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Survey of Integrated and Non-Integrated Formulae on Suspended Sediment Load; Case Study: Soolegan River, North Karoon Basin, Iran

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ABSTRACT

Predictions of suspended sediment load for Soolegan River, Iran using selected empirical equations were made based on 355 data sets. Data include flow discharges from 3.11 m3/s to 43.81 m3/s, flow velocities from 0.22 m/s to 1.03 m/s, and flow depths from 0.5 to 1.03 m. Equations of Einstein (1950), Bagnold (1966), Toufalleti (1968), Brooks (1963), Chang-Simons-Richardson(1965),Lane-Kalinske (1941) are used in the evaluations. Selection was made based on the purpose of this paper, illustrating the performance of six suspended sediment formulas in Soolegan River; the integrated formulae were also evaluated. Graphical comparisons of the calculated and measured transport rates are shown. The accuracy and reliability of these formulas are verified. Results of the evaluations showed that Brooks had the best estimations while the same results for integrated formulae showed that Lane –kalinske and Bagnold estimated the suspended sediment discharges better than integrated and non-integrated ones.

Keywords

Evaluation; Soolegan River; Integration; suspended sediment formulae

1. Introduction

Sediments can cause lots of problems including: sediment blockage of roads and culverts, sedimentation of small reservoirs and recreational lakes, sedimentation on large alluvial fans, river channel damage caused by low sediment supply, and lack of effective government control over soil erosion and sedimentation in the past (Outhet and Morse 2009). Fine-grained sediment is a natural and essential component of river systems and plays a major role in hydrological, geomorphological and ecological functioning of the rivers (Owns et al. 2005). Fluvial processes of erosion, sediment transport and deposition determine the changing form and sedimentary structure of naturally adjusting riparian zones (Steiger et al. 2003). Improving knowledge on suspended sediment yields, dynamics and water quality is one of today's major environmental challenges addressed to scientists and hydropower managers (Owens et al. 2005). These advances will continue in the future as the acquisition of reliable and long-term suspended sediment concentration (SCC) time series are generalized to many hydrometric stations. Rinaldi et al. (2009) described and illustrated a methodology that defines a scientifically-based strategy for promoting future sustainable

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management of sediment and channel processes within a catchment. The methodology is based on a diagnosis which incorporates retrospective analyses of channel geometry, causes of changes and hydraulic sediment budgets to evaluate potential sediment transport. Kim and Lee (2012) studied the effects of the parameters in relation to hydraulic characteristics included in the flow and sediment transport. In mountainous catch-ments, major fractions of the annual suspended sediment yields (SSY) are transported over a very short time period generally corresponding to several floods (e.g. Meybeck et al. 2003; Mano et al. 2009).

Therefore, high-frequency SSC monitoring is required for reliable SSC and SSY estimates. Nevertheless, a reliable and easy method to obtain a direct, continuous SSC measurement is not currently available. Although a great progress is expected with, for instance, the backscatter acoustic method (Wren et al. 2000; Gray and Gartner 2009). Their application is still limited to large rivers and canals. Work on quantification of fine-grained sediment movement based on the time-dependent, advection-dispersion equation was presented by Scarlatos and Li (1992). Erosion and sediment transportation determination are the important matters in watershed management. Management of watershed can be easier if the amounts of sediment discharges in rivers are measured very accurately (Rieger and Olive 1986).

Also, during 1980's sediment transport theory had been increasingly applied to the design of sewers, particularly in major interceptor sewer schemes. But, in the absence of any universally recognized guidance, the design methodologies and criteria adopted were developed on a project-by-project basis, building on the increasing experience and understanding of the subject of the designer (Butler et al. 2003). Roth and Capel (2012) showed that by changing the method of managing a watershed, sediment yield would be changed. Rivers can be affected by multiple natural and human-induced changes to sediment supply and to sediment transport capacity. Assessment of the relative importance of these changes enables appropriate river management (Young et al. 2001). On the other hand, suspended sediment estimation is the most important problem, because there are so many groups that need this kind of data (Hicks and et al. 2000). Development of hydraulic sediment occurs in response to needs of the active programs of water resources projects.

Most of the information concerning the feedback effect of sediment transport on flow characteristics relates to the case of suspended sediment (Omid et al. 2010). A number of sediment transport models and formulas can be found in the literature that is used to study sediment transport in alluvial channels. Most of the transport models are based on simplified assumptions that are valid in ideal laboratory conditions only and may not be true for much complicated natural river systems. Models based on more sophisticated theoretical solutions require a large number of parameters that are impossible or difficult to gather for a natural river system (Choudhury and SundarSil 2010).

A large percentage of the annual sediment yield from a watershed is transported by a stream during a small number of floods that occur in a relatively short period of time in a year. This fact can be considered as a reason why simplified equations are inaccurate (Demissie 2009). Xia et al. (2010) compared four different methods of determining bank full discharge in the lower Yellow River and found that a method using a stage–discharge relation from one-dimensional hydrodynamic model is of higher prediction accuracy than the other three methods. Eder et al. (2010), compared five different methods and integrated models of calculating SSC in a classic non-linear optimization setting, which allows gauging their relative merits, and showed that for the calculation of the total suspended sediment, application of a single event rating approach was already sufficient to obtain reliable event loads with respect to the observed benchmark turbidity data.

Tena et al. (2011) found that calculations of sediment load are based on continuous discharge and turbidity records, the latest calibrated with direct suspended sediment sampling that covered the whole range of observed hydraulic conditions. Gao, (2011) found that in practice, the empirical equation can be used to estimate the maximum possible bed-load transport rates during high flow events, which is useful for various sediment-related river managements. Kisi (2010) compared three methods of neural network to each other, a comparison of the results indicated that the NDE models give better estimates for suspended sediment in river than NF, NN and RC techniques. In this paper, predictions of suspended sediment in Soolegan River were made and analyzed using the selected equations; these equations were also integrated by applying SPSS-17 software

2. Material

2.1. Study area

Application of six suspended sediment estimation formulae is tested in Soolegan River, Iran. Sediment discharge and concentration and also water discharge series obtained from the stations are used to develop and verify model performance. Soolegan Station is located in Soolegan River at 14' 51° latitude 31° 38' longitude. Drainage area of this river is about 1992 km^2 and the station that these data are used from, is located in 2086 meters above sea level. This river is located in North karoon basin. The basin is a part of Zagros mountainous lands and is covered by limy and marly soils. The mean rainfall of the basin is about 500 mm, which is considerable in comparison to other areas in Iran. This basin also is covered with semi-dense forests. The main source of this river is Vanak River and its length is recorded to about 164 km and the drainage area of this river includes 22 percent of North Karoon basin.

2.2 Data sources

All data used in this study lie within the range of data used in the development of the selected equations. This is illustrated in table 1. Data were collected during about 30 years. Abnormal distribution of data have such effects that may lead to high fluctuations in fig. 1 and reduces the reliability of analytical results, thus normalization of data is necessary. First, imperfect data were eliminated and then omitted data were estimated by using interpolation. Data adopted in this study were obtained from Khoozestan regional water organization, gathering information in the field and also analyzing the results in laboratory.

Data used in this study are collected from one of the smallest rivers in Iran. The river data include the data from Soolegan and this river is categorized as a small river with aspect ratio smaller than 5. Data includes flow discharges from 3.11 m^3/s to 43.81 m^3/s, velocities from 0.22 m/s to 1.03 m/s, and flow depths from 0.5 to 1.03 m. Data from 1986 to 2007 were used for validation and calibration of the methods.

3. Methodology

3.1. Formulae

The six suspended sediment formulae estimate the suspended sediment discharge based on river morphology, suspended sediment and water discharges data measured in the river. These six formulae include Einstein, Bagnold, Tofalleti, Brooks, Chang-Simons-Richardson, Lane and Kalinske (Bajestani 2005). Among these methods, just Einstein's formula has two coefficients and the rest five equations do not have any. Thus these formulae would be divided into two classes: 1-formule with coefficients (a non dimensional parameter which is put in a formula to calibrate it for special region or time), 2-formulae that do not have any coefficients. The second kind of formula can be divided into two classes: 1-formulae that show nonlinear relationship between discharge and input parameters, 2-formulae that have linear relationship between estimated discharges and input parameters.

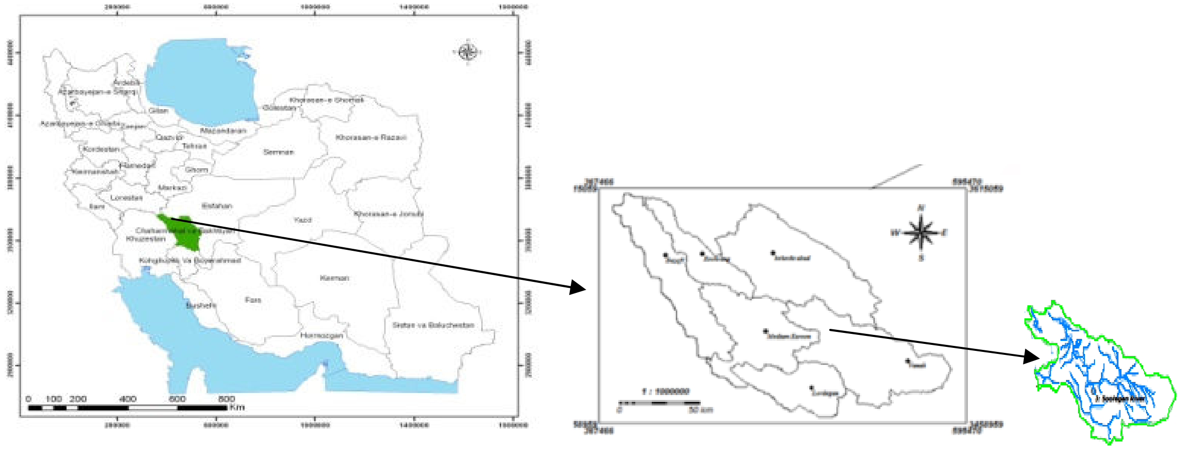


Fig.1.Soolegan River

Table 1. Range of data used in development of the equations

Data source	Laboratory-field-formula
Minimum suspended sediment discharge(ton/d)	0.2
Maximum suspended sediment discharge(ton/d)	120.219
Minimum water discharge(m^3/s)	3.11
Maximum water discharge(m^3/s)	43.81
Mean of suspended sediment discharge(ton/d)	18.90
Mean water discharge(m^3/s)	23.46
Mean velocity of water(m/s)	0.625
Flow depth(m)	Up to 1.03

Model performance was tested using (D_v), "Correlation Coefficient" (CC) and Nash–Sutcliffe model ‘‘Efficiency Coefficient” (EC). D_v represents well the predicted values match to the observed series and correlation coefficient describes how simulated and observed data set move. Nash–Sutcliffe model ‘‘Efficiency Coefficient” (EC) is an important statistic describing model fitness. A value of EC= 1 indicates perfect model fit, while EC= 0 represents that the model is as good as the mean model (Choudhury and SundarSil 2010). Nash–Sutcliffe (Ns) coefficient is estimated as:

$$Ns = 1 - \frac{\sum_i (Q_m - Q_s)_i^2}{\sum_i (Q_{m,i} - \bar{Q}_m)^2} \qquad (1)$$

In which Qm_i is the observed data, Qsi is the estimated data and $\bar{Q}m$ is the mean of the observed data. There is another formula that estimates (D_v), the difference percentage coefficient as:

$$D_v = \frac{V - V'}{V} \times 100 \qquad (2)$$

In which V' is the estimated data and V is the observed data.

3.2. Formulae Calibration

There are two conditions in models calibration; if the formulae are considered in the first class of the first division, the calibration would be done rewriting the method in "C" programming language. But if the formulae are supposed to put in the second class of the first division, the situation would be different because here the formulae are classified into two parts. The formulae that have linear relationship can be calibrated by using SPSS 17, but another group cannot be calibrated as the same because SPSS 17 cannot analyze the nonlinearity relationships between parameters. So the nonlinearity formulae in this article were not calibrated.

4. Results

4.1. Evaluation

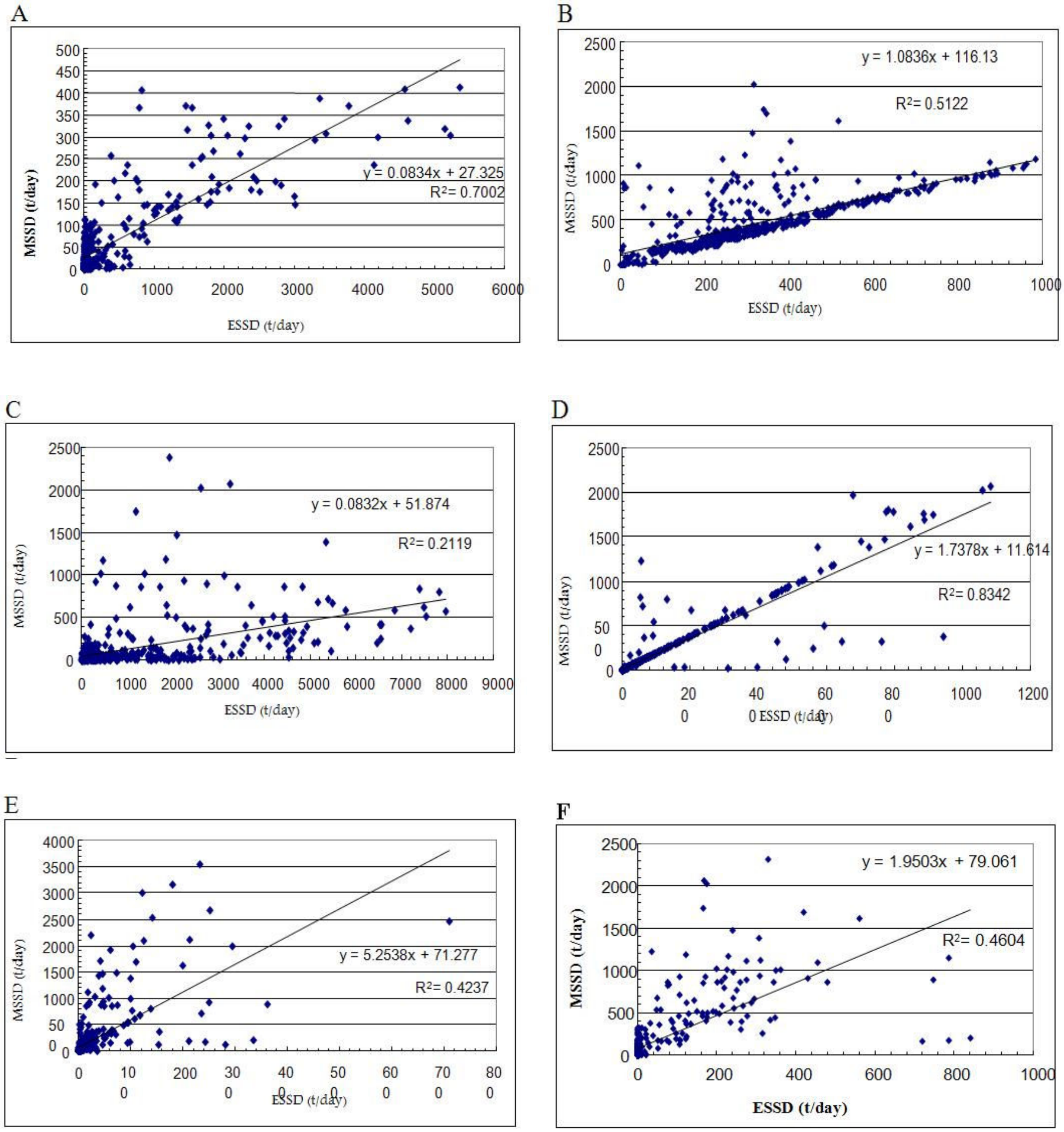
Evaluation of suspended sediment load estimation shows that all the formulae except one vary in the same direction. The evaluation of these six formulae is shown in table 2. Among all the equations, Brooks has the best estimation for suspended sediment load.

All the figs. 2 evaluate the performance of the formulae considering each estimated suspended sediment discharge by the equations in function of observed suspended sediment discharge. It can be recognized that Chang-Simons-Richardson (1965) in contrast with other equations estimates the suspended sediment load discharge more accurately but not as well as Brooks Eq., also it is obvious that Lane-Kalinske and Bagnold formulae estimate the suspended sediment discharge with the same accuracy. Einstein can be considered as the same accuracy but not exactly. In addition it must be noted that Tofalleti is the formula that cannot be introduced for any estimation through the suspended sediment load discharges in rivers at all. The forth fig. shows that Brooks estimated the suspended sediment discharge with the highest accuracy and also it can be said that this formula in comparison with others has the least error in calculation. On the other hand it must be told that this formula is more adaptable with the situation in the river. In these graphs the coefficient that shows the evaluation of the formulae is determination coefficient. Brooks has the most determination coefficient among other formulae.

4.2. Calibration methods application

To apply the suspended sediment, flow discharge and suspended sediment concentration in Soolegan River, the three formulae were calibrated using SPSS 17. SPSS is a software which has the ability to extract an equation among two ranges of data, using regression method and the formula in SPSS, the best suggested equations for each of the formulae were obtained. One of these three formulae is Einstein, which is calibrated by rewriting in "C" programming language. In this way each input parameter was used to find Einstein equation coefficient. Performance of these three formulae is evaluated in table 3.

Figs. 3, 4 and 5 show if the integration of the formulae is effective in improving their performance or not. As it is shown, the accuracy of all of the formula is raised after integration. Determination coefficient is again used to show the evaluation of the formula. In all three formulae the accuracy is increased. But this increase was the most in Lane -Kalinske in comparison to other two formulae. On the other hand, integration has not influenced a lot on the accuracy of Einstein formula.



MSSL: Measured Suspended Sediment Load; ESSL: Estimated Suspended Sediment Load

Fig. 2. Observed and estimated suspended sediment load values by; a) Chang-Simons-Richardson, b) Einstein, c) Toufalleti, d) Brooks, e) Lane-Kalinske, and f) Bagnold in Soolegan

Table2: Methods performance in Soolegan River

formulae	R^2	NS	D_v
Einstein	0.51	0.49	-0.28
Lane-Kalinske	0.42	0.39	-1.033
Bagnold	0.46	0.75	0.2
Brooks	0.83	0.65	0.14
Toufalleti	0.21	0.68	-4.03
Chang-Simons-Richardson	0.70	0.71	-1.67

Table 3. performance of three integrated formulae

Formulae	R^2	CE	D_v
Lane-Kalinske	0.75	0.79	-3.46
Bagnold	0.70	0.81	0.08
Einstein	0.60	0.55	-0.56

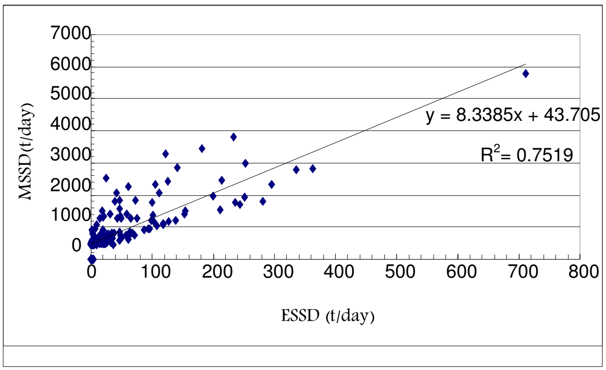


Fig. 3. Observed and estimated suspended sediment load by integrated Lane-Kalinske values in Soolegan

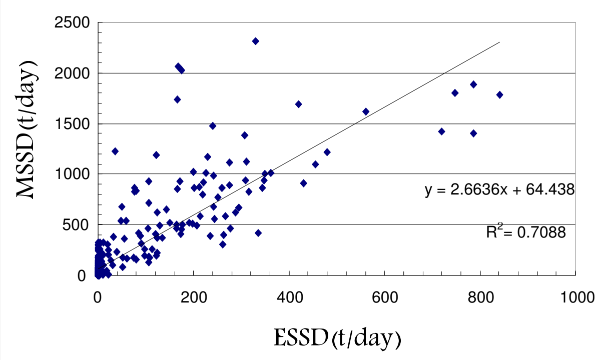


Fig. 4. Observed and estimated suspended sediment load by integrated Bagnold values in Soolegan

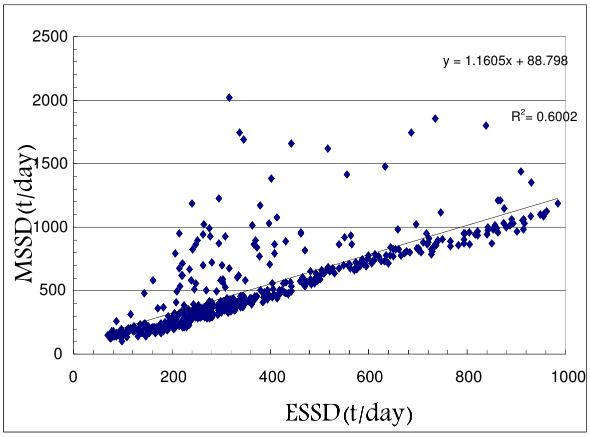


Fig. 5. Observed and estimated suspended sediment load by integrated Einstein values in Soolegan

5. Conclusion

A study on the suspended sediment load on a river with aspect ratio smaller than 5 was conducted. From the evaluations of the selected transport equations, the three equations namely, Brooks, Chang-Simons-Richardson, and Einstein showed good performance when tested against field data in comparison to other formulae. On the other hand, another three formulae's performance was poor. Result of this paper are consistent with what was found by Ghomshi and Torabipoodeh 2003; Hassanzadeh 2007; Martin 2003 and also the great change in accuracy of Bagnold by integration is consistent with the results of Zhao et al. 1999. Although the results are consistent with these findings but are not consistent with the results of Girma and Horlacher 2004. They have shown that Bagnold formula can estimate the suspended sediment load with a high accuracy. Three of the formulae were calibrated among all six formulae: Einstein, Lane-Kalinske and Bagnold.

Performance Evaluation of these integrated formulae showed that integrated Lane-Kalinske and Bagnold had better estimated suspended sediment load but Einstein performance did not change anymore. All three equations that gave the best results are still not significant enough to be used on rivers in other countries, despite the good data source used in development of the equation. Further analysis is necessary in the future. Although some of these formulae perform good and some of them not, but it cannot be said that these formulas perform the same for all rivers. So, more research on the performance of these formulae is suggested in other rivers. By determination of the best suspended sediment transport formula for a special river, there is no need for field measurement of the suspended sediment load. In addition, by selecting best formula for the river for future projects such as dam construction and other great and expensive projects, suspended sediment and total load values in the river will be estimated and predicted easily, without spending so much money for going to the field and measuring these values. Of course, in this way by knowing river changing trend and using the selected formula, the best location and capacity for the watershed and river management would be predicted.

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