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APPLICATION OF THE USBR EQUATION FOR SURVEYING BALANCE OF SEDIMENT YIELD IN DEZ RIVER BRANCHES IN IRAN

Accurate determination of mean annual sediment load (MASL) of natural rivers will affect administrative aspects of water planning in dams. The MASL in Dez River in the southwest Iran has been considered. Sezar and Bakhtiari are its two branches. The amount of MASL was predicted by the USBR equation with three scenarios: using mean value of sediment discharge, using probabilistic classification of river flow data and using separation of wet and dry months. The results show that the USBR equation can be used to evaluate MASL in the Dez basin.

1. INTRODUCTION

The study on the flow, sediment transport, and channel evolution processes in rivers began centuries ago but river dynamics emerged as a distinct discipline of science and technology only after DuBoys established a bed-load formula in 1879 and Rouse proposed a function for the vertical distribution of suspended sediment in 1937. River dynamics deals with river flow and sediment problems such as turbulent flow in alluvial channels, movable bed roughness, sediment settling, incipient motion, transport, deposition, and erosion. River dynamics also incorporates the study of fluvial processes, including river pattern classification, channel evolution laws, and regime theory. It provides physical principles and analysis methods for river engineering [1].

Iran is located in arid and semi-arid region whose water management planning is necessary to supply required water demand. The construction of reservoirs is one of the methods of water supplement. Sediment deposition reduces the storage capacity and life span of reservoirs. The deposition will extend upstream upon time and submerge more land, while sediments, especially coarse particles, will be detained by

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reservoirs, causing erosion in downstream channels. The deposition and erosion processes and the ultimate equilibrium profiles in reservoirs and downstream channels are topics of concern. After reservoirs reach equilibrium states, their efficiency in terms of flood control, power generation, and sediment detention may be significantly reduced, and then problems with dam decommission and rehabilitation and their impacts on the environment become important. Considering that the most of sediment loads occur in flood mode, and the measurement of sediment load will be accomplished with errors, using the methods of high accuracy will be valuable. Hydrological method of estimating sediment loads is used to predict sediment discharge of a river stream.

Since the 1970s, an interest has been growing in estimating the fluvial transport of suspended sediment. The reasons are numerous and diverse, and include such issues as contaminant transport, water-quality trends, reservoir sedimentation, channel and harbour silting, soil erosion and loss, as well as ecological and recreational impacts [2–6]. A further impetus, at least in the USA, stems from the need to determine total maximum daily loads (TMDLs) for sediment, as well as for many sediment-associated constituents, under the requirements of the Clean Water Act of 1972. Nearly 17% of all currently required TMDLs deal with excess sediment or its presumptive biological impact [7]. The calculation of fluxes or loads requires both discharge and concentration data [4, 8]. Typically continuous or near-continuous discharge data can be calculated from in situ devices such as stage recorders. Stage is then converted to discharge based on a site-specific stage–discharge relationship.

On the other hand, the vast majority of suspended sediment concentration (SSC) data typically result from manually collected individual samples taken at fixed temporal intervals; occasionally, the fixed interval samples are supplemented by event samples. More recently, as a result of the presumed linkage between SSC and discharge, SSC data have been generated on the basis of hydrological based sampling rather than on fixed interval (calendar based) sampling [5, 6]. Although both approaches can provide a representation of the site-specific range of SSC, the hydrological approach will do so more rapidly than the fixed interval approach; however, samples are still collected manually. Horowitz addressed the prediction of suspended load in the Mississippi river using sediment rating curves and found out that the sediment rating curves can be used for best evaluation of annual sediment load in a 20-year period [9]. Eder et al. addressed the study of suspended sediment load regarding hysteresis effects and found out that some parameters such as rainfall amount, water percentage of soil and maximum rainfall intensity are affective on suspended sediment load [10].

Dez River is one of the most important rivers in western south of Iran. It is used as one of the main water resources and much water management planning is carried out on it. In this paper, the sediment yield of Dez River branches has been studied using United States Bureau of Reclamation (USBR) hydrological methods. Then, the portion of each branch in sediment yield has been determined. Finally, measured and estimated values have been compared and the portion of the each branch has been selected.

2. METHODS AND MATERIALS

Hydrological methods are used to estimate suspended sediment load in rivers. The common tool for suspended load assessment is sediment rating curve. According to numerous researches and technical reports, the following relation is presented by USBR:

$$Q_s = aQ_w^b \tag{1}$$

where Q_s is the sediment discharge (ton·day^{-1}), Q_w is water flow discharge (m^3·s^{-1}), *a* and *b* are constants of equations. The above equation is obtained from the exponential regression relationship between sediment load and flow discharge which are measured directly. One of the most important applications of rating curve is for predicting annual sediment yield. Checking results of empirical equations and numerical models is another application of this curve.

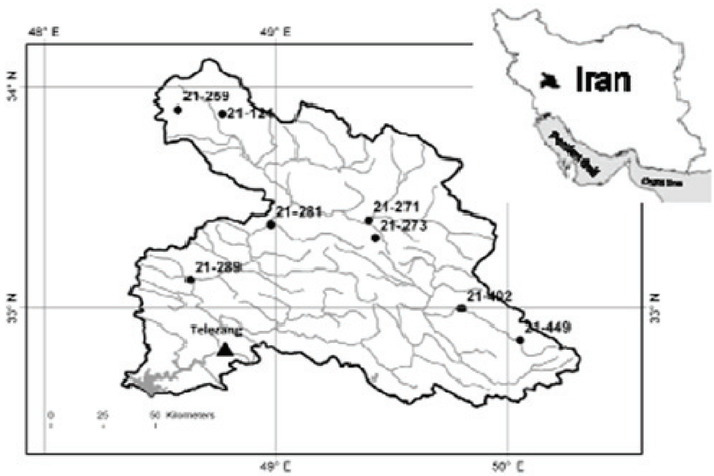

Fig. 1. Map of the Dez basin

Dez dam (fig. 1) is located in the 25 km of northeast of Dezful. Its longitude and latitude are 48°28′ and 32°57′, respectively. The minimum and maximum altitudes of Dez basin are 19 m and 4124 m, respectively. The average altitude of Dez basin is 1676 m. This basin is located in the west of Zagros mountain. According to its hypsometric curve, only 8% of total area has altitude less than 1000 m. Dez River has two main branches: Bakhtiari branch and Sezar branch. In this regard, daily flow and sediment information of three hydrometric stations are used. These three stations are: Bakhtiari Tang Pang (BTP), Sezar Tang Pang (STP), and Taleh Zang (TZ). The geographical features of the stations are given in Table 1. It is worth noting that Taleh Zang Station is the last station before Dez dam; in other words, this station measured total sediment yield, which enters to the dam reservoir. According to measured values, mean annual sediment load (MASL) of BTP, STP and TZ stations are 10.2, 5.2, and 17.5 Mm^3, respectively.

Table 1

Geographical features of hydrometric stations

Station	Longitude	Latitude	Altitude [m]	Area [km^2]
STP	48°46′	32°56′	600	9206
BTP	48°45′	32°45′	540	6390
TZ	48°46′	32°49′	480	16213

Derivation of sediment rating curve. Using sediment flow data, sediment rating curves were derived for STP, BTP and ST stations. In these stations, flow rating curve has been used to measure flow discharge. The flow discharge measurements covered 9–1119 $m^3 \cdot s^{-1}$, 9–710 $m^3 \cdot s^{-1}$, and 39–2133 $m^3 \cdot s^{-1}$ in STP, BTP, and TZ stations, respectively. Flow discharge statistical properties of measured and calculated flows and sediment discharges are presented in corresponding subsections. Table 2 shows a and b coefficients in each station, r represents the correlation coefficient of the exponential curve between Q and Q_s.

Table 2

Coefficients of the sediment rating curve in USBR equation

Station	USBR Relationship		r
	a	b	
STP	0.2131	2.0744	0.9232
BTP	0.0618	2.2774	0.8906
TZ	0.0649	2.1413	0.9039

Three different scenarios were used to evaluate the mean annual sediment load (MASL) in each station based on sediment rating curve in this research: (1) using mean value of sediment discharge, (2) using probabilistic classification of river flow data, (3) using separation of wet months and dry months. The third method was used as a technique for the two early methods. These three scenarios have been discussed in the next sub-sections.

Mean value of sediment discharge. By this method, regression equation of power type (USBR equation) was used to calculate the daily sediment discharge corresponding to the daily flow discharge. Then, the MASL was determined for each station. Table 3 shows the results of these calculations for three stations. In the table, STDEV represents standard deviation of data. In Figure 2, the results obtained by this method and measured values are shown.

Table 3

Amount of MASL using the first scenario for three stations

Station	No. of data	Measured values				Calculated values			
		Mean [10^6 m^3]	STDEV	Max [ton·day^{-1}]	Min [ton·day^{-1}]	Mean [10^6 m^3]	STDEV	Max [ton·day^{-1}]	Min [ton·day^{-1}]
STP	327	5.2	72640.9	839745	13	14.3	42836.6	449859.2	20.3
BTP	260	10.2	161427.5	2286761	33	6.8	97540.2	1207397.5	9.2
TZ	401	17.5	157572	2326280	36	9.3	83103	870850	165

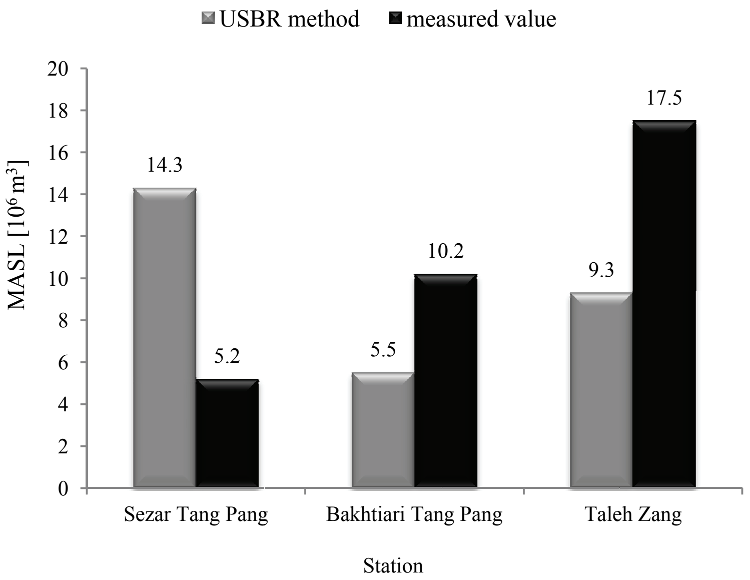

Fig. 2. Result of the first scenario

Probabilistic classification of river flow data. By this method, daily flow discharges were classified into different groups. Then, probability of each class was determined. The probability mean discharge graphs were plotted for the mean value of each class. Table 4 shows the annual sediment load calculated based on probability discharge graphs for each station. According to Table 4, the sediment yields in three stations were calculated. The results are given in Table 5, cf. Fig. 3.

Table 4

Annual daily average sediment discharge in three stations using USBR equation

Probability classification	USBR Relationship		
	STP station	BTP station	TZ station
0.01–40	42.60	182.88	231.80
40–50	34.01	221.71	218.19
50–60	86.85	335.83	412.35
60–70	214.27	558.24	706.27
70–80	438.16	1137.04	1307.69
80–90	1016.06	2312.84	2687.87
90–95	1270.39	2756.21	2884.50
95–98	1767.56	3228.58	3035.35
98–99	1457.78	2526.30	2112.41
99–99.8	2909.63	3436.53	3053.32
99.8–99.9	476.10	903.61	977.85
99.9–99.99	1123.19	1441.41	1102.80
Total [ton·day^{-1}]	10836.60	19041.18	18730.40

Table 5

Amount of MASL by the second scenario for three stations

Station	No. of data	Measured values				Calculated values			
		Mean [10^6 m^3]	STDEV	Max [ton·day^{-1}]	Min	Mean [10^6 m^3]	STDEV	Max [ton·day^{-1}]	Min
STP	327	5.2	72640.9	839745	13	3.3	371803.5	1828542.5	6.0
BTP	260	10.2	161427.5	2286761	33	5.8	866058.8	4032517.9	29.5
TZ	401	17.5	157572	2326280	36	5.7	628130.0	3003553.1	51.0

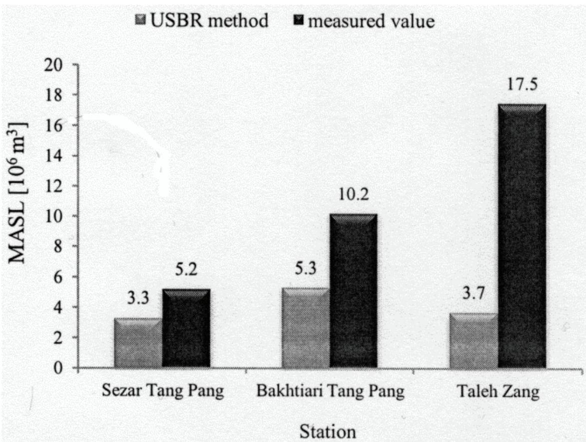

Fig. 3. Final results of the second scenario

Separation of wet months and dry months. By this method, annual average of flow discharge for each station was considered as criteria for classifying wet months and dry months. The results are given in Table 6. According to the calculations, different values for constants, *a* and *b* of the USBR equation for wet and dry months are given in Table 7.

Table 6

Wet months and dry months in three stations

Sezar Tang Pang				Bakhtiari Tang Pang				Taleh Zang			
Annual mean discharge 115.14 ($m^3 \cdot s^{-1}$)				Annual mean discharge 144.83 ($m^3 \cdot s^{-1}$)				Annual mean discharge 198.5 ($m^3 \cdot s^{-1}$)			
Wet month	*Q*	Dry month	*Q*	Wet month	*Q*	Dry month	*Q*	Wet month	*Q*	Dry month	*Q*
XII	134.2	XI	20	III	215	X	45.9	I	210.9	VII	156.1
II	140	X	54.4	IV	325.4	XI	60.3	II	288	VIII	102.7
III	225.6	I	109	V	312.7	XI	100	III	217.2	IX	72.3
IV	324.3	VI	84.1	VI	185	I	103.3	IV	255.7	X	69.4
V	197	VII	43.1			II	143.6	V	459	XI	103.1
		VIII	28.8			VII	114.8	VI	262.4	XII	185.6
		IX	21			VIII	77				
						IX	56.2				

Table 7

Coefficients of the USBR relationship in wet and dry months

Station	Wet months			Drymonths		
	a	*b*	*r*	*a*	*b*	*r*
STP	0.4445	1.9360	0.9052	0.1998	2.0701	0.8497
BTP	0.0484	2.3191	0.8945	0.0598	2.2870	0.8025
TZ	0.0630	2.1516	0.9123	0.1503	1.9473	0.8234

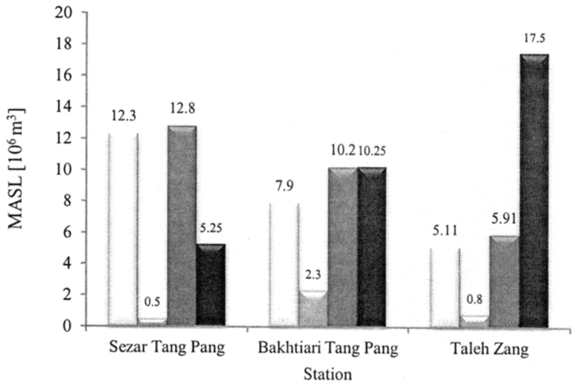

Fig. 4. Results of the third scenario

Table 8

Prediction of the sediment load for the Sezar Tang Pang station during wet and dry months

Probability classification	USBR Relationship	
	Wet month	Dry month
0.01–40	798.12	12.32
40–50	650.55	13.30
50–60	959.38	21.35
60–70	1766.24	38.89
70–80	2330.01	71.27
80–90	6511.58	139.78
90–95	9016.75	247.27
95–98	5872.17	161.95
98–99	6285.28	182.82
99–99.8	5117.48	387.68
99.8–99.9	645.31	178.57
99.9–99.99	581.85	161.03
Total [ton·day^{-1}]	40534.71	1616.22

Table 9

Prediction of the sediment load for the Bakhtiari Tang Pang station during wet and dry months

Probability classification	USBR Relationship	
	Wet month	Dry month
0.01–40	1546.12	110.30
40–50	990.07	57.14
50–60	1290.41	77.38
60–70	1843.05	122.24
70–80	2520.30	201.34
80–90	4175.34	340.24
90–95	3627.14	242.03
95–98	3940.05	1584.00
98–99	2957.47	2372.46
99–99.8	2416.42	1938.06
99.8–99.9	305.25	244.77
99.9–99.99	275.29	220.74
Total [ton·day^{-1}]	25886.91	7510.70

In addition, flow discharge in each station was classified and finally, probability–mean discharge curve was plotted. Tables 8–10 show annual sediment load in STP, BTP, and TZ stations regarding wet and dry month classification and probability discharge curves, respectively. The results presented in Tables 8–10 are compared in Table 11. Figure 4 shows the results of the third scenario.

Table 10

Prediction of the sediment load for the Taleh Zang station during wet and dry months

Probability classification	USBR Relationship	
	Wet months	Dry months
0.01–40	313.31	122.27
40–50	396.62	58.87
50–60	562.65	76.36
60–70	909.39	85.92
70–80	1346.22	117.91
80–90	1992.88	259.69
90–95	1934.36	179.23
95–98	2696.28	211.98
98–99	2203.95	221.34
99–99.8	3194.70	477.15
99.8–99.9	548.17	230.02
99.9–99.99	717.93	558.90
Total [ton·day^{-1}]	16816.46	2599.64

Table 11

Probability classification for wet and dry months

Months	Statistical properties	STP		BTP		TZ	
		measured	calculated	measured	calculated	measured	calculated
Wet	Mean [ton·day^{-1}]	22252.8	16983.7	30452.5	34705.1	64083.0	48847.0
	STDEV	74705.1	43011.5	128178.1	124344.5	197216.0	104308.0
	Max [ton·day^{-1}]	355145.9	839745.0	6312168.6	6398179.4	2,326,280	916215.0
	Min [ton·day^{-1}]	59.0	243.9	1.5	0.5	91.0	588.0
Dry	Mean [ton·day^{-1}]	11419.5	3567	3081.7	5038.4	10189.0	5197.1
	STDEV	69761.3	17897.7	49895.8	51941	58089.3	23922.1
	Max [ton·day^{-1}]	624323.0	165216.5	3580541.5	3680437.0	728916.1	283171.3
	Min [ton·day^{-1}]	13.0	18.9	0.1	0.03	36.0	188.0
Total [10^6 m^3]		5.2	12.8	10.2	10.2	17.5	5.9

3. RESULTS AND DISCUSSION

Applying of the USBR equation is a hydrological method used to evaluate sediment load in natural streams. Dez River located in the southwest of Iran is one of the main resources for water supply. In the paper, USBR equation was applied to evaluate the portion of each branch in the total sediment load of the Dez River. Sezar Tang Pang, Bakhtiari Tang Pang, and Taleh Zang are three hydrometric stations whose measured data were used in this research. The Taleh Zang station is the last one before the Dez dam. This station measured total load of sediment which should be equal to sum of Bakhtiari Tang Pang and Sezar Tang Pang stations, analytically. Three scenarios were used to evaluate MASL: using the mean value of sediment discharge, using probabilistic classification of river flow data, and using separation of wet and dry months. Significant differences were found between calculated and measured values based on the mean value of sediment discharge (Fig. 2). This scenario is not recommended for each station, but the sum of STP and BTP values satisfies sediment mass continuity. The corresponding errors for STP, BTP and TZ stations are 172.3%, –33.3% and –47%, respectively. The USBR equation used in the second scenario underestimated the obtained values (Fig. 3). The differences between measured and estimated values are significant. The errors in sediment load predicted for STP, BTP and TZ stations are –37.1%, –43.4%, –67.4%, respectively. The second scenario can be considered as an approach to evaluate sediment load in three stations. Figure 4 shows good agreement between measured and estimated values in BTP station. The errors of sediment prediction in STP, BTP and TZ stations are 144%, –5% and –66.2%, respectively. The ratio of sediment load in wet and dry months to total sediment load in BTP station is 77.4% and 22.6%, respectively (Fig. 4). It can be concluded that:

- The application of the USBR equation based on scenarios used gives significant errors in the MASL predicting. The second seems to give the least errors.
- The USBR equation can be used to evaluate MASL in BTP station using wet and dry month separation method with probabilistic classification of flow discharge approach.
- The application of the USBR equation based on the first scenario is recommended to estimate MASL of the Dez River basin.
- Inaccurate measurement of flow discharge may be due to big difference between the measured and calculated sediment loads in STP station.
- As is seen, there is no mass balance between sediment load in STP, BTP and TZ stations. This may result from inaccurate flow and sediment discharge measurements in the stations.

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