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Investigation of performance of sediment transport formulas based on measured data in Euphrates river, up stream of AL – Abassiya Barrage

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Abstract

Reliable prediction of sediment discharge is very important element in the evaluation of sedimentation in reservoir , local scour or deposition around hydraulic structures , river bed degradation , etc.The existing sediment discharge formulas are derived in flumes or tested with limited field data . Hence , the performance of these formulas are unknown in reference with measured flow and data of sediment in natural river. This paper presents the evaluation of eight existing sediment transport formulas (Enguland-Hanssen,Ingls-Lacey, Ackers-White,Yang1972,Yang 1978,Bagnold,Ariffin and Van Rijn) against the field data obtained from twenty cross sections along entire study reach (up- stream AL-Abbasiya Barrage) .Measured data included the hydraulic parameters of different cross sections and the properties of sediment particles.

Samples of water sediment have been taken at each section in addition to bed samples using home-made samplers, while hydraulic parameters were founded using Acoustic Doppler Current Profile (ADCP) device.

Although significant deviations are found between predictions and measured values in these evaluations , two formulas respectively (Acker-White and Van Rijn)gave a reasonably good agreement .

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

الخلاصة

التوقع المعقول لتصريف الرسوبيات هو عامل مهم جدا في تقييم الترسيب في الخزانات ، الانجراف الموقعي أو الترسيب حول المنشآت الهيدروليكية ، تآكل قاع الأنهار ..الخ . معادلات حساب تصريف الرسوبيات اشتقت في القنوات أو فحصت لبيانات حقلية محدودة . لذلك أداء هذه المعادلات غير معلوم بالمقارنة مع التصريف المقاس ومع بيانات الرواسب في الأنهار الطبيعية . هذا البحث يعرض تقييم ثمان معادلات مشهورة لنقل الرسوبيات وهي

(Enguland-Hanssen , Inglis- Lacey , Ackers-White, Yang ,Bagnold ,Ariffin,and Van Rijin)

بالاستفادة من البيانات الحقلية التي حصل عليها من عشرون مقطع على طول حقل الدراسة (مقدم سدة العباسية) . البيانات المقاسة تضمنت المتغيرات الهيدروليكية لمختلف المقاطع وكذلك خواص الجزيئات المترسبة . عينة خليط الماء والراسب قد اخذت لكل مقطع بالإضافة إلى عينة من قاع النهر باستخدام أجهزة اخذ العينات المصنعة محليا ، بينما المتغيرات الهيدروليكية قد وجدت باستخدام جهاز (ADCP).

على الرغم من إيجاد انحراف مهم بين القيم المقاسة والمحسوبة في هذا التقييم ، صيغتان على التوالي

(Van Rijin&Ackers-White) أعطت نتائج معقولة .

Notation

A	Cross – section area
A_1	Constant used in eq.(11)
B	Width of the river .
C	Mean value of sediment concentration
C_1	Constant used in eq.(12)
C_V	Volumetric sediment concentration
D	Water depth
d_{50}	Median size of sediment
F_{gr}	Sediment particle mobility number
n	Constant used in eq.(2-34)
Q	water discharge
q_s	Sediment discharge per unit width
R	Hydraulic radius of stream
Sg	Specific gravity
T	Top width
u_*	Shear velocity
V	Mean velocity
V_{cr}	Critical average water velocity at incipient motion
W	Fall velocity of particle
γ	Specific weight of fluid
γ_s	Specific weight of sediment grains
τ_{cr}	Critical shear stress
τ_0	The average shear stress
τ_*	Dimensionless shear stress
ρ	Density of fluid
ρs	Density of sediment grain
ν	Kinematics viscosity

Introduction

The quantity of sediment flows through the natural alluvial rivers or which is the reliable sediment transport model that can be recommended , are the main problem usually faced by the scientists and engineers who are engaged in many projects related to sediment control .Many physical phenomena generated in river due to the sediment scour and deposition , such as reservoir sedimentation , river bed degradation , local scour or deposition around hydraulic structures , impairing the protection of sensitive turbines in hydroelectric power station , effect on level of water and performance of any structure such as regulator , lateral channel ,etc. Each of physical phenomena is unique in its combination . While there are many sediment transport formulas available , which make it very hard to select the suitable one for a given river and situation . This problem is even more complex for Euphrates River in Iraq , up- stream Al-Abassiya Barrage which can be seen the effect of sediment deposition on gate of this barrage and it is operating . Hence , the use of field data is available in making reasonable evaluation and selection of sediment transport formulas for a site condition under study .

In this paper, total sediment discharge formulas are tested based on field data collected from study reach , southern Iraq (see figure 1) .

Description of the Study Reach

Iraq has two big rivers, Tigris and Euphrates. Euphrates ranks as one of the major rivers in the world . With its source in southern Turkey and outlet in Shatt al Arab water way which connects to the Arabian Gulf . Thick Pleistocene and recent alluvial deposits cover large areas of its basin and the oldest exploded rocks along the course of the river in Iraq are of Eocene-Oligocene age and are composed mainly of limestones **(Al-Ansari et al .,1988).**

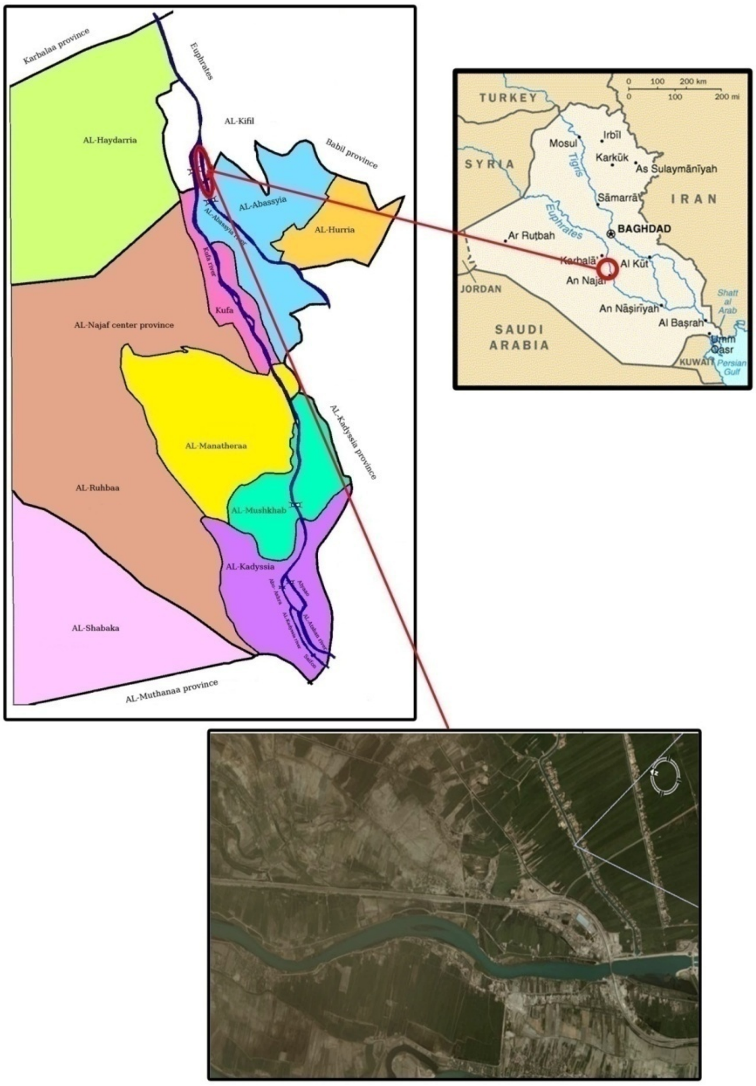


Figure (1): Reach-study location by Ref. www.googlemap.com

The region in this study is located between longitude E 44.22°,29',45" to E 44.21°,77',52" and latitude N 32.08°56',19" to N 32.11°,88',39". In this region , Al- Abbasiya barrage is constructed at the Euphrates river it is location between Al-Hilla and Al-Kufa city . The length of a study reach was about 5 Km up stream of barrage with an average width 200m, as shown in figure (2). The data used in this study are collected from 20 sections in the Euphrates river located upstream of Al-Abbasiya barrage. The river undertaken is categorized as a large river with aspect ratio greater than 10. Flow depth ranges between 0.25m to 6.5m with flow ranging between (36-86 $m^3/_{sec}$). The width of the river ranges between (85-225 m) .The average flow velocities (0.09-0.17 $m/_{sec}$) and the median sediment size (0.07-0.11 mm) for the bed material composition were observed . Total bed material load ranges between (5.36-16.0 $kg/_{sec}$).

Figure (2): The positions of cross-sections (C.S.) in the region of study, by Google Earth©.

Field Measurements

The data used in this study are collected from section (1) to section (20) through the period from (1-2-2011) to (1-7-2012) . Twenty cross sections all located up stream of barrage were selected at intervals about 250 m extended from Al- Abbasiya barrage downward the water flow direction. The cross sections of river were observed by taking reference point on the left side bank (with respect to the flow direction) from the reference point at each cross section transect sampling involves establishing one or more transect lines across a surface (see figure 2).Cross section area , velocity , discharge , width , depth and other hydraulic properties are determined by passing Acoustic Doppler Current meter Profiles (ADCP) device along transect lines which was operated from an anchored boat see fig (3). After proceeding appropriate calibration for this device , all information about field work which lies to computed discharge, cross section area and other hydraulic properties appear in Son Tek River Surveyor (SRS) . (SRS) Program starts recording all information after interconnecting with ADCP device .Other data in field related to sediment properties are gained by using home - made sampler (Integrating samplers and dredge sampler).

water – sediment mixture over are taken over a period of time by withdrawing Integrating Sampler from the ambient flow of a relative small motion . Also the bed sediment samples are taken by used dredge sampler . The sampling of suspended and bed sediment are taken from columns were chosen at The 1/4, 1/2,3/4 of the width of stream at each transect lines to find representative sample of entire cross section .

A summary of data used in this study is presented in table (1)

Table (1) Primary Data and Parameters

Sec No	Q m3/sec	R m	V m/sec	Sg	d50 mm	A m 2	T m	S	W m /sec
1	38.5	2.33	0.09	2.7	0.1162	432.92	185.6	0.00007	0.00973
2	52.0	2.19	0.11	2.68	0.125	487.32	224.48	0.00007	0.0099
3	48.1	2.44	0.1	2.67	0.121	490.71	198.96	0.00007	0.00981
4	60.3	3.72	0.12	2.68	0.118	516.2	132.83	0.00007	0.0097
5	39.3	2.47	0.08	2.7	0.111	493.92	196.18	0.00007	0.00941
6	85.5	2.522	0.17	2.71	0.11	510.56	199.08	0.00008	0.0096
7	83.9	2.22	0.17	2.7	0.112	506.65	226.58	0.00008	0.0098
8	59.9	2.69	0.15	2.69	0.108	396.03	148.67	0.00008	0.00922
9	54.8	2.83	0.15	2.7	0.114	363.97	124.83	0.00008	0.0098
10	52.8	3.36	0.12	2.72	0.091	434.78	124.96	0.00008	0.0092
11	67.4	2.74	0.16	2.71	0.093	412.26	145.63	0.00008	0.0098
12	69.5	2.046	0.14	2.73	0.092	500.39	241.29	0.0001	0.0091
13	48.8	1.991	0.13	2.69	0.0908	382.91	189.81	0.0001	0.00913
14	54.7	2.52	0.11	2.68	0.091	494.25	192.34	0.0001	0.0092
15	37.1	2.41	0.09	2.68	0.0906	421.12	172.92	0.0001	0.0093
16	60.5	3.02	0.19	2.7	0.0925	314.57	100.72	0.0001	0.0091
17	36.0	2.853	0.13	2.69	0.0903	285.32	99.24	0.00012	0.0089
18	67.1	3.61	0.17	2.72	0.0923	388.24	103.75	0.00007	0.00921
19	47.9	2.88	0.13	2.69	0.0925	357.03	121.76	0.00007	0.00903
20	49.5	2.68	0.15	2.68	0.0908	321.38	119.74	0.00007	0.0089

Sediment Transport Formulas Assessments

The quantity of sediment discharge in alluvial river depends on many variables such as flow velocity , discharge , depth of flow , shear stress , fall velocity , stream power , alignment of river , temperature and properties of sediment particle . It is very difficult to simultaneous incorporate all these variables and to develop one sediment transport formulas . In the following , the eight formula tested are briefly presented .

Bagnold's Formula (1966)

Bagnold (1966) developed a sediment transport formula based on the concept of energy balance . He stated that the available power of the flow supplies the energy for the transport of sediment . **(Simons and Senturk , 1977)** his relation is :

$$\left(\frac{\gamma}{\gamma s-\gamma}\right) \tau_0 \, v \left(\frac{e_b}{\tan \alpha} + 0.01 \frac{v}{w}\right) \qquad \text{...........(1)} \; q_t = q_{bw} + q_{sw} =$$

q_t is expressed as dry weight per unit time and width in $(\frac{kg}{sec.m})$, q_{bw} is the bed load discharge as dry weight per unit time and width in $(\frac{kg}{sec.m})$, q_{sw} is the suspended load discharge as dry weight per unit time and width in $(\frac{kg}{sec.m})$, e_b bed load efficiency factor , α = the coefficient of dynamic solid fraction .

Engelund and Hansen Formula (1967)

Engelund and Hansen applied Bagnold's stream power concept and the similarity principle to obtain a sediment transport function **(Raudkivi, 2010).**

$$q_s = 0.05 \, \rho s \, V^2 \left(\frac{d_{50}}{g(sg-1)}\right)^{1/2} \left[\frac{\tau_0}{(\gamma s-\gamma)\, d_{50}}\right]^{3/2} \qquad \text{................(2)}$$

q_s is sediment discharge per unit width , d_{50} is median size of sediment , τ_0 is bed shear stress , g is gravitational acceleration .The previous formula is dimensionally homogenous and it can be used with any consistent set of units .

Inglis – Lacey Formula (1968)

The Inglis – Lacey formula was first developed by Ingles **(Inglis,1968**). He introduced the mean sediment size , fall velocity and sediment concentration into lacey regime relationship

$$q_s = 0.562 \, \frac{(\nu g)^{1/3}}{w} \, \frac{V^2}{g d_{50}} \, \frac{\rho V^3}{g} \qquad \text{................(3)}$$

q_s is sediment discharge per unit width , w is fall velocity of particle , ν is kinematics viscosity , this formula is dimensionally homogenous .

Yang Formula (1972)

This formula relates the bed material load to the rate of energy dissipation of the flow as an agent for sediment transport. The theory of minimum rate of energy dissipation states that when a dynamic system reaches its equilibrium condition, its rate of energy dissipation is at a minimum. The minimum value depends on the constraints applied to the system. For a uniform flow the energy dissipation due to the sediment transport can be neglected (**Yang , 1972**). Yang equation for sand transport is

$$\mathrm{Log}c = 5.435 - 0.286\,\mathrm{Log}\frac{W\,d_{50}}{\nu} - 0.457\frac{U_*}{W} + \left(1.799 - 0.409\,\mathrm{Log}\frac{Wd_{50}}{\nu} - 0.314\frac{U_*}{W}\right) * \mathrm{Log}\left(\frac{V\,S}{W} - \frac{V_{cr}S}{W}\right)$$

……….(4)

The dimensionless critical velocity at incipient motion can be expressed :.

$$\frac{V_{cr}}{W} = \frac{2.5}{\log\left(\frac{u_* d_{50}}{\nu}\right) - 0.06} + 0.66; \qquad 1.2 < \frac{u_* d_{50}}{\nu} < 70 \qquad \text{……….(5)}$$

$$\frac{V_{cr}}{w} = 2.05; \qquad \frac{u_* d_{50}}{\nu} \geq 70 \qquad \text{……….(6)}$$

Where :C= The total sediment concentration in ppm by weight ,VS=unit stream power ,$V_{cr}S$ = critical unit stream power required at incipient motion ,S = the energy slope , v is mean velocity.

Ackers and White Formula (1973)

Ackers and White (1973) deduced that only a part of the shear stress on the channel bed is effective in causing motion of coarse sediment. In the case of fine sediment, however, suspended load predominates and the total shear stress contribute to sediment motion , **(Ackers and White, 1973)**.On the premise, the sediment mobility is described by the parameter:

$$\frac{C\,D}{Sg\,d_{35}}\left(\frac{u_*}{V}\right)^n = c_1\left(\frac{F_{gr}}{A1} \quad 1\right)^m \qquad \text{………..(٧)}$$

Where

C =concentration by weight , D = water depth .

$$F_{gr} = \frac{u_*^{\,n}}{\sqrt{gd_{50}(sg-1)}} \left(\frac{V}{\sqrt{32}\log(\frac{10D}{d_{35}})}\right)^{1-n} \qquad \text{............(8)}$$

$$n = 1 - 0.56\log d_{gr} \qquad \text{............(9)}$$

$$d_{gr} = \text{dimensionless particle size} = d_{35}\left(\frac{g(sg-1)}{v^2}\right)^{1/3} \qquad \text{.........(10)}$$

$$A1 = \frac{0.23}{\sqrt{d_{gr}}} + 0.14 \qquad \text{.........(11)}$$

$$\log c_1 = 2.86\log d_{gr} - (\log d_{gr})^2 - 3.53 \qquad \text{...........(12)}$$

$$m = \frac{9.66}{\sqrt{d_{gr}}} + 1.34 \qquad \text{............(13)}$$

Yang Formula (1979)

Yang introduced another formula to estimate the quantity of sediment without any criteria for incipient motion(**Yang,1979**) . This formula can be expressed by

$$\log C = 5.165 - 0.1531\log\frac{wd_{50}}{v} - 0.297\log\frac{u_*}{w} + \left(1.78 - 0.36\log\frac{wd_{50}}{v} - 0.48\log\frac{u_*}{w}\right)\log\left(\frac{VS}{W}\right) \qquad \text{.........(14)}$$

C = sediment concentration by weight.

Van Rijn Suspend Load Formula(1984)
As reported in (Van Rijn,1993):

$$q_s = F\,v\,D\,c_a \qquad \text{..........(١٥)}$$

$$F = [(a/D)^{z'} - (a/D)^{1.2}]/[\left(1-\frac{a}{D}\right)^{z'}(1.2 - z')] \qquad \text{.........(١٦)}$$

D = average depth of flow .

$$c_a = \text{reference concentration } (\text{—}) = 0.015\left(\frac{d_{50}}{a}\right)(T^{1.5}/D_*^{\,0.3}) \qquad \text{.......(١٧)}$$

$$a = \text{reference level} = 12\,D\,10^{\left(-\frac{c}{18}\right)} \qquad \text{........(١٨)}$$

$$T = \text{bed shear stress parameter} = \frac{\tau'_b - \tau_{b,cr}}{\tau_{b,cr}} \qquad \text{.........(١٩)}$$

$$D_* = d_{50}\left(\frac{(sg-1)g}{v^2}\right)^{\frac{1}{3}} \qquad \text{........(20)}$$

τ'_b = effective bed shear stress = $\rho\, g\, (\frac{V}{C'})^2$ ....(٢١)

C' = grain – related Chezy coefficient = 18 $\log(\frac{4\,D}{d_{90}})$ ....(٢٢)

C=Chezy coefficient = v $(D\,S)^{-0.5}$ ....(٢٣)

S=energy slope z'=suspension number = $Z + \Psi$ ....(٢٤)

z = suspension number = $W/\beta k u_*$ ....(٢٥)

β =ratio of sediment and fluid mixing coefficient

$= 1 + 2(\frac{W}{u_*})^2$ ....(٢٦)

k=constant of von karman =0.4 , $c_0 = 0.65$

Ψ' =stratification correction $= 2.5(\frac{W_s}{u_*})^{0.8}\ (\frac{c_a}{c_0})^{0.4}$ ....(27)

Van Rijn Bed Load Formula (1984)

Van Rijn, followed Bagnolds (1954) approach ,assumed that the motion of the bed load particles is dominated by particle saltation (jumps) under the influence of hydrodynamic fluid force (**Van Rijn,1993**). His bed load formula is :

$$qb = 0.053\,\Delta^{0.5}\, g^{0.5} d_{50}{}^{1.5} D_*{}^{-0.3}\, T^{2.1} \quad .....T<3 \qquad ....(28)$$

$$qb = 0.1\Delta^{0.5}\, g^{0.5} d_{50}{}^{1.5} D_*{}^{-0.3}\, T^{1.5} \quad ......T>3 \qquad ....(29)$$

qb=volumetric bed load transport (m^2/s),

Δ=relative density =sg-1 (—) ....(30)

D_* =dimension less particle parameter(—)= $[(sg-1)g/v^2]^{1/3}$ ....(31)

ν = kinematic viscosity coefficient (m^2/s)

$T = (\tau'_b - \tau_{b,cr})/\tau_{b,cr}$ ....(32)

τ'_b = effective bed-shear stress = $\rho\, g\, (u/c')^2$ ....(33)

u= depth mean flow velocity

c'= grain – related Chezy coefficient = 18 log(4h/ d_{90}) ....(34)

$\tau_{b,cr}$= critical bed -shear stress according to equations

$\tau_{b,cr} = \theta_{cr}[(\rho s - \rho) g\, d_{50}]$ ....(35)

when θ_{cr} = critical shield parameter

$\theta_{cr} = 0.24\,D_*^{-1}$ for $1 < D_* < 4$ …….(36)

$\theta_{cr} = 0.14\,D_*^{-0.64}$ for $4 \le D_* < 10$ …….(37)

$\theta_{cr} = 0.04\,D_*^{0.1}$ for $10 \le D_* < 20$ ……..(38)

$\theta_{cr} = 0.013\,D_*^{0.29}$ for $20 \le D_* < 150$ ……..(39)

$\theta_{cr} = 0.055$ $D_* \ge 150$ …….(40)

$D_* = = [(sg-1)g/v^2]^{1/3} d_{50}$ = particle parameter …….(41)

Ariffin Formula (2004)

Ariffin had derived her sediment transport equation based on regression **(Saddon ,2008)** . She had carried out field investigation on rivers in Perak and Selangor on Malaysia with flow depth (0.36-2.44 m). Her proposed equation is :

$$C_V = 1.156\times 10^{-5}\left(\frac{R}{d_{50}}\right)^{0.716}\left(\frac{u_*}{w}\right)^{-0.975}\left(\frac{u_*}{V}\right)^{0.507}\left(\frac{V^2}{gD}\right)^{0.524} \quad …….(42)$$

C_V the total sediment concentration , D is mean depth , w is fall velocity ,v is average flow velocity , u_* is shear velocity = $\sqrt{g\,D\,S}$, g is gravity constant , d_{50} is median grain size (50 % by weight of finer material)

Methods of Evaluation and Selection Transport Models

The various existing functions were developed from different sets of field and laboratory data and their predictions may be good in some applications and not in others. As result, different functions may give widely differing results for a given river . A formula that predicts sediment discharge adequately for one river does poorly for the other river due to the different hydraulics and sediment characteristics of rivers in all regions . In this study the adopted sediment transport equations have been tested with the present data to show which to be nearly reliable and considered as a prdictive formula for a river reach at hand. The formulas used in testing were Enguland&Hansen , Inglis &Lacey , Van Rijn, Ackers&White , Yang , Bagnold and Ariffin .These models are chosen because they are well – known and are based on their performance by other investigators . And they represent the two main types of firmulas bed- shear stress and energy concept .The method used for evaluation the formulas is discrapency ratio. This method including Calculating the deviation of predicted sediment discharges from measured values or by means of discrepancy ratio r ,which is the ratio between predicted and measured sediment discharge . In this study , eight sediment discharge models were tested using field data from study – reach , table (2) shows the comparisons between the formulas according to data falling in the specified discrepancy ranges .

Table (2) iscrapency ratio

	Discrepancy ratio		
Formula	**0.75-1.25**	**0.5-1.5**	**0.25-1.75**
Enguland- Hansen	_	_	5%
Inglis -Lacey	5%	20%	25%
Van Rijn	5%	35%	60%
Ackers -White	15%	45%	65%
Yang(1972)	_	_	_
Yang(1979)	_	_	_
Bagnold	_	_	_
Ariffin	_	20%	45%

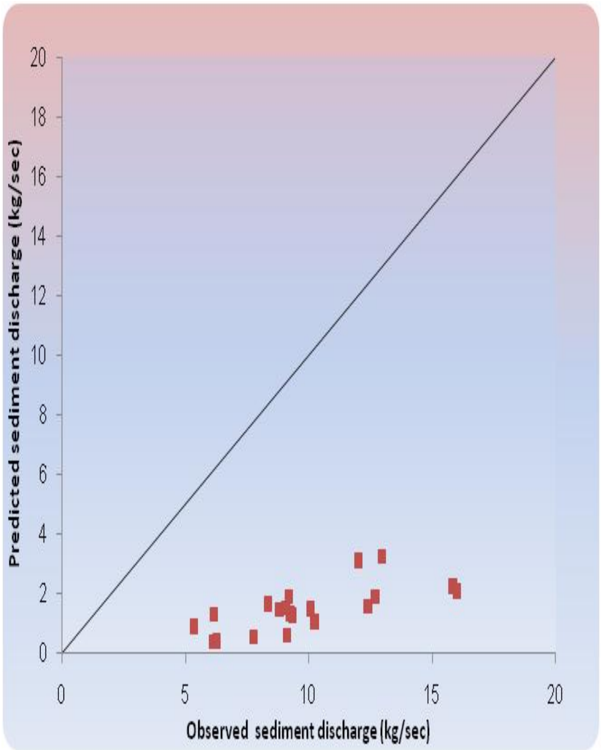
Discussion

Figures (4a-4h) are the plots of the predicted against measured discharge for the formulas evaluated . As can be seen from Table (2) , the maximum frequency of 65% was attained for the range $0.25<r<1.75$ for the formula of Ackers-White , followed by Van Rijn 60% and Ariffin 45%.

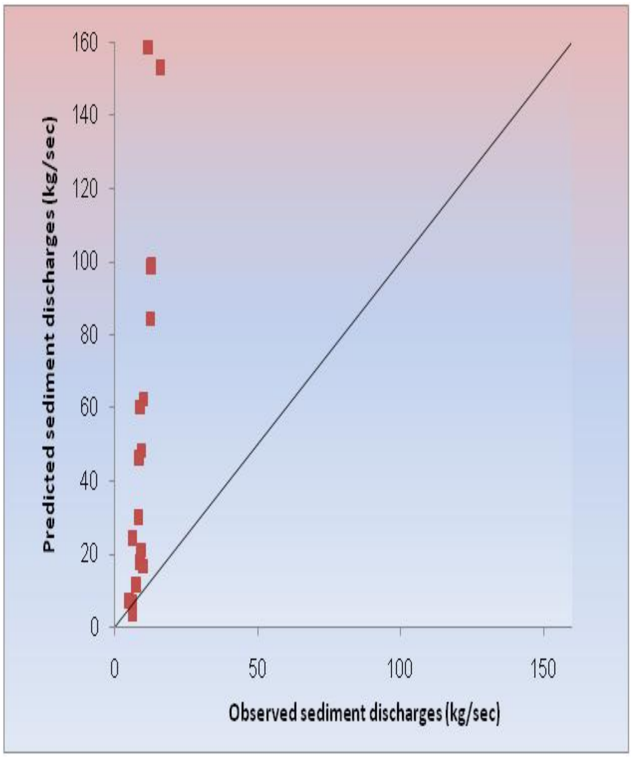
Overall , no accurate method exists to predicted the measured values . None of the formula selected with discrepancy ratio , r value close to unity , therefore the evaluation of this formula are very necessary before using in a specified field project .

Further observation of Figure (4-a) shows that (Engelund-Hansen) formula predicted total sediment discharge less than the measured values and the divergence in result is increasing with increasing water discharge .

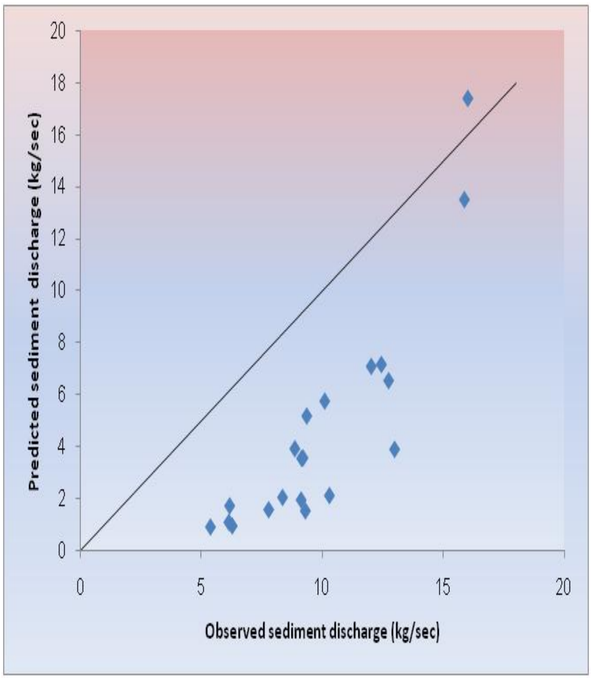
Inglis-Lacey formula predicted total sediment discharge of study reach more than the measured values as shown in figure (4-b) when the maximum frequency of 25% was attained for the range $0.25<r<1.75$.



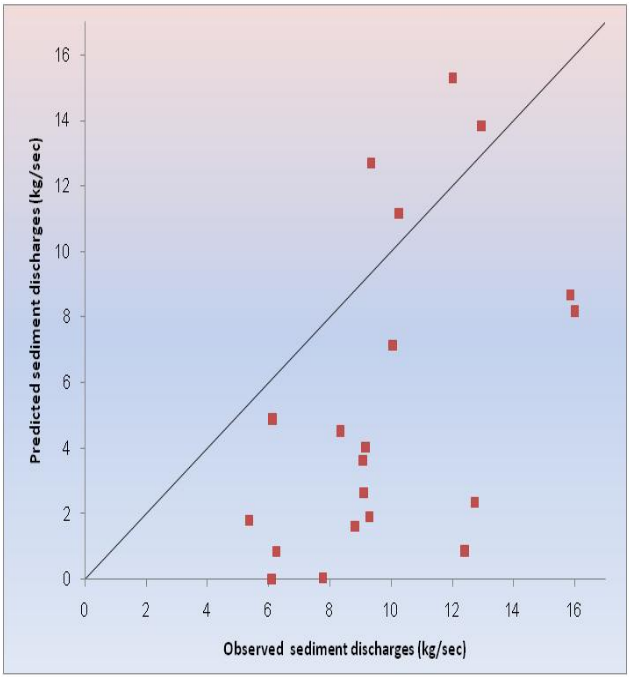
Fig(4-a)



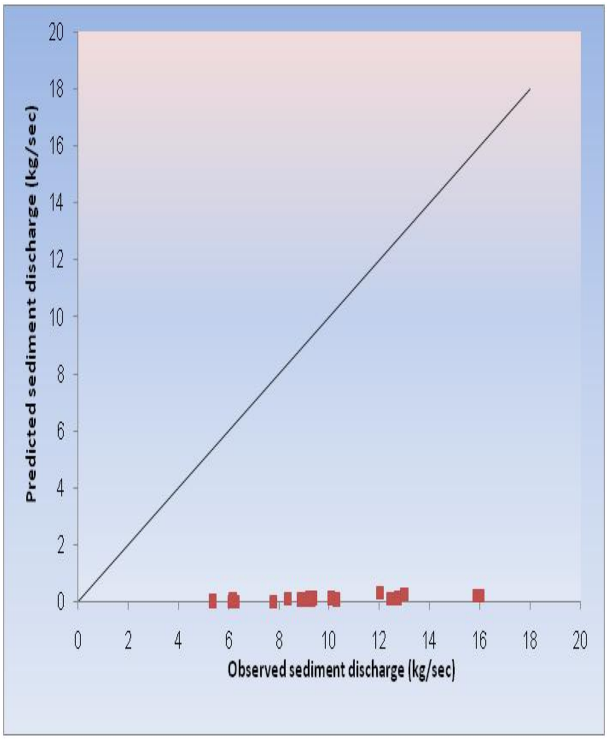
Fig(4-b)



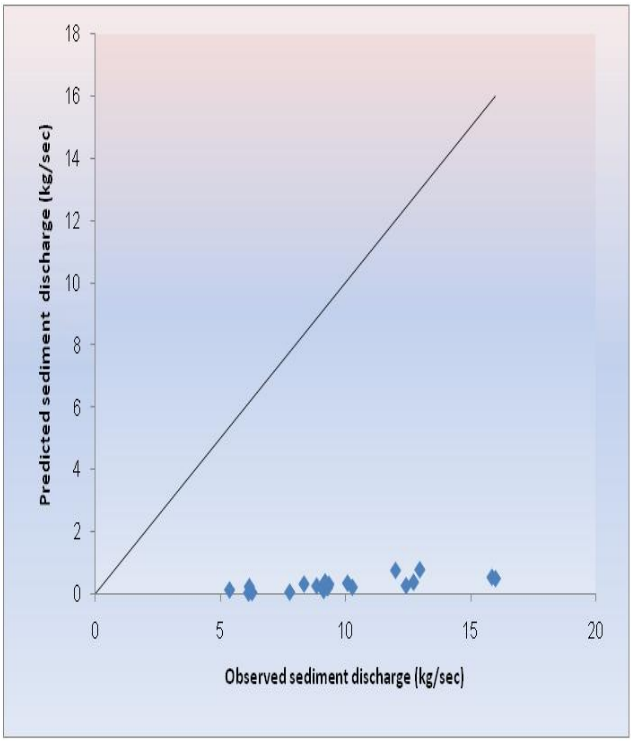
Fig(4-c)



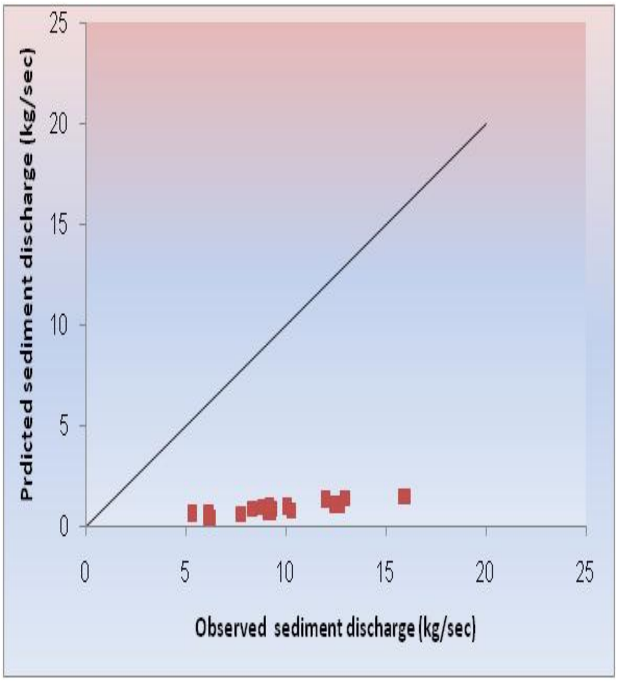
Fig(4-d)



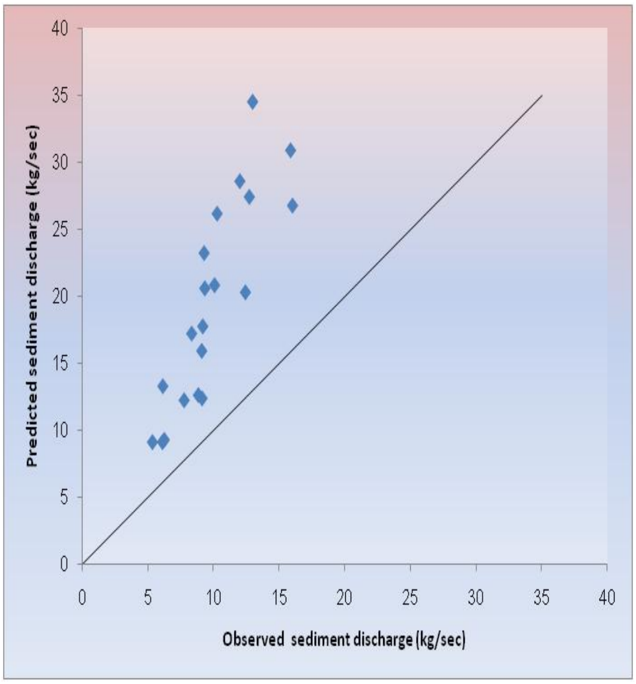
Fig(4-e)



Fig(4-f)



Fig(4-g)



Fig(4-h)

Comparison between computed and measured sediment load : (4-a)Engelund – Hansen , (4-b)Inglis – Lacey, (4-c) Van Rijn , (4-d)Ackers White, (4-e)Yang 1972, (4-f)Yang 1978, (4-g) Bagnold, (4-h)Ariffin

The results from Van Rijn formula (fig 2-c) shows that predicted total sediment discharge is less than measured values except one section , the depicted points fall below the perfect line agreement . Ackers and White gives under predicted the measured values and over predicted in some section . As can be seen in fig (2-d) , the maximum frequency of 45% was attained for the range $0.5<r<2$. From the fig (4e,4f) , it can be noted that the Yang formulas are under predicting the values of sediment discharge and all values are quite far on the perfect line agreement . Also Bagnold formula give the result like Yang formula .

The last formula tested against the measured values is Arifin Formula . This formula predicted total sediment discharge more than the measured values . About 45% of the calculated values agree in the range (0.25-1.75) limit with observed values .

Summary and Conclusion

Out of eight formulas evaluated only few of then were found with reasonable agreement with the field data . Based on the analysis of this results , the following conclusion are given :

1- Eight sediment transport formulas used in this research do not estimate total sediment discharge well unless adjustment were done to improve their performance .

2- From eight formula assessments , the best estimates of study reach sediment discharge were produced by Ackers-White and Van Rijn methods as less erroneous predictions were obtained .In Ackers-White method less scattered points depicted $r=1$ when 65% of data fall in range $0.5<r<1.5$ .Conversely Yang and Bagnold give very poor performance in predicting correct value of sediment discharge.

3- Other formulas either under estimate sediment discharges such as (Enguland-Hansen) or overestimate sediment discharge such as (Inglis – Lacey,Ariffin) formula.

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