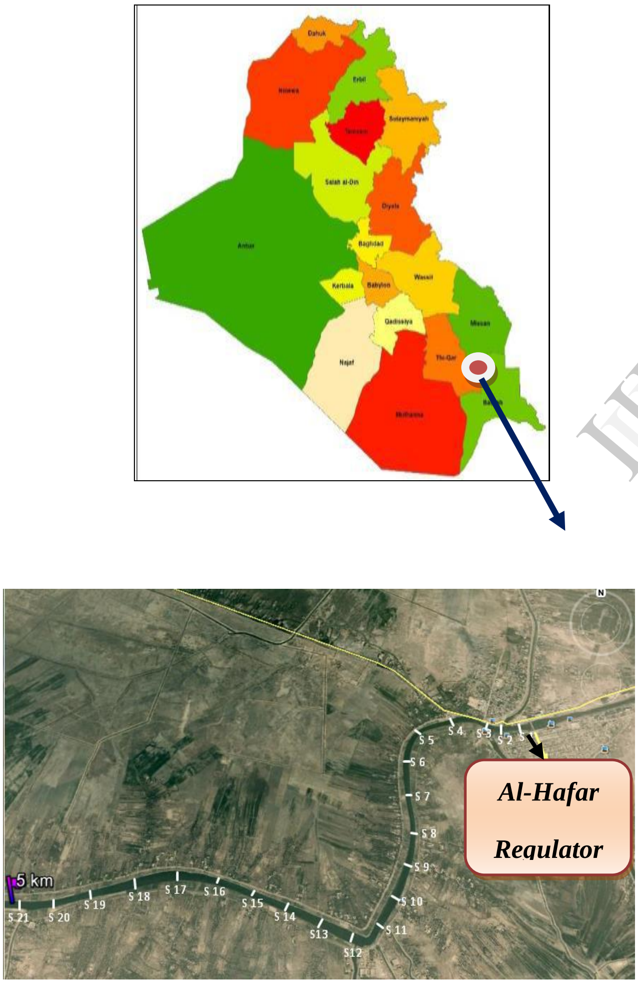


Fig. 1: The positions of cross-sections (C.S.) in the region of study, by Google Earth©

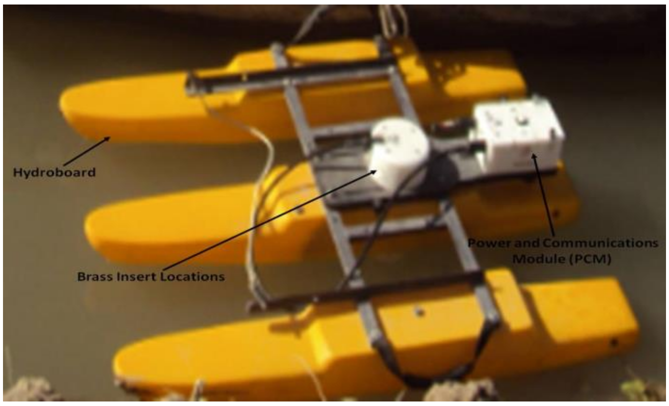
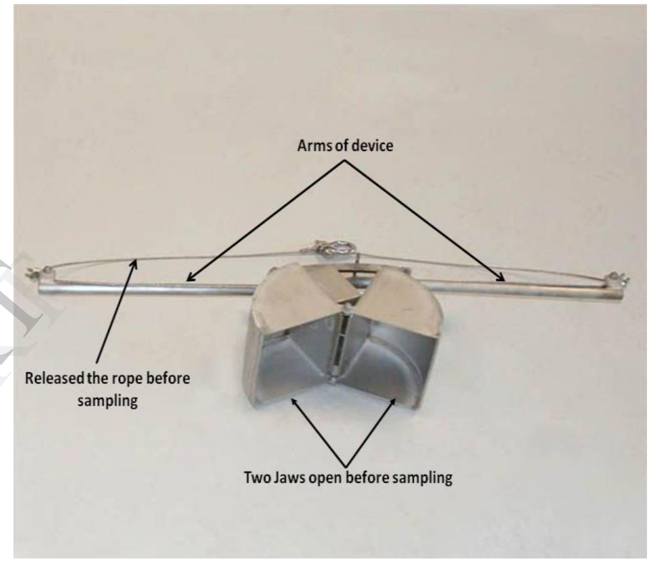
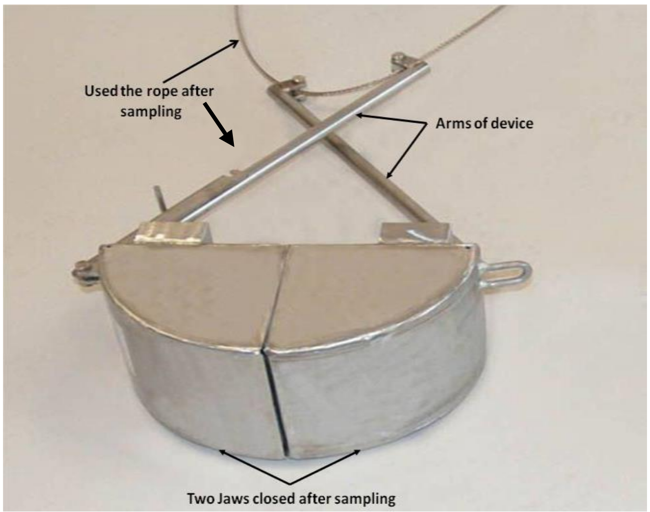


Fig. 2: ADCP(M9) adapter



(A) Before sampling



(B) After sampling

Fig. 3: Bed material sampler

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Suspended sediment in river is sampled to determine the sediment concentration .Different sediment samplers and procedures are available for sampling in a stream. Because of the flow acceleration ,there is some effect on the accuracy of measurement, it is imperative that sampling process would disturb the flow as little as possible**[1]**. Depth integrating samplers continuously accumulate a representative sample from a stream vertical. The sampler is lowered slowly down to approximately 10 cm (3.9 in) from the top of the streambed. It is then raised to the water surface at the same speed **[4]** in the same location of bed material . The sampler consists of a bottle with the capacity of one liter, an intake nozzle of (8 mm) in diameter. An air escape of (6mm) in diameter with long plastic tube and control valve to control the entering of water sediment mixture into the sampler **[5]**, shown in Fig. 4.

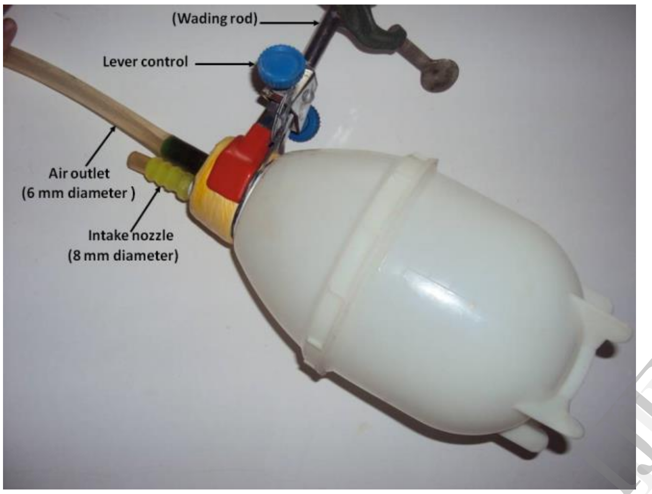

Fig. 4: Suspended sediment homemade sampler

4. LABORATORY MEASUREMENTS

The laboratory work is needed to construct the grain size distribution curve of the bed material samples was drown for each sections as a results of sieve analysis and hydrometer test, and to obtain specific gravity value of the observed sediment samples, also to find sediment concentration.

4.1 Sediment Concentration Measurement

The concentration of suspended sediment was determined from the samples that were taken from specified locations of a study reach by using a filtration method Fig. 5.

A well- mixed sample is filtered using a suitable filter and the residue retained on the filter is dried in oven at a constant (103-105) c°.Each filter paper was pre-dried for 60 minutes and weighted, and then it was clipped to the filter funnel and moistened with distilled water. A volume of 250 ml of the sample was measured into a graduated cylinder and poured through the filter, and all interior surface of the cylinder were washed out into the filter funnel with distilled water. After the completion of filtration, the filter paper was dried in oven and re-weighed .The difference between the two weights, divided by the volume of the sample, gives the concentration of the suspended sediment as follow**[6]:**

$$C = \frac{W_2 - W_1}{V} \quad \text{....(1)}$$

C= Concentration of suspended sediment in mg/l (P.P.m).

W_1= Weight of dry filter paper in mg.

W_2= Weight of dry filter paper + suspended sediment in mg.

V= Volume of sample (l).

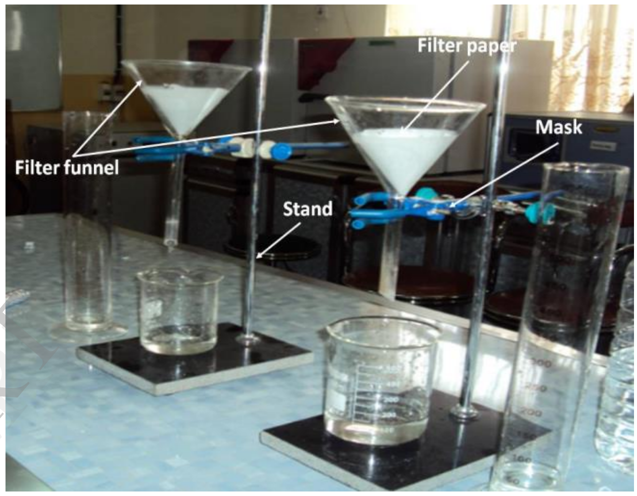

Fig. 5: Filtration method

Table 1: Primary data and parameter

Sec. No	1	2	3
Q_w(m^3/sec)	34.62	34.23	39.79
V (m/sec)	0.316	0.158	0.32
G_S	2.73	2.66	2.65
d_{50} (mm)	0.152	0.113	0.112
A (m^2)	109.4	216.3	124.3
B (m)	55.01	107.44	70.83
R_h (m)	1.99	2	1.75
ν (m^2/sec)	1.05×10^{-6}	1.05×10^{-6}	1.05×10^{-6}
W_s (m/sec)	0.016668	0.009407	0.009199
U_* (m/sec)	0.0312	0.0313	0.0293
Sec. No	**4**	**5**	**6**
Q_w(m^3/sec)	40.37	40.87	42.56
V (m/sec)	0.312	0.345	0.343
G_S	2.69	2.73	2.7

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d_{50} (mm)	0.105	0.1	0.102
A (m^2)	120.1	116.7	121.3
B (m)	47.77	51.05	60.02
R_h (m)	2.51	2.28	2.02
ν (m^2/sec)	1.06×10^{-6}	1.07×10^{-6}	1.07×10^{-6}
W_s (m/sec)	0.007543	0.008431	0.008958
U_* (m/sec)	0.0351	0.0334	0.0315

Sec. No	**10**	**11**	**12**
Q_w (m^3/sec)	22.97	22.95	24.97
V (m/sec)	0.25	0.195	0.23
G_S	2.65	2.66	2.7
d_{50} (mm)	0.1	0.098	0.1
A (m^2)	92	117.5	108.8
B (m)	60.19	49.60	74.36
R_h (m)	1.53	2.37	1.46
ν (m^2/sec)	1.07×10^{-6}	1.07×10^{-6}	1.07×10^{-6}
W_s (m/sec)	0.007294	0.008096	0.007508
U_* (m/sec)	0.0274	0.0341	0.0268

Sec. No	**13**	**14**	**15**
Q_w (m^3/sec)	26.36	27.40	27.42
V (m/sec)	0.256	0.243	0.234
G_S	2.69	2.68	2.7
d_{50} (mm)	0.099	0.101	0.125
A (m^2)	102.9	112.6	116.9
B (m)	56.72	51.39	46.65
R_h (m)	1.81	2.19	2.50
ν (m^2/sec)	1.06×10^{-6}	1.07×10^{-6}	1.07×10^{-6}
W_s (m/sec)	0.008454	0.007599	0.011436
U_* (m/sec)	0.0298	0.0327	0.035

Sec. No	**16**	**17**	**18**
Q_w (m^3/sec)	27.82	13.48	14.76
V (m/sec)	0.257	0.123	0.162
G_S	2.69	2.67	2.68
d_{50} (mm)	0.113	0.127	0.147
A (m^2)	108.2	109.3	91.1
B (m)	50.01	69.22	64.99
R_h (m)	2.16	1.58	1.40
ν (m^2/sec)	1.06×10^{-6}	1.20×10^{-6}	1.21×10^{-6}
W_s (m/sec)	0.009462	0.010445	0.013612
U_* (m/sec)	0.0325	0.0278	0.0262

Sec. No	**19**	**20**	**21**
Q_w (m^3/sec)	13.93	12.46	14.10
V (m/sec)	0.135	0.117	0.135
G_S	2.7	2.69	2.72
d_{50} (mm)	0.123	0.11	0.1
A (m^2)	103.6	106.2	104.2
B (m)	52.18	44.11	47.94
R_h (m)	1.98	2.41	2.17
ν (m^2/sec)	1.21×10^{-6}	1.21×10^{-6}	1.22×10^{-6}
W_s (m/sec)	0.009915	0.007970	0.006724
U_* (m/sec)	0.0312	0.0344	0.0326

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5. SEDIMENT DISCHARGE MEASUREMENT

The measurement of sediment discharge is essential to determine the quantity of sediment load to establish or check analytical or empirical sediment transport equations. Then sediment discharge can be calculated by multiplying the concentration with the flow discharge **[2]**. As the following

$$\mathbf{Qs = C \times Q \times 0.001} \quad \text{.....(2)}$$

Table 2 illustrates the calculated sediment discharge resulting from Equation (2).

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Table 2: Field sediment discharge for each section

No. Sec.	water discharge (m^3/sec)	Average Concentration (g/m^3)	Sediment discharge (Kg/sec)
1	34.62	165.45	5.728
2	34.23	155.5	5.323
3	39.79	167.825	6.678
4	40.37	164.36	6.635
5	40.87	171.52	7.010
6	42.56	168.33	7.164
7	22.77	125.29	2.853
8	23.58	132.5	3.124
9	23.82	130.25	3.105
10	22.97	150.33	3.453
11	22.95	135.64	3.113
12	24.97	140.53	3.509
13	26.36	147.25	3.881
14	27.40	144.44	3.957
15	27.42	141.83	3.889
16	27.82	145.45	4.046
17	13.48	101.35	1.366
18	14.76	118.25	1.745
19	13.93	112.55	1.568
20	12.46	95.78	1.193
21	14.10	114.37	1.613

6. DEVELOPMENT OF EMPIRICAL FORMULA

The dimensional analysis is a good way in dealing with a complex problem if it is Correctly applied. The principal use of dimensional analysis is to deduce from a study of the dimensions of the variables in any physical system certain limitations on the form of any possible relationship between those variables. The method is of great generality and mathematical simplicity **[7]** The result of dimensional analysis depended on the most important variables are selected according to groups**[8]**.

Group 1: Variables related to the characteristics of sediments

(d_{50} ,w_s ,ρ_s , Q_S)

Group 2: Variables related to geometric and hydraulic properties of stream channel .

(B, R_h ,V, ρ,ν,U^*)

Using Buckingham's π-theorem procedure as presented in **[9],** the variables used for the field and the laboratory work and their relationship are as follows:

$Q_S = \emptyset(d_{50}, w_s, \rho_s, B, R_h, V, \rho, \nu, U^*)$ ….(3)

Or $F(Q_S, d_{50}, w_s, \rho_s, B, R_h, V, \rho, \nu, U^*)$ = constant ….(4)

The number of primary dimensions involved is 3, i.e., m = 3 (M, L, T). The total numbers of variables are 10. Therefore, the number of π-terms is 7

Thus, F {π1, π2, π3, π4, π5, π6, π7} = constant ….(5)

The repeating variables are selected (ρ ,w_s , R_h) i.e ,the first variable representing the fluid property ,the second representing the sediment characteristics and the third representing the hydraulic property. The results of the analysis are listed in Table 3.

Table 3 : π parameters

π	π_1	π_2	π_3	π_4	π_5	π_6	π_7
parameter	$\frac{Q_S}{\rho\, w_S\, R_h^2}$	$\frac{d_{50}}{R_h}$	$\frac{\rho_S}{\rho}$	$\frac{B}{R_h}$	$\frac{V}{w_S}$	$\frac{U^*}{w_S}$	$\frac{\nu}{w_S\, R_h}$

Then, the equation can be expressed as the following:

$$\frac{Q_S}{\rho\, w_S\, R_h^2} = F\left(\frac{d_{50}}{R_h}\right)\left(\frac{\rho_S}{\rho}\right)\left(\frac{B}{R_h}\right)\left(\frac{V}{w_S}\right)\left(\frac{U^*}{w_S}\right)\left(\frac{\nu}{w_S\, R_h}\right) \quad …..(6)$$

The following procedure was followed to reduce the number of π-terms:

π3 and π4 may be replaced by another π_8

$$\pi3 \times \pi4 = \pi8 = \left(\frac{\rho_S}{\rho}\right) \times \left(\frac{B}{R_h}\right) = \left(G_S \frac{B}{R_h}\right) \quad ….(7)$$

Using the same approach, π_2 and π7 can be combined to evaluate π9

$$\pi2/\pi7 = \pi9 = \frac{d_{50}/R_h}{\upsilon/(w_S R_h)} = (d_{50}\, w_s/\nu) \quad ….(8)$$

Thus, the functional relationship becomes:

$$\frac{Q_S}{\rho\, w_S\, R_h^2} = F\left(\frac{V}{w_S}\right)\left(\frac{U^*}{w_S}\right)\left(G_S \frac{B}{R_h}\right)\left(\frac{d_{50}\, w_S}{\nu}\right) \quad ….(9)$$

The final form of the equation has to be determined by the conducting of the regression analysis with help of SPSS program on the observed data. These data were divided into two groups: the first group including of 13 different sections was randomly selected for the derivation of the new equation while the second group (8 sections) was used for verification of Empirical Formula .The regression analysis was conducted and be found by using the following formula:

$$\boldsymbol{Q_S = 1.352 \times 10^{-6}\ \rho\, w_s\, R_h^2 \left(\frac{V}{w_s}\right)^{1.4} \left(\frac{U^*}{w_s}\right)^{0.96} \left(G_S \frac{B}{R_h}\right)^{1.3} \left(\frac{d_{50}\, w_s}{\nu}\right)^{0.86}} \quad \textbf{…..(10)}$$

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The coefficient of determination of equation (10) was found to be equal (R^2=0.9946). Fig. 6 shows a well accepted relationship between the predicted and the observed values of sediment discharge for 13 sections.

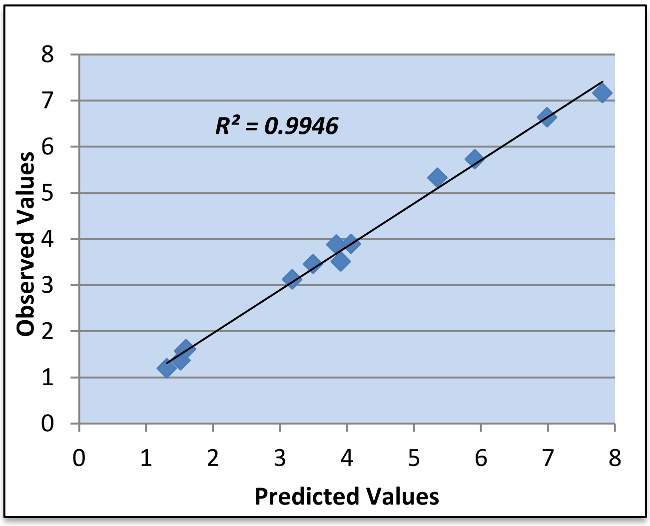

Fig. 6: Observed and predicted values for (13) sections.

7. VERIFICATION OF THE PROPOSED FORMULA

To verify that the proposed formula has been used eight remaining sections of the sediment discharge measured and predicted a long the area of study reach. It demonstrates the coefficient of determination (R^2 = 0.9948). This step provides an independent verification of the precision of the mentioned formula because non of the data are used to obtained this proposed formula.

A well agreement between the observed and the predicted sediment discharge can be realized for eight sections in Fig. 7.

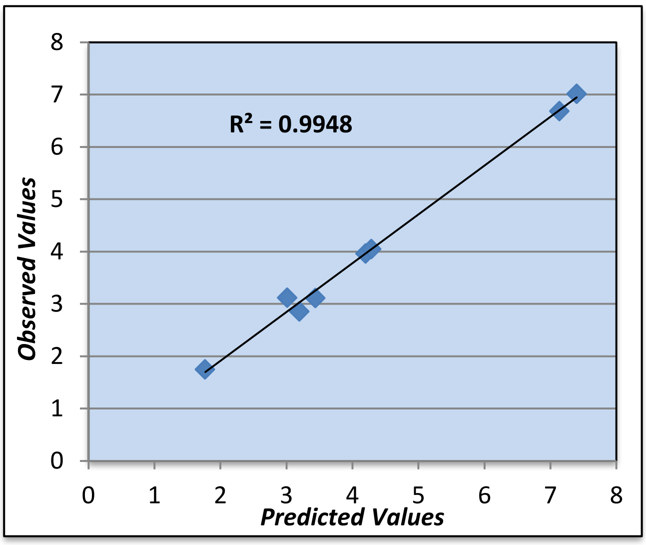

Fig. 7: The Observed and predicted values for the eight sections

8. COMPARISON USING STATISTICAL RELATIONS

Three methods are used in this research to evaluate the performance Empirical formula through comparing with measured values.

8.1 Mean Standard Error

A mean standard error was used in order to select the best formula since due to the high difference between predicted and measured sediment rates at various intervals **[10]**.

$$MSE = \frac{100}{N} \sum_{n=1}^{n} \left| \frac{s_o - s_c}{s_o} \right| \qquad \ldots(11)$$

In which:

MSE is a Mean Standard Error; s_o an observed sediment rate; s_c is a predicted sediment load and N is the number of the predicted values.In this method, a lower statistical criterion (close to zero) shows a higher accuracy in the model performance.

The Empirical Formula gave the Mean Standard Error (MSE) equal to 5.35%. Thus it is produced quite good performance to estimate the amount of bed material load in the study area comparing with measured values.

8.2 Discrepancy Ratio

Discrepancy ratio**[11]** is defined as the ratio between computed and measured sediment loads. It was used as an error measure that is calculated as:

$$\text{discrepancy Ratio (R)} = \frac{computed\ q_s}{measured\ q_s} \qquad \ldots(12)$$

When the discrepancy ratio is equal to one (R=1)**[10]** for the value of the Empirical Formula that indicate the predicted value is identical to the measured value for reach of study .The discrepancy ratio is scheduled with the ranges (0.75-1.25) ,(0.5-1.5) ,and (0.25-1.75). The results are 100% for all ranges.

8.3 Root Mean Squared Error

The root mean square error calculation is a well known and frequently used method of error analysis. It accurately depicts the magnitude of deviations of and estimated (measured or calculated) value from the actual value sought**[12]**. The RMSE has the same units as the measured and calculated data. Smaller values indicate better agreement between the measured and the calculated values**[13][14].**

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(s_o - s_c)^2}{N}} \qquad \ldots(13)$$

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In which: s_o observed sediment rate, s_c is predicted sediment load and N is the number of predicted values. The Empirical Formula gave $RMSE$ equal to 0.27% .

9. CONCLUSIONS

According to the results which are obtained by this study for twenty one cross sections on Euphrates river up-stream of Al- Hafar regulator ,in Al- Nasiriyah city the following points are concluded:

A good agreement was observed between the measured values and the computed values of the total sediment discharge for Empirical Formula which it has been developed in term of five dimensionless parameters: $(Q_s/\rho\, w_s\, R_h^2\,,\ V/w_s\,,\ U_*/w_s\,,\ G_s\, B/R_h$ and $d_{50}w_s/\nu$ This formula is based on thirteen section of data and other eight sections are used to certify it. The Empirical Formula is applicable under the following conditions:

- Flow velocity (0.117 – 0.345) m/sec.
- Water discharge (12.46 – 42.56) m^3/sec.

A verage concentration of suspended load (95.78 – 171.52) mg/l.

- Median grain size (0.098 – 0.152) mm.

From through statistical methods used for comparison noted that the Empirical Formula proposed is good accurate in calculation the amount of sediment in the search area comparing with measured values. Where the average predicted annual total sediment discharge has been estimated through field measurements ,it were (120783) ton ,While the Empirical Formula gave the average annual sediment discharge was (126144) ton.

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- ***Notations***

Symbol	***Meaning***	***Unit***
Q_S	Total sediment load	kg/sec
ρ	Density of fluid	kg/m^3
w_s	Fall velocity of particle	m/sec
R_h	Hydraulic radius	m
V	Mean velocity	m/sec
U^*	Shear velocity	m/sec
G_S	Specific gravity	--
B	Width of river	m
d_{50}	Median grain size	m
ν	Kinematics viscosity	m^2/sec
Q	water discharge	m^3/sec
C	The sediment concentration	PPm
ρ_S	Density of sediment	kg/m^3

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