

Adjustment of Bagnold's Suspended Sediment Formula

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Abstract: This paper examines the problem of calibrating a suspended sediment equation, Bagnold, which consists of measured, calculated parameters (about 31 years' data) in Soolegan River. The analyses are directed toward the question of how systematically to change the values of the coefficients and form of the formula by comparing equation results with field data. By calibrating this formula for this river, it was found that the ratio of R^2 increased and improved to an acceptable amount in comparison with the former one (0.46 to 0.70). Proper calibration of this equation requires an accurate representation of the suspended sediment discharge in water body and selecting appropriate equation coefficients.

Key words: Suspended sediment equation • Bagnold • Calibration • Soolegan River

INTRODUCTION

Improving knowledge on suspended sediment yields, dynamics and water quality is one of today's major environmental challenges addressed to scientists and hydropower managers [1]. 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. In mountainous catchments, major fractions of the annual suspended sediment yields (SSY) are transported over a very short time period generally corresponding to several floods [2, 3]. 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 [4, 5]. 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 [6]. 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 [7]. On the other hand suspended sediment estimation is the most important problem; because there are so many groups that need this kind of data [8]. The 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 [9]. 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 [10]. Xia *et al.* [11] 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.* [12] compared

five different methods and also 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 of 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.* [13] 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 [14] 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 [15] compared three methods of neural network with each other, a comparison of results indicated that the NDE models give better estimates for suspended sediment in river than NF, NN and RC techniques. In this paper, calibration of suspended sediment discharge for Soolegan River is presented. Bagnold suspended sediment discharge equation, the formula that was selected for this purpose, is one of the equations that include four input parameters and is so simple.

MATERIALS AND METHODS

Study Area: Application of Bagnold formulae is tested in Soolegan River in Iran. Sediment discharge and sediment concentration and also water discharges series for the stations are used to develop and verify models performances. Soolegan Station is located in Soolegan River at 14° 51' latitude 38° 31' longitude. The drainage area of this river is about 1992 km² and the station that these data are used from, is located in 2086 meters higher than sea level. This river is located in North Karoon basin. The basin is one part of Zagros mountainous lands and is covered by limy and marly soils. The mean rainfall depth of the basin is about 500 mm, which in contrast with other areas in Iran is considerable. This basin also is filled with semi-dense forests. The main source for 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 (Figure 1).

Data Sources: The range of 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.

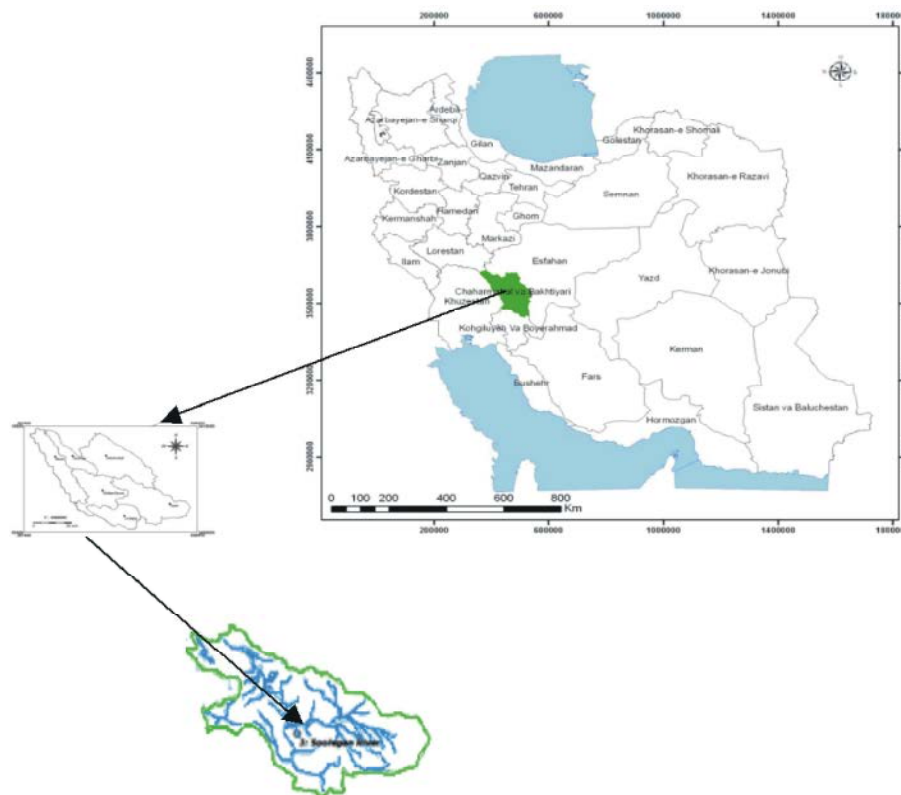


Fig. 1: Soolegan River

Table 1: Bagnold suspended sediment discharge estimation equation parameters

Measured Input parameters	Calculated Input parameters	Laboratory input parameters	Taken input parameters
Water Depth	n	D65	Suspended sediment concentration
Water discharge	Water velocity	D90	Suspended sediment discharge
Area	-	D50	-
width	-	-	-

The numbers of the years that data was collected from is about 30 years. Abnormal distribution of data have such effects that may lead to high fluctuations in figures and reduces the reliability of analytical results, thus normalization of data is necessary. At first imperfect data were eliminated and then the absent data were estimated by using interpolation method (Table 1). Data used in this study are collected from one of the smallest rivers in Iran. The river data include the data from Soolegan. The river under study is categorized as a small river with aspect ratio smaller than 5. Data covers flow discharges from 3.11 m³/s to 43.81 m³/s, flow velocities from 0.22 m/s to 1.03 m/s, flow depths from 0.5 to 1.03 m. Data from 1986 to 2007 were collected for validation and also calibration of the methods.

Methodology

Suspension: The finer particles of the sediment load of streams move predominantly as suspended load. Suspension as a mode of transport is opposite to what Chang-Simons-Richardson called “surface creep” and to what he defines as the heavy concentration of motion immediately at the bed. In popular parlance this has been called bed load, although as defined in this publication bed load includes only those grain sizes of the surface creep which occur in significant amounts in the bed.

Equation: Bagnold [16] derived a stream-based sediment transport model. In that model, Bagnold assumes the sediment is transported in two modes, i.e., the bed load transport and the suspended transport. The bed load sediment is transported by the flow via grain to grain interactions; the suspended sediment transport is supported by fluid flow through turbulent diffusion. The suspended sediment rate can be calculated using the below formula [16].

$$g(S_g - 1)q_{sm} = 0.01 \tau (\bar{u}^2 / \omega_s) \quad (1)$$

where ω_s is the fall velocity of sediment, S_g is assumed as the ratio of water density by sediment density. \bar{u} Is the mean velocity τ is the shear stress and at last q_{sm} is the sediment discharge.

Table 2: Methods performance in Soolegan River

Formulae	R ²	NS	D _v
Bagnold	46/0	75/0	2/0

Equation Evaluation: Model performances (Table 2) were tested using (D_v), “coefficient of correlation” (CORR) and Nash-Sutcliffe model “efficiency coefficient” (CE). D_v represents well the predicted values match with the observed series and coefficient of correlation describes how simulated and observed data set move. Nash-Sutcliffe model “efficiency coefficient” (CE) is an important statistic describing model fitness. A value of CE = 1 indicates perfect model fit while, CE = 0 represents that the model is as good as the mean model [10]. Nash-Sutcliffe coefficient is estimated using below formula.

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

In which $Q_{m,i}$ is the observed data, Q_s is the estimated data and \bar{Q}_m is the mean of the observed data. Also there is another formula that estimates (D_v), the difference percent coefficient. The formula is;

$$D_v = \frac{V - V'}{V} \times 100 \quad (3)$$

In which V' is the estimated data and V is the observed data. There is another coefficient that is used for showing the performance of this formula against real values which is called R^2 .

Equation Calibration: The suspended sediment equation used in this analysis is Bagnold, the suspended sediment equation, described by Bagnold [16]. This formula has 4 input parameters. A list of the important parameters in the suspended sediment is given in Table 1. The parameters are W (the width of the river), D (the depth of the river), q (the water discharge), C (the suspended sediment concentration), A (the area of horizontal cross of the river). These parameters and their coefficients, revealing the interdependence between the parameters and the suspended sediment discharge estimation processes.

Table 3: Results of calibration of Bagnold suspended sediment equation

Bagnold formula in Soolegan River	Suggested Formula for Bagnold in Soolegan River
$-172/759 + 7/48D + 0/015V + 159/467RH = Q$	$\frac{(-759/226 + 12482/902D + 645/887(RH \times V)^{2/9})}{1000} = Q$

Each parameter can be found in different constituent equations. Changing one coefficient to improve the calibration of one constituent will affect the estimation of suspended sediment discharge. Based on the important effect of adjusting coefficients, the efficient calibration (Table 3) of a suspended sediment equation should begin with the parameter that affects the fewest constituents. In calibrating the coefficients in suspended sediment equation of Bagnold, Spss-17 was used to estimate the coefficients that are existed in formula. For calibrating Bagnold equation, using this software, it was desirable to change the existed coefficients in formula to reach the point that the amount of C/O ratio increase to an acceptable value. Therefore, to calibrate a particular constituent, the most efficient method is to look and select the parameters that affect the fewest other constituent equations. The sensitivity of the model results to four input parameters is not addressed here. As many of the equations that use laboratory measured parameters or direct field, measurements should be done either in the laboratory or as separate field measurements. For example, the four input parameters that are used in this equation are measured in the field, beside these measured data there are some parameters are calculated by another equation that is not mentioned here. Also, before adjusting suspended sediment equation coefficients, the effects of different equation processes should be tested, such as calculating some existed coefficients.

CONCLUSION

Performing a series of calibration runs with varying parameters and then making comparisons to field data can be a futile exercise, which the discharges of suspended sediment can change when a single coefficient is adjusted. In order to find the correct coefficient values in haphazard fashion, an inordinate number of calibration runs with varying coefficients values for a number of different inputs must be made. By calibrating, it was found that Bagnold formula perform better if the existed coefficients are changed, in this paper Bagnold formula was adjusted for Soolegan River. Also it was illustrated that the amount of R^2 ratio increased (0.46 to 0.70), Figures 2-3. Using the calibration method outlined here, the calibration process can be made more systematic and efficient.

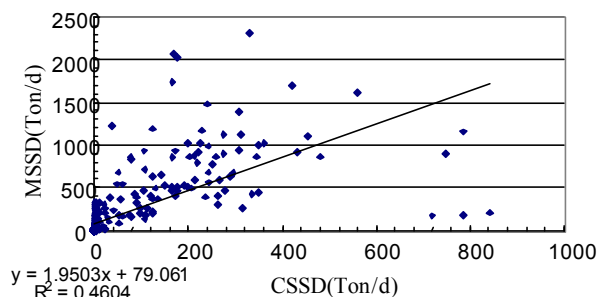


Fig. 2: Performance of Bagnold formula

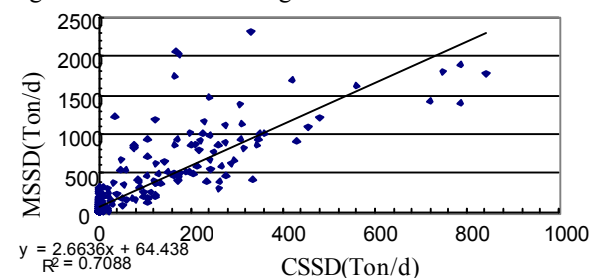


Fig. 3: Performance of Improved Bagnold

ACKNOWLEDGEMENTS

I would like to thank several individuals who provided valuable assistance at various stages of this project. Regional water organization staffs provided valuable information and advice regarding field data for the Soolegan River.

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