Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345 (Online)
An Open Access, Online International Journal Available at www.cibtech.org/sp.ed/jls/2014/04/jls.htm
2014 Vol. 4 (S4), pp. 2345-2351/Bordbar and Mehdi

Research Article

SEDIMENT RATING CURVE MODIFICATION (CASE STUDY: MARUN DAM, BEHBAHAN, IRAN)

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ABSTRACT
Sediment discharge estimation has significant role in any river engineering planning. Suspended sediment load in more rivers has significant role of sediment yield. Because of its complexity, several estimators have been developed to predict suspended sediment discharge. USBR equation, with regression base, is one the most applicable models in sediment discharge calculation. Basic of this equation is a regression line fitting on sediment discharge and flow discharge pairs. Lack of data, skewed error related to regression type of trend line cause over or under-estimation of estimator. In this paper, FAO method was used to decrease USBR errors. Edanak station on Marun River, Behbahan Iran was selected for the research. Three statistical indices were calculated to monitoring FAO modification as STDEV, GSD and RMSE. According to calculations, amount of these three indices were calculated for USBR and FAO methods as (547.97, 1.41, 614.12) and (1269.04, 0.031, 31.7), respectively. Results showed FAO method has significant effect on increasing sediment rating curve estimations.

Keywords: *Suspended Sediment Discharge, Sediment Rating Curve, USBR, FAO*

INTRODUCTION
Soil erosion is a complex dynamic process by which the productive soil surface is detached, transported, and accumulated at a distant place. It produces exposed subsurface where the soil has been detached and the detached deposited in low-lying areas of the landscape or in water bodies downstream in a process known as sedimentation.

Soil erosion and sedimentation are concurring environmental processes with varied negative and positive impacts. The negative impacts include the removal of nutrient rich topsoil in upland areas and subsequent reduction of agricultural productivity in those areas.

In irrigation projects, soil erosion and sedimentation cause reduction of irrigation conveyance capacities and reservoir storage volumes. They also reduce irrigation water quality by increasing water turbidity. In the lowlands, deposition of soil from eroded uplands causes changes in river channels and subsequent increase in flood vulnerability of the floodplain farmlands and residential areas.

Suspended sediment transport (SST) rate estimation in fluvial streams is one of the most important studies in river engineering problems for assessing appropriate methods to prevent sedimentation problems, which has been studied more than one hundred years. SST rate has close interaction with water quality, erodibility of catchments, reservoir sedimentation, channel silting, ecological aspects, etc (Walling, 1977; Ferguson, 1986; Horowitz *et al.*, 2001).

There are several methods to evaluate suspended load rate which can be categorized in two main groups: theoretical methods and data-based (hydrological) methods. The last one has regression basic that are more applicability than to theoretical methods because of data lack of data and their simplicity. Therefore, hydrological methods often are used other than methods. Sediment rating curve (SRC), which is called USBR equation, is the common method of hydrological approaches for SSC estimation. This curve is drawn by fitting a line (or multiline) through the cloud of sediment discharge and flow discharge points which is called as single-line sediment rating curve. SRC equation is as following:

$$Q_S=aQ_W^b \qquad (1)$$

Which QS and QW are sediment and water discharge, respectively; a and b are coefficients. SRC can be used to evaluate SSD during ungagged days. The first suspended sediment concentration (SSC) measuring has been done in 1845, on Mississippi River. Corresponding values of flow discharge and SSC are used to derivate SRC. This method can be used reliably in permanent and main rivers (Quilbe-Rousseau and Duchemin, 2006; Telvari, 2001).

Application of SRC to estimate suspended sediment discharge (SSD) has been reported by researches: Asselman; Kazama *et al.*, ; Quilbe and Duchemin; Mano *et al.*, ; Alexandrov *et al.*, (Pavanelli and Bigi, 2004; Asselman, 2000; Kazama *et al.*, 2005; Mano *et al.*, 2009; Alexandrov *et al.*, 2010). Because of regression basis of SRC, difference between measured and calculated values of SSD is occurred. Lack of hydrometric stations, low accuracy measured data and lack of SSC samples reduce SRC accuracy (Sadeghi *et al.*, 2008).

Walling and Web stated that more errors will occur extrapolating SRC (Walling and Webb, 1981). Thomas reported 51% under-estimate of SSD by using SRC (Thomas, 1985).

Achite and Ouillon have been reported 20-25 percent over-estimate of SRC. Also, they stated to use long term data and climate change condition to derivate SRC (Achite and Ouillon, 2007). Quilbe and Duchemin results showed that data dispersion will increase SRC estimations errors (Quilbe and Duchemin, 2006).

As above mentioned, it will be worthwhile to develop relations to increase SRC accuracy. According to equation 1, log-log diagram often use to for regression estimator, because appropriate distribution of SSC and flow discharge is Log-normal II. Therefore two skewed will be expected. The first one is originated from selected method of linear regression model.

The second one is resulted due to transport from logarithmic to original form. The first method can skewed can be decreased using least square approach. But the second one should be modified by adding independent constant coefficients to equation. These two methods were applied for SRC in different alluvial streams which have had acceptable results. Jones *et al.*, stated that using FAO method will increase SRC estimates (Jones *et al.*, 1981).

Jansson used flow discharge classification to derive SRC. His studies shows more accuracy (Jansson, 1996). Boning reported two above mentioned skewed will increase SRC errors (Boning, 2001). Cohn *et al.*, proposed to modify SRC estimations in flood condition and low SSC samples. Their results showed that SRC output have more errors in two mentioned conditions (Cohn *et al.*, 1989). Wang and Linker proposed using added coefficients (long term trend of SSC, …) to increase SRC estimations. This method will have acceptable estimation (Wang and Linker, 1999).

In this paper, FAO method will be used for Marunriver, Edanak station, Behbahan, Iran. There are three stations on Marun River before Marun dam which Edanak is the last hydrometric station. River flow conditions are presented in table 1 for three stations.

Edanak longitude, latitude and height are 50o 25'(East) and 30o 57' (North) and 610 m, respectively. Marun catchment area in this station is 2754 km2 that has vegetation cover. Mean slope is catchment and river (near the station) are 2.05 and 1.13 percent, respectively. Figure 1 shows Marun dam and Edanak station.

Table 1: Marun River discharge distribution

Station	Period (year)	Mean Monthly Discharge (m^3s^{-1})	Mean Maximum Discharge (m^3s^{-1})	Mean Minimum Discharge (m^3s^{-1})
Edanak	32	54	116	18.1
Behbahan	46	50	120.2	11.9
Cham-Nezam	21	67.5	125	23.5

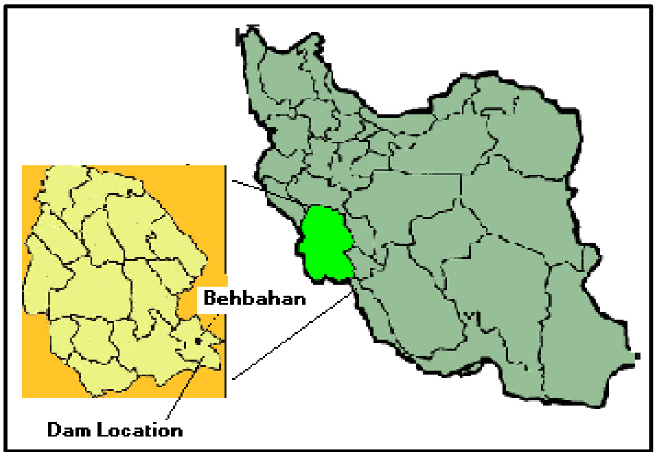


Figure 1: Location of Marun Dam, Behbahan, Iran

MATERIALS AND METHODS

Using SRC to estimate SSD is a common approach in river engineering planning. According to regression based of SRC, over and under-estimation is occurred. Preventing these errors, FAO method was applied in Edanak station.\

FAO Method

FAO (1981) developed the following equation to calculate a coefficient in equation (1) for SRC error modification:

$$a' = \frac{\bar{Q}_S}{\bar{Q}_W^{\,b}} \qquad (2)$$

Where $\bar{Q}_S$ and $\bar{Q}_W$ are mean annual values of measured SSD and flow discharge, respectively. After determining sedimentation equation using FAO and USBR methods, by comparing statistical parameters, such as root mean square error (RMSE), root mean square error to mean estimated data (GSD) ratio, correlation coefficient between estimated and observed (R) sediments the best equation were selected and sediment of the stations were estimated according to the selected approach. Applied equations for every statistical index are as following:

$$RMSE = \sqrt{\frac{\Sigma (Q_{s(measured)} - Q_{s(Estimated)})^2}{n}} \qquad (3)$$

$$GSD = \frac{RMSE}{\bar{Q}_{s(estimatd)}} \qquad (4)$$

Which $Q_{s(measured)}$ and $Q_{s(estimated)}$ are measured and estimated values of suspended sediment discharges, n is total number of data.

RESULTS AND DISCUSSION

Using measured values, SRC has been shown in Figure 2. Sediment rating curve is presented on the chart. Amount of SRC coefficients, a and b, are 4.5605 and 1.1105 respectively. A comparison between measured and estimated values of SSD is presented in table 2. Figure 3 shows measured and estimated values of SSD. As it clear, there is no good agreement between measured and predicted values. The difference is significant in high SSD.

To apply FAO method, mean value of measured SSD was calculated as 940.36 (ton.day-1). Therefore, a' coefficient was determined as: $a' = \frac{940.36}{56.96^{1.1105}}$ =10.56. on the other words, SRC based on FAO modification was derived as following:

$Q_S = 10.56 Q_W^{1.1105}$ (5)

The results are presented in table 3. Figure 3 shows measured vs. estimated values of SSD. As it clear, there are good agreements in low values. At high values differences increase. It should be noted that high sediment discharges occur in flood condition which measured data have low accuracy. Therefore, one of the main reasons of significant difference is out of computing.

Three statistical indices were calculated to identify FAO method effect on SRC estimations. According to tables 2 and 3, (STDEV, RMSE, GSD) values for USBR and FAO methods are (547.97, 1.41, 614.12) and (1269.04, 0.031, 31.7), respectively. The percent of modifications of three mentioned indices are: -131.6%, 97% and 95%, respectively. According to these modifications, significant corrections have been done on USBR estimations. These results are presented in Figure 4 graphically. Obvious differences can be observed in both methods.

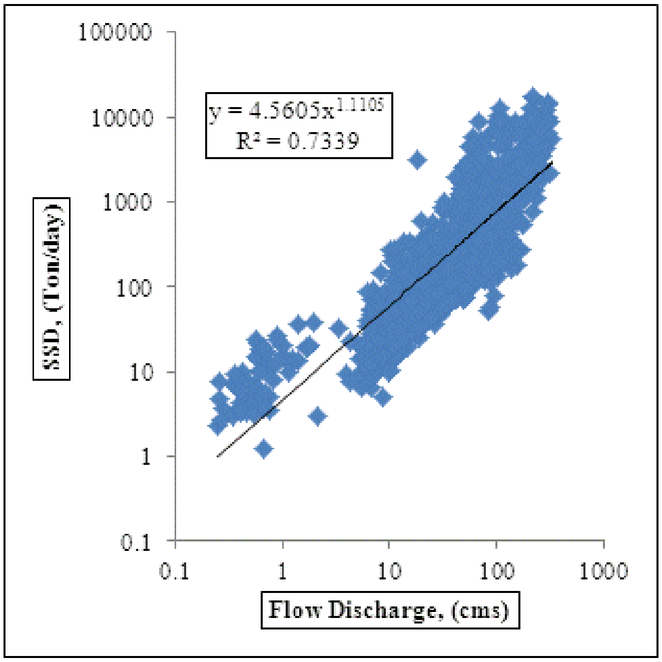


Figure 2: Sediment rating curve, Edanak station

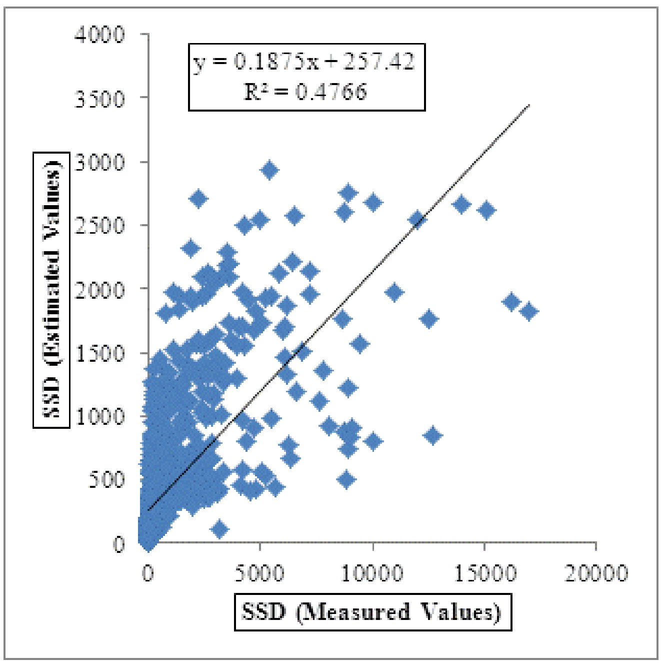


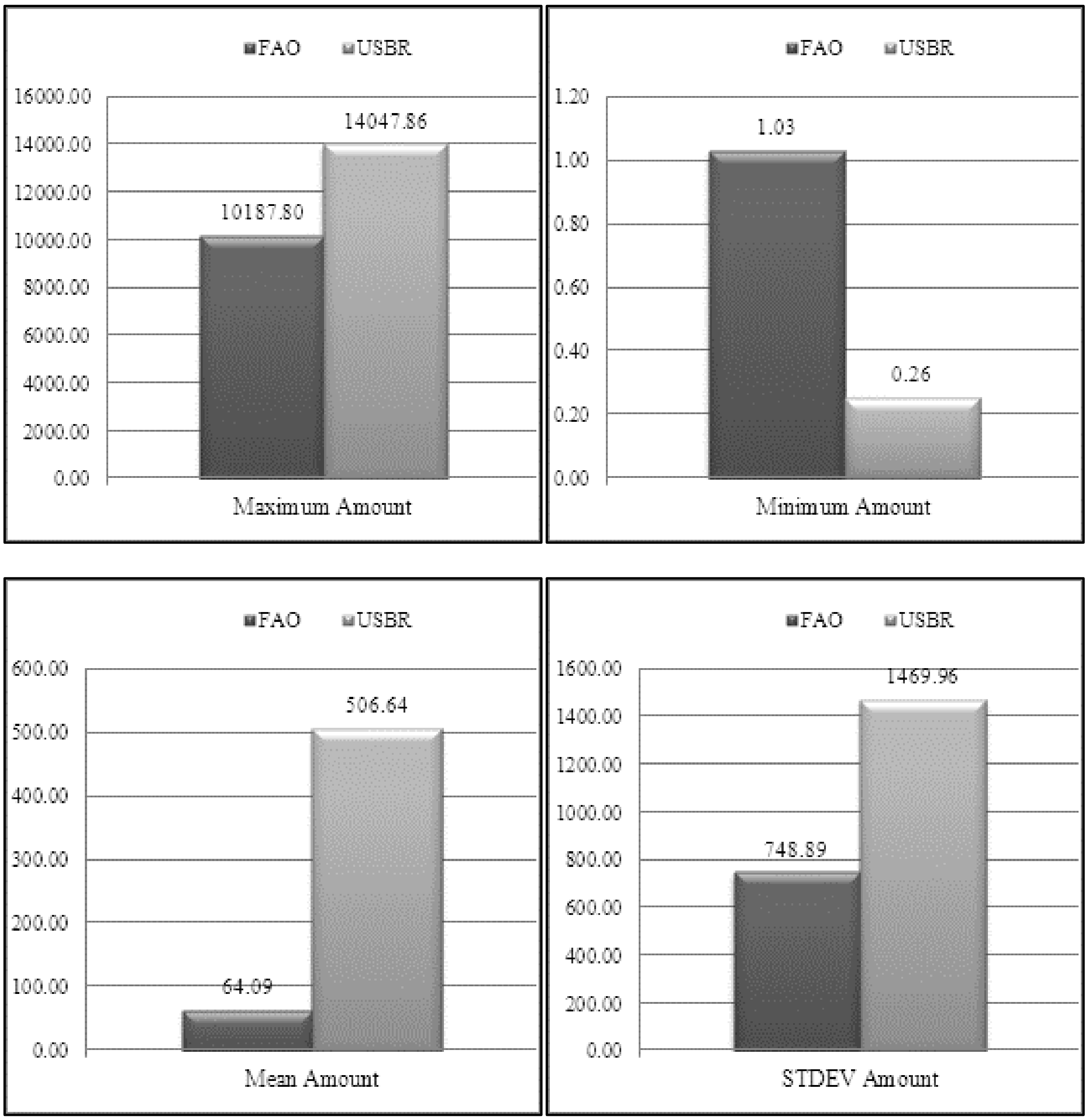
Figure 3: Amount of SSD (Measured vs. Estimated)

Table 2: Measured and estimated SSD characteristics using SRC

	Maximum	Minimum	Mean	STDEV	RMSE	GSD
Measured	16981.29	1.235	940.3641	2017.933		
Estimated	2933.421	0.978194	433.7221	547.9709	612.26	1.41
Difference	14047.86	0.256806	506.642	1469.962		

Table 3: Measured and estimated SSD characteristics using FAO equation

	Maximum	Minimum	Mean	STDEV	RMSE	GSD
Measured	16981.29	1.235	940.3641	2017.933		
Estimated	6793.482	2.265389	1004.453	1269.041	31.7	0.031
Difference	10187.8	1.030389	64.08877	748.8928		



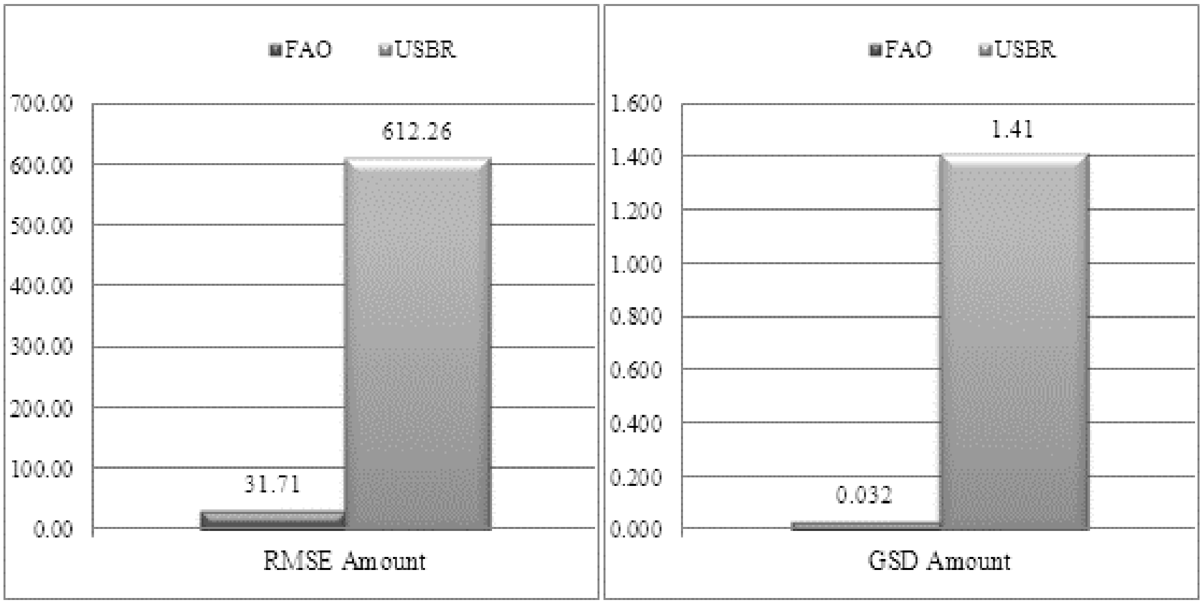


Figure 4: Comparison of statistical indices between FAO and USBR estimator

ACKNOWLEDGMENT

This paper is extracted from research work of title "THE ESTIMATION OF SEDIMENT LOAD TO DAM RESERVOIR USING HYDROLOGICAL METHODS (CASE STUDY: MARUN DAM)". The authors would like to thanks Ahvaz Branch, Islamic Azad University, Ahvaz, Iran for its kindly cooperation due to this research work.

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