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# Determination of optimized sediment rating equation and its relationship with physical characteristics of watershed in semi-arid regions: A case study of Pol-Doab watershed, Iran

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**Abstract**

Managers always consider the precise estimation of sediments in watersheds due to various conditions, such as soil and water resources management, construction, infrastructure and economical and social issues. In this condition, an optimized determination of sediment rating equation (typical method until now for sediment yield estimation) is essential to investigate sediment yield in rivers. In this study, the best sediment rating equation was determined for four hydrometric stations of Pol-Doab watershed in Markazi province using sediment rating curves types (single-linear, multi-linear, mean loads) together with bias correction factors (FAO, Quasi-Maximum Likelihood Estimator [QMLE], Smearing, Minimum Variance Unbiased Estimator [MVUE] and β). The results showed that the optimized equation in stations is the mean loads (MVUE), which can used for prediction of sediment yield in annual scale. Moreover, FAO factor is more accurate for the estimation of sediment yield in high variability conditions for monthly, weekly and daily scales. According to the obtained results, accurate representation of variability intensity of sediment yield is associated with the rating curves types, since the monthly rating curve is more accurate. Also, the results indicated that the watershed average slope has direct relation with *b* coefficient of rating equation, and when using this parameter, the rate of sediment yield can be determined for month, season and hydrological periods. Based on the obtained results, with increase in the watershed average slope, the slope of suspended sediment concentration (SSC) equation is also increased.

***Keywords:*** Bias correction factors; Physical characteristics of watershed; Pol-Doab watershed; Sediment rating curve

## 1. Introduction

Given that in the past, the importance of water and its quality and quantity problems existed, maintenance and protection of the present water resources is an undeniable necessity (Soler *et al*., 2007). On the other hand, recognition of high importance of land resources is an important case that should be treated by propagating and developing an optimized land use. The consequence of this interactive recognition of soil and water resources can improve the welfare of people and make economical independence for countries (Pandey *et al*., 2009; Ahmadi *et al*., 2011).

Researches of sediment yield in watersheds are important strategy in water conservation and land management programs. In researches related to sediment yield in watersheds, suspended sediment concentration (SSC) is often investigated as the rivers transporting the sediments to downstream like a carrier tape (Hu *et al*., 2011). Increase in the sediment concentrations (in addition to impact on water quality), causes sedimentation in reservoirs and channels, and makes other environmental problems (Walling, 1977; Horowitz, 2003; Warrick and Rubin, 2007; Memarian Khalilabad, 2009). Various researches have shown that the maximum sediment load is observed during floods, and relationship

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between SSC and runoff during floods varied since many details of sediment load transfer mechanisms, including the effect of temporal characteristics of storms on relation between SSC and water discharge cannot carefully be discovered and identified (Sadeghi *et al*., 2008b). Continuous monitoring and review of SSC and discharge, in addition to the present improved equation, show the effective processes on runoff and sediment production in the watershed, which with respect to them, the management solutions can be presented to decrease the input sediment to dams reservoir (Soler *et al*., 2007).

Suspended sediment load of rivers depends on the environment of sediment resource and its conditions (Syvitski *et al*., 2000). The estimation of this suspended sediment was carried out using techniques and models of erosion and sedimentation, by different watershed characteristics, such as drainage area, topography, land use and geology, because sedimentation is more related to watershed characteristics than precipitation characteristics (Sadeghi *et al*., 2008b). Preston *et al*. (1989) presented a classification of the methods of SSC estimation in rivers based on the direct measurement and statistical analysis (that is, more considered in hydrology science). This classification includes three methods, such as, regression estimators, average estimators and ratio estimators. Sediment rating curves are considered in regression estimator class which is the subject of this research, as this method is now a typical method for sediment yield estimation in rivers.

Sediment rating curves (SRC) is based on the relationship between discharge and SSC using an exponential function model that can be as follows (Syvitski *et al*., 2000; Iadanza and Napolitano, 2006; Hu *et al*., 2011; Zhang *et al*., 2012):

$$Q_S = aQ_W{}^b \quad (1)$$

where $Qs$ is the sediment concentration (mg/L or ton/day), $Qw$ is the discharge (m$^3$/s) and $a$ and $b$ are the equation coefficients. In logarithmic sheet, $a$ is the vertical distance of rating curve intersection with $X$ axis till coordinate center, and $b$ is the gradient of optimized line. After obtaining the rating curve coefficients from regression analysis and having no real physical meanings, thus, the rating curve can be considered as a black box. However, these two coefficients are related to erosive power and transport capacity in rivers (Iadanza and Napolitano, 2006; Hu *et al*., 2011). According to Mimikou (1982), environmental conditions, such as watershed characteristics, river hydraulic conditions and sediments type, affect these coefficients. This relationship can be found by using regression correlation of watershed characteristics with $a$ and $b$ coefficients.

Various researches have been presented on the evaluation of the sediment rating curve, bias correction factors (CFs) and relationship of equation coefficients with watershed characteristics. Cohn (1995) by evaluating correction methods like Quasi-Maximum Likelihood Estimator (QMLE), Smearing, and Minimum Variance Unbiased Estimator (MVUE), stated that these methods have almost the same results, if (1) the linear regression model is correct; (2) there is an adequate sample (that is, 30) for regression equation calibration; and (3) the model is used only for data interpolation. Based on the results of Cohn (1995), if all these conditions are satisfied, QMLE is the best method, and when the first condition is not satisfied (the model has no normal distribution), the Smearing method estimates better. On the other hand, Blanco *et al*. (2010) concluded that SRC has no acceptable efficiency in sediment prediction, especially in flood events. Ladewig (2006) found out that the QMLE estimator is more suitable than Smearing. Achite and Ouillon (2007) with the regression relationship investigation between daily discharge and sediment concentration in the semi-arid basin of the Algeria concluded that SSC variations in the annual scale are more than the seasonal scale. Also, more fine sediments are transported during autumn (48%) and spring (32%) and coarse sediments are transported during events, especially in the summer. Zarris *et al*. (2005) with the investigation of 30 samples of discharge-SSC in dam upstream of the Greece with the application of single-linear and bi-linear rating curves concluded that single-linear rating curve underestimates sediment. But in bi-linear rating curve the predicted and observed values are very close. Sadeghi *et al*. (2008a) provided the fourth root of transformation data with regard to their conditions in the rising and falling branches of hydrograph as optimization curve rating. Khanchoul *et al*. (2009) appropriated the discharge classification based on the flood seasonal to the rating curve in SSC prediction of torrential events. Hu *et al*. (2011) with temporal and spatial analysis of rating curve in Yangtze River found out that human activities have a significant influence on the rating curve parameters. They also showed that before dam construction, the sediment rating curve slope is more than after constructing in downstream.

Because most areas of Iran are located in the arid and semi-arid climates (that have irregular precipitation regime), thus, there are flooding precipitations with different amounts of sediments yield in their rivers. Also, due to lack of facilities, monitoring and continuous review of discharge and SSC in most rivers are not possible. Therefore, the aim of this study was to assess the rating equations and bias CFs, and in this situation the best relation between discharge and SSC can be presented.

## 2. Materials and Methods

### *2.1. Pol-Doab watershed*

Pol-Doab watershed (49º 4' 15"-49º 52' 12"E and 33º 44' 42"-34º 12' 13"N) located within an area of 1751 km$^2$ in Ghareh-Chaie basin in Iran (Fig. 1). Table 1 shows the major drainages formed from the three rivers, called Bazeneh (Bazeneh subwatershed), Azna (Shazand subwatershed), and Tooreh (Nahremian subwatershed). Geology formation in watershed is a sandy dolomite, limestone, quaternary, hilly metamorphic and igneous units of Sanandaj-Sirjan zone. Mean annual precipitation is 430 mm, mean annual temperature is 11.5°C, and climate is cold semiarid.

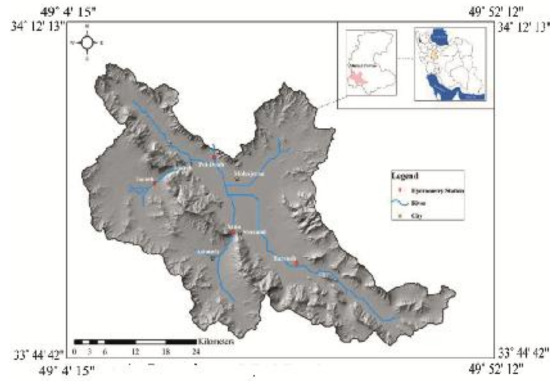

Fig. 1. Location of Pol-Doab watershed and its hydrological stations

Face agriculture mainly are located in slopes of hills and mountains, and agriculture based on irrigation are located on quaternary unit in low slope.

According to Figure 1, there are four discharge-sediment measurement stations on drainages of Pol-Doab. Table 1 shows the upstream physiographic characteristics of the stations based on the digital layers analysis in ArcGIS 9.3 software.

Table 1. Physiographic characteristics of discharge-sediment stations in the upstream of Pol-Doab watershed

| *Station* | *Pol-Doab* | *Nahremian* | *Shazand* | *Bazeneh* | *Middle section* |
|---|---|---|---|---|---|
| Area (km$^2$) | 1751 | 277 | 261 | 295 | 918 |
| perimeter (km) | 285.19 | 71.78 | 75.94 | 99.41 | 187.87 |
| Main river length (km) | 71.2 | 20.6 | 23.4 | 38.3 | 32.9 |
| Area mean slope (%) | 20.46 | 16.23 | 21.17 | 25.62 | 19.45 |
| Area mean elevation (m) | 2374 | 2257 | 2303 | 2362 | 2101 |
| Time concentration (h) | 11.25 | 4.1 | 4.44 | 6.78 | 5.64 |
| Annual discharge mean (m$^3$/s) | 4.597 | 0.992 | 0.871 | 0.717 | --- |

### *2.2. Sediment rating curve type*

Different methods have been presented for the prediction of sediment rating curve, in that most of the sediments have followed the U.S. Bureau of Reclamation (USBR). In single-linear rating curve type (regardless of the scatter points), the best fitting line (using least squares method), is crossed of data points. This is used only for one regression line and for all values of discharge and SSC. In multi-linear rating curve type (or broken line), with regard to the status of the scatter points that have direct contact with data properties, more than one line cloud is needed to cross the data sheet. Harrington (2013) showed that the most accurate load estimate on River Bandon (in Ireland) is found with the use of a stage separated power curve, while the most accurate load estimate on River Owenabue is found by using a general power curve. Therefore, several rating curve equations are determined corresponding to the number of lines. For example, according to Walling and Weeb (1988) and Khanchoul *et al*. (2009), in investigating the seasonal effects on sediment transport, data of discharge and SSC can be classified based on seasonal; other type of classification in this method is a monthly base value of discharge and SSC, that its rating curves have high accuracy. The third type of rating curve is known as "logged mean loads within discharge classes" (Jansson, 1996). In this method, according to conditions of scatter data, discharge values are classified into few groups and SSC values are classified based on this few groups. Then, the average values in each group are obtained and sediment rating curve is drawn based on their averages. This method, in addition to be given more valuation to high discharge and SSC, point's number are also minimized. This will decrease log transformed error that depends on the scatter points and number (Jansson, 1996).

*2.3. Bias in sediment rating curve*

Rating curves are often given from log-transformed data (Iadanza and Napolitano, 2006). To change the data condition from logarithmic to normal, a type of bias is entered into the linear regression model, which is often negative (Ladewig, 2006), while in the non-logarithmic condition, the slope of the correlated linear is higher than log-transformed (Iadanza and Napolitano, 2006). In fact, this bias is caused by residuals values (difference between observed and predicted data) having no normal distribution and its value is greater than zero (Kao *et al*., 2005). In most cases, this bias leads to "underestimation" of SSC in prolonged periods. This underestimation that arises from the scattered points is related to hysteric effects, and can show different values of SSC in similar discharges in the rising and falling branches of hydrograph (Asselman, 1999).

*2.4. Sediment rating equations*

To investigate sedimentation, first of all, the discharge-SSC data corresponding to the study stations were prepared from the water organization of Markazi province in Iran. Thus, sediment rating curve types like single-linear, multi-linear and mean load were drawn based on the least squares regression. In single-linear, a line was fitted for all the discharge-SSC data in each station. In multi-linear discharge-SSC, all data in Pol-Doab station (outlet) according to the season of spring (April-June), summer (July-September), autumn (October-December) and winter (January to March) were also classified. Also, a two-linear rating curves based on the hydrological period, humid (January to May) and dry (June to December) were drawn for this station. In logged discharge-SSC, mean loads were used for discharge-SSC classes' mean in each station for fitting a line between data mean.

Then, by using five CFs, including: FAO, QMLE, Smearing, MVUE and β, *a* coefficient was corrected in each rating curve equations. Therefore, based on the types of rating curve and CFs, six single-linear annual equations and six mean load annual equations were prepared in each station. Also, for Pol-Doab station, six equations were prepared for each season and each hydrological period.

*2.5. Bias FCs*

For correct prediction or with the least error in log-transformed data, correction factor (CF) is suggested for the sediment rating equation. CF can affect equation as follows:

$$Q_S = CF.aQ_W{}^b \tag{2}$$

*Qs*, *Qw*, *a* and *b* are the parameters that are related to USBR in Equation 1, and *CF* is the correction factor. Five *CF* are presented in this study.

*FAO*

FAO method (Jones *et al*., 1981) has been proposed for the modification of data, and approximate observation and prediction of values in the arid and semi-arid areas. In this method, the α coefficient as CF is replaced with a coefficient as follows:

$$Q_S = \sim Q_W{}^b \tag{3}$$

$$\sim = \frac{\bar{Q}_S}{\bar{Q}_w^b} \tag{4}$$

$\bar{Q}_S$ is the average SSC of the observed samples (ton/day), and $\bar{Q}_w$ is the average flows of the observed samples (m$^3$/s).

*QMLE*

QMLE (Ferguson, 1987), is applied to correct the log-transformed impact with normal distribution assumption of residuals errors and is usually used with negative bias. This method is called the parametric CF1 method, with a CF based on the residual standard error squared of regression equation as follows:

$$CF_{QMLE} = e^{(2.561S^2)} \tag{5}$$

*e* is the exponential function (equal to 2.718) and $S^2$ is the average square error of the regression in base-10 of logarithms as follows:

$$S^2 = \frac{\sum_{i=1}^{n} (\log C_o - \log C_e)^2}{n-2} \tag{6}$$

*Co* is the observed SSC (ton/day), *Ce* is the predicted SSC (ton/day) and *n* is the number of observed data.

*Smearing*

Smearing factor (Duan, 1983) known as the nonparametric CF2 method is presented for bias deleting of normal distribution rejection of the errors residual (*εi*), as follows:

$$CF_{Smearing} = \frac{1}{n}\sum_{i=1}^{n} 10^{£_i} \quad (7)$$

$$£_i = \log(C_o) - \log(C_e) \quad (8)$$

*MVUE*

MVUE (Cohn *et al*., 1989) is presented for the linear fitting of the logarithm data. In this method, for each sediment-discharge data, a correction coefficient is calculated and their average is computed as CF:

$$CF_{MVUE} = \frac{\sum_{i=1}^{n} g_{m_i}}{n} \quad (9)$$

$$g_{m_i} = \frac{m+1}{2m}\left\{(1-V)S^2\right\} \quad (10)$$

$$V = \frac{1}{N} + \left[\frac{(\ln(Q_x) - Q_{Bar})^2}{QVar}\right] \quad (11)$$

*gm* is the Finney function, that is, the CF for sample *i*; *m* is the degrees of freedom for regression equation (*n-1*); *V* is the function of distribution variables; *Qx* is the observed flow in sample *i*; *QBar* values are the mean of observed flows and *QVar* is the observed flows variance.

*β coefficient*

Correction coefficient β was presented by Kao *et al*. (2005) for sediment rating curves correction in the Taiwan Rivers. This coefficient is the result of the divided residuals total per the predicted regression model and this can be positive or negative. This method can reduce the error of the predicted values in high flows as follows:

$$CF = 1 + \quad (12)$$

$$= \frac{\sum_{i=1}^{N} (£_i)}{\sum_{i=1}^{N} aQ_w^{\ b}} \quad (13)$$

*2.6. Evaluation criteria's*

Performance rate determination of sediment rating equations required the evaluation. The aim of this evaluation is to introduce the optimization model (equation) in watershed management programs. Using the evaluated criteria's, such as *P* (Precision), *RMSE* (Root Mean Square Error), and *ME* (Maximum Error or Nash and Sutcliffe), each equation was evaluated based on the observed and predicted values of sediment rating equation as follows:

$$RMSE = \left(\frac{\sum_{i=1}^{n} (SSC_o - SSC_e)^2}{N}\right)^{0.5} \quad (14)$$

*SSCo* is the SSC observed value and *SSCe* is the SSC estimated value. When *RMSE* was taken to be smaller, the difference between estimated and observed values is lower, and estimation accuracy is more.

$$ME = 1 - \left[\frac{\sum_{i=1}^{n} (SSC_o - SSC_e)^2}{\sum_{i=1}^{n} (SSC_o - SSC_m)^2}\right] \quad (15)$$

*SSCm* is the mean of the SSC observed values. While *ME* is the change of endless negative to unit, and when it is more near to unit, meaning accuracy is higher (Pandey *et al*., 2007).

$$P = \frac{\sum_{i=1}^{n} \frac{SSC_e}{SSC_o}}{N} \quad (16)$$

For *P* is as accuracy criteria and it is more near to unit, this means its accuracy is higher.

*2.7. Determination of effective parameters on sediment rating equation coefficients*

In the second part of this study, the relationship between *a* and *b* coefficients of the sediment rating equation with watershed physiographic characteristics were investigated. For this to be illustrated, the regression relationships between *a* and *b* coefficients of the optimized sediment rating equation with watershed characteristics were created as shown in Table 1. These include area, perimeter, main river length, average slope, average elevation, time concentration and annual flow mean. Thereafter, the functions of linear, logarithmic, polynomial, power, exponential and moving average were delaminated, and the optimized equation was determined. Finally, results were described with more attention being paid to the type and circumstances of the equations.

## 3. Results and Discussion

*3.1. Sediment rating equations*

Sediment rating equations, including single-linear and logged mean loads have been presented in each station based on the squares least regression as shown in Table 2. For Pol-Doab station, sediment rating equation of multi-linear (seasonal and hydrological period) is as shown in Table 3.

The results in Table 2 show that the correlation coefficient in the mean load equations is higher than the single-linear equations. Therefore, in the single-linear method, the correlation coefficients are in range of 0.723 to 0.863, but in the mean load method, the correlation coefficients are in range of 0.940 to 0.972. As shown in Table 3, except in summer, other equations of seasonal and hydrological period have high correlation coefficient.

### *3.2. Correction coefficients*

The correction coefficients values, QMLE, Smearing, MVUE and β have been shown for each rating curve type in Tables 4 to 7.

Table 2. Sediment rating equations of single-line and mean load in stations of Pol-Doab watershed

| Rating curve type | Singe-linear | $R^2$ | mean loads | $R^2$ |
|---|---|---|---|---|
| Pol-Doab | $Q_s=7.847Q_w^{1.403}$ | 0.86 | $Q_s=16.853Q_w^{1.434}$ | 0.94 |
| Azna | $Q_s=11.383Q_w^{1.447}$ | 0.85 | $Q_s=18.748Q_w^{1.608}$ | 0.97 |
| Tooreh | $Q_s=7.749Q_w^{1.446}$ | 0.72 | $Q_s=14.942Q_w^{1.570}$ | 0.97 |
| Bazeneh | $Q_s=7.328Q_w^{1.638}$ | 0.83 | $Q_s=8.301Q_w^{1.742}$ | 0.94 |

Table 3. Sediment rating equations of multi-linear (seasonal and hydrological period) in Pol-Doab station

| Rating curve type | | Pol-Doab | |
|---|---|---|---|
| | | Rating equation | $R^2$ |
| Seasonal | Spring | Qs=7.716Qw1.545 | 0.88 |
| | Summer | Qs=4.866Qw1.054 | 0.31 |
| | Autumn | Qs=7.944Qw1.373 | 0.82 |
| | Winter | Qs=6.540Qw1.320 | 0.72 |
| Hydrological period | Humid | Qs=6.253Qw1.535 | 0.80 |
| | Dry | Qs=7.247Qw1.289 | 0.70 |

Table 4. Correction coefficients of single-linear rating equation in the studied stations

| Correction factor | Pol-Doab | Azna | Tooreh | Bazeneh |
|---|---|---|---|---|
| FAO | 6.74 | 3.58 | 2.58 | 14.27 |
| QMLE | 1.65 | 1.39 | 1.60 | 1.58 |
| Smearing | 1.87 | 1.51 | 1.56 | 2.01 |
| MVUE | 1.10 | 1.06 | 1.09 | 1.09 |
| β | 1 | 1 | 1 | 1 |

Table 5. Correction coefficients of mean load rating equation in the studied stations

| Correction factor | Pol-Doab | Azna | Tooreh | Bazeneh |
|---|---|---|---|---|
| FAO | 2.98 | 1.96 | 1.39 | 12.22 |
| QMLE | 2.22 | 1.60 | 1.87 | 1.42 |
| Smearing | 0.87 | 0.93 | 0.91 | 1.49 |
| MVUE | 1.17 | 1.09 | 1.13 | 1.07 |
| β | 0.99 | 0.99 | 0.98 | 0.99 |

Table 6. Correction coefficients of seasonal rating equation in Pol-Doab station

| Season | FAO | QMLE | Smearing | MVUE |
|---|---|---|---|---|
| spring | 5.532 | 1.530 | 1.548 | 1.084 |
| summer | 1.674 | 1.816 | 2.186 | 1.114 |
| autumn | 5.103 | 1.552 | 1.715 | 1.085 |
| winter | 2.494 | 1.673 | 1.656 | 1.102 |

Table 7. Correction coefficients of hydrological period rating equation in Pol-Doab station

| Hydrological period | humid | dry |
|---|---|---|
| FAO | 5.4 7 | 5.28 |
| QMLE | 1.61 | 1.66 |
| Smearing | 1.59 | 2.01 |
| MVUE | 1.09 | 1.10 |
| β | 1 | 1 |

Based on the obtained results, FAO value is more than the other coefficients, that is, in increasing coefficient. Smearing factor, only in the three stations in the mean load method, is in decreasing coefficient and in other conditions is in increasing coefficient. Also, QMLE factor is as well as Smearing and is in increasing coefficient. According to these results, MVUE value is usually less than FAO, Smearing and QMLE. Also, β value in single-linear and multi-linear is without effect, but the mean load is in decreasing coefficient.

### *3.3. Ranking of evaluation criteria's values*

For the selection of optimized equation in each station, evaluation criteria's ranking was used. Thus, the nearest ME and P value tend to the unit and nearest RMSE value tends to zero in the station, representing that the difference in minimum between predicted and observed values of sediment, has rank of one number. The criteria's next values in the related station are ranked based on its rates. Tables 8 to 10 show the ranking sum based on RMSE, ME, and P. For example in Table 8, Bazeneh station, FAO factor, and single-linear type, ME rank is 10, RMSE rank is 10, and P rank is 11. Therefore, its ranking sum is 31.

Table 8. Ranking sum based on RMSE, ME, and P for sediment rating equations in the study stations

| station | Ranking sum of Correction factor | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | USBR | | FAO | | QMLE | | Smearing | | MVUE | | β | |
| | s.l. | m.l. | s.l. | m.l. | s.l. | m.l. | s.l. | m.l. | s.l. | m.l. | s.l. | m.l. |
| Bazeneh | 19 | 15 | 31 | 32 | 17 | 10 | 15 | 9 | 20 | 14 | 19 | 16 |
| Azna | 23 | 17 | 15 | 18 | 21 | 11 | 20 | 19 | 22 | 14 | 23 | 18 |
| Tooreh | 21 | 9 | 20 | 25 | 17 | 23 | 17 | 10 | 20 | 16 | 21 | 10 |
| Pol-Doab | 23 | 17 | 15 | 12 | 21 | 15 | 20 | 19 | 22 | 16 | 23 | 18 |

s.l.: single-linear m. l.: mean load

Table 9. Ranking sum based on RMSE, ME, and P for the seasonal rating curve in Pol-Doab station

| Season | USBR | FAO | QMLE | Smearing | MVUE | β |
|---|---|---|---|---|---|---|
| spring | 11 | 7 | 9 | 8 | 10 | 11 |
| summer | 11 | 7 | 6 | 11 | 10 | 11 |
| autumn | 11 | 7 | 9 | 8 | 10 | 11 |
| winter | 9 | 15 | 8 | 5 | 8 | 9 |

Table 10. Ranking sum based on RMSE, ME, and P for hydrological period rating curve in Pol-Doab station

| Hydrological period | USBR | FAO | QMLE | Smearing | MVUE | β |
|---|---|---|---|---|---|---|
| humid | 11 | 7 | 8 | 9 | 10 | 11 |
| dry | 11 | 7 | 9 | 8 | 10 | 11 |

### *3.4. Optimized equations of discharge-SSC*

According to results in Tables 8 to 10, with comparison of ranks sum in each row, minimum value is represented by optimized equation in the related station. Priorities of the third discharge-SSC relationships in annual temporal scale (single-linear and mean load) were determined as shown in Table 11. Also, priorities of first to third discharge-SSC relationships in seasonal and hydrological period temporal scale were determined as shown in Tables 12 and 13.

Table 11. Priorities of first to third discharge-SSC relationships annual in the study stations

| Priorities | Bazeneh | Azna | Tooreh | Pol-Doab |
|---|---|---|---|---|
| 1 | Mean load - Smearing | Mean load- QMLE | Mean load- USBR | Mean load- FAO |
| 2 | Mean load- QMLE | Mean load- MVUE | Mean load– Smearing<br>Mean load- β | Mean load– QMLE<br>Single linear- FAO |
| 3 | Mean load - MVUE | Single linear- FAO | Mean load - MVUE | Mean load - MVUE |

Table 12. Priorities of first to third discharge-SSC seasonal relationships in Pol-Doab stations

| Priorities | spring | summer | autumn | winter |
|---|---|---|---|---|
| 1 | FAO | QMLE | FAO | Smearing |
| 2 | Smearing | FAO | Smearing | QMLEMVUE |
| 3 | QMLE | MVUE | QMLE | βUSBR |

Table 13. Priorities of the first to third discharge-SSC hydrological period relationships in Pol-Doab stations

| Priorities | spring | summer | autumn | winter |
|---|---|---|---|---|
| 1 | FAO | QMLE | FAO | Smearing |
| 2 | Smearing | FAO | Smearing | QMLEMVUE |
| 3 | QMLE | MVUE | QMLE | βUSBR |

According to the results in Table 11, the first priority optimized relations to SSC-discharge in annual scale of the four stations were based on the mean load rating curve. Also, in the second and third priority (except the third priority in Azna station), the mean load rating curve has optimized method.

The optimized CFs show that each of the four stations in the first priority has not been followed from a particular CF. As shown in Tables 11 and 12, CF value for Bazeneh, Azna, Tooreh and Pol-Doab is 1.494, 1.605, 1 and 2.967, respectively. With attention to these, except Tooreh station, correction values are more than unit. Therefore, they were also called increasing CFs, where it has predicted SSC more than USBR original relation.

Also, in the second and third priority, each station has followed from a particular CF. But, it is most important to include MVUE factor with mean load rating curve in the four stations. This CF for Azna station is in the second priority and, for Bazeneh, Tooreh and Pol-Doab stations is in the third priority.

According to results shown in Table 12, the optimized CFs in spring, summer, autumn and winter season for Pol-Doab stations are FAO, QMLE, FAO and Smearing, respectively. Also, with attention being paid to results in Table 13, FAO factor in both humid period and dry period was optimized CF. while QMLE and Smearing are in the second and third priorities.

As shown in Tables 14 and 15, the best relationship between *a* and *b* coefficients of mean load rating curve and subwatersheds characteristics have been presented. The results in Table 14 show that watershed average slope has the most correlation (0.437) with a coefficient of SSC rating curve, that its relation is reversed. It means that with increase in the slope, the *a* coefficient decreases. With attention paid to the results in Table 15, *b* coefficient has high correlation (R2) with subwatershed characteristics. But, the average slope was expected, and the other parameters have reversed relation with this coefficient.

Table 14. Relationship between a coefficient of mean load rating curve with subwatersheds characteristics

| Parameter (x) | Best relationship | R2 |
|---|---|---|
| Area (km2) | $a = 12.732\ e^{0.0002x}$ | 0.09 |
| Perimeter (km) | $a = 12.647\ e^{0.0008x}$ | 0.05 |
| Main channel length (km) | $a = 18.02\ x^{-0.070}$ | 0.01 |
| Average slope (%) | $a = 51.888\ e^{-0.062x}$ | 0.44 |
| area average elevation (m) | $a = 3518.1 e^{-0.002x}$ | 0.13 |
| Tc (hr) | $a = 16.667\ x^{-0.094}$ | 0.01 |
| Annual average flow (m3/s) | $a = 13.459\ x^{0.182}$ | 0.19 |

Table 15. Relationship between B coefficient of mean load rating curve with subwatersheds characteristics

| Parameter (x) | Best relationship | $R^2$ |
|---|---|---|
| Area ($km^2$) | $b = 1.679\ e^{-9E-0.5x}$ | 0.68 |
| Perimeter (km) | $b = 1.714\ e^{-0.0006x}$ | 0.58 |
| Main channel length (km) | $b = 1.715\ e^{-0.002x}$ | 0.36 |
| Average slope (%) | $b = 0.020\ x + 1.172$ | 0.36 |
| area average elevation (m) | $b = 2.104\ e^{-0.0001x}$ | 0.01 |
| Tc (hr) | $b = 1.739\ e^{-0.014x}$ | 0.33 |
| Annual average flow (m3/s) | $b = 1.617\ x^{-0.083}$ | 0.80 |

## 4. Conclusion

In this research, an assessment of sediment rating equations was carried in four hydrometric stations in the Pol-Doab watershed. Therefore, based on the types of rating curve and CFs, six single-linear annual equations and six mean load annual equations in each station were prepared. Also, for Pol-Doab station, six equations for each season and each hydrological period were prepared. Thereafter, when using evaluation criteria's, the optimized equations were determined. Also, the relationship between *a* and *b* coefficients of SSC optimized were obtained.

According to the obtained results, the mean load method in annual scale is more preferred than the single-linear method. Also, for CFs, the SSC original rating equation has been faced with underestimation problem and by applying CF this problem would be decreased. This result has conformity with researches of Endreny and Hassett (2005). The results has shown that by integrating mean load rating curve with MVUE, CF can be satisfactory in annual sediment yield prediction; but the sediment yield prediction during flood events has no well ability. Cohn (1995) also identified that the MVUE for sediment yield prediction of peak flood has low accuracy. For β CF, it was identified that the factor in single-linear rating curve has no improving effect as the CF; but the mean load rating equation is as a decreasing factor. Kao *et al*. (2005) identified that this issue can decrease the difference between the observed and estimated sediments in high flow.

Moreover, it was concluded that the application of the FAO CF in humid and dry periods rating curves was applied as spring and autumn seasons can be suitable in sediment yield estimation in various flows intensity. FAO CF cannot have high accuracy for SSC estimation in summer and winter seasons, since FAO CF presents high value than other CFs, then the other CFs should be used. This means that seasonal multi-linear rating curve is more accurate than hydrological period. Then monthly rating curve in monthly scale is undoubtedly most accurate than other types. These results have also been provided by Khanchoul *et al*. (2009).

As mentioned ealier, the *b* coefficient value of SSC rating equation was a rating curve slope, then if this slope is to be more, the SSC variability will be higher. With attention being paid to the single-linear rating curve in annual scale (is as USBR original equation), *b* value in this equation has average value than *b* value of seasonal and hydrological period equations. Therefore, this parameter can be considered as the criteria for sediment yield rate estimation and can be used for the comparison of sediment yield in month, season and hydrological periods.

Our results show that for multi-linear rating equation of hydrological period, the *b* coefficient in humid period was more than its average value. This means that humid periods have high rates of sediment yield in the Pol-Doab watershed. Since *a* coefficient has inverse relation with the *b* coefficient, then with increase in the watershed average slope, the *b* coefficient (rating curve slope) was also increased in all cases. For the other watershed characteristics, the results show the poor relationship with *a* coefficient.

Based on our results, watershed average slope has direct relation with *b* coefficient; this means that with increase in the watershed average slope, the slope of SSC equation is also increased. Finally, it can be concluded that among watershed physical characteristics, the watershed average slope has inverse relation with the *a* coefficient and direct relation with the *b* coefficient of the sediment equation.

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