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A Study on Sedimentation in Sefidroud Dam by Using Depth Evaluation and Comparing the Results with USBR and FAO Methods

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Abstract. One of the fundamental issues with the operation of surface water resources is erosion, and sediment transport. Reducing the reservoir's useful life and declining the reservoir storage are subsequences of erosion and sediment transport. These natural events occur in different geographical circumstances. Since the major part of the watershed sedimentation consists of suspended sediments, the amount of suspended loads, has a special priority. (Kişi 2007) Determining the amount of erosion or sediment transportation is practically very difficult. So far different methods have been proposed and among are methods for estimating the suspended load of rivers, hydrometer station sediment survey, sediment rating curve approach, depth evaluation and extrapolation are common. In order to determine the density of sediments, rating curve methods are the most popular. The rating curve method uses power relations fitted curve water discharge and sediment discharge. Hydrologists use rating curve methods in the case that there is no real suspended load, or if the sedimentation data is not accurate enough and remarkable differences in results are observed between measurement data and outcome, or when there are no long term measurements. It should be noted that measuring and monitoring the amount of suspended load by using depth evaluation method is costly. In this study, the FAO and USBR approaches are used to estimate the performance of sediment rating curve methods, and the results are compared with the results of the depth evaluation of Sefidroud watershed. The results of this study indicate that USBR method can be introduced as an optimization method in the Sefidroud watershed by using classified statistics.

Keywords: Rating curve method, FAO, USBR, sedimentation, depth evaluation

1. Introduction:

Estimating the useful life and economic yield play an important role in the initial design of dams. Useful life is the time it takes for a reservoir to be filled with sediment input from upstream water sources. In some cases reservoirs are filled faster than was expected, or before the end of their anticipated useful life.

The annual decrease of reservoir capacity due to sedimentation ranges from approximately from 0.5% to 1% of the total reservoir volume, which for many dams is much more than 4% or 5% , so subsequently most of the dams lose their ability to store water after 25 or 30 years (Verstraeten, Poesen et al. 2003) . The following are three factors that cause incorrect estimation of the useful life and economic efficiency of a reservoir, therefore filling the reservoir faster than predictions. 1-Lack of Statistical Year: more annual available data from water discharge and sediment discharge will allow for a better estimation of sediments in comparison with what happens in reality. 2- Ignoring standards of sampling: some elements like ignoring the manuscript of sampling, over concern with samples in lower discharge ranges, choosing most samples from fixed points and the insufficiency of the amount of samples in flood discharges cause inaccurate calculations of sediment estimation. 3-Choosing an inappropriate method to estimate water. In order to customize the sedimentation in the watershed, there are different approaches. Experts use different methods and each method leads to different results.

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One of the most important examples of a famous early filled dam is the Kebec dam located 10 km far from Ankara in Turkey in which 60% of reservoir volume was lost in over 30 years. (Simons and Şentürk 1992). Another case was in Yasuoka dam reservoir in Japan, 85% of the reservoir capacity was again lost in the span of 13 years (KANTOUSH and SUMI 2010). Even the reservoir of the dam which was built on the Salmon River in Kansas State in the U.S was filled completely after 1 year. One of the dams in Iran that faced a similar dilemma of over sedimentation is Sefidroud dam About one sixth of the reservoir volume is considered reservoir dead storage, while a lifetime of 100 years was predicted for it. But a remarkable amount of sediments continue to cause a decreasing volume rate of 4% annually. Thus the maximum span of its useful life will not exceed 30 years.

Morris made a series of empirical models for estimating reservoir sediment load, based on mapping and field observation (Morris and Fan 1998). Sharifan and Koochakzade estimated the amount of suspended load of the prominent rivers in Golestan province daily and annually, using USBR method (Sharifan 2002). Morehead et al (2003) indicated that changes in the amount of sediment being transported is more associated with discharge changes (Morehead, Syvitski et al. 2003). The results of Sadeghi's (2005) studies express the ability of the regression concept to produce two separate equations for falling and rising branches of the hydrograph (Sadeghi 2005). Sarangi and Bhattacharya (2005), Dehghani et al. (2009) compared the sediment rating curve method with artificial neural network, to estimate the amount of suspended sediment and the results revealed the high accuracy of artificial neural network approach in forecasting the amount of sediment suspended discharge load (Sarangi and Bhattacharya 2005; Dehghani.AA 2009). Furthermore, Achite and Ouillon, stated that in regression equations, the predicted values are 20% to 25% more than the real values and according to available time series, long term periods are needed to estimate in a more accurate manner (Achite 2007). Abolvaset and Shabradfar (2007) calculated the suspended load by using an input scale discharge, monthly temperature and Levenberg Marquardt method (Abolvaset 2007) . Shoushtari and Kashefipour (2007) stated 3 input discharge, precipitation over the rest of the day before ,with the width of the water level to be more affect by the amount of suspended load rather than other parameters (Shoushtari 2007). Because of the high cost of the continuous measuring and monitoring of transport sediment in rivers, the normal sediment rating curve is used (Kalvandi SM 2010). Of sediment rating curve methods, FAO and USBR can be mentioned. This study aims to investigate the reasons of the premature filling in the reservoir of Sefidroud dam by using depth evaluation method, and compare the results with FAO and USBR.

2. Materials And Methods:

Case study: The geography and natural structure of Sefidroud lake watershed. The Sefidroud watershed is located in the area of Alborz Mountains and Zagros mountains one across the other. This watershed coordinates are between 46.30^0 to 51.13^0 east longitude, and 34.55^0 to 37.52^0 north latitude. The area of the watershed is almost 55000 km^2. About 73% of watershed area is located in the mountainous regions and the rest of it is located on the plains and foothills.

Sefidroud is the largest river in terms of watershed area, and it contains the superlative volume of water among other rivers in the central and northern part of Iran. It is the confluence of River QezelOzan and River Shahroud that meet in a town called Manjil. The highest level of the watershed is 4820 m above sea level, and the minimum level is 27 m below the sea level.

Sefidroud dam profile: the purposes of building the Sefidroud dam were civil construction development, economic improvement, flood control, regulation of Sefidroud river, creation of an adequate and reliable water source to supply water for 240000 hectares of Gilan area, and using hydroelectric potential energy. Sefidroud dam is a buttress- type concrete gravity structure one, and its height is 106 m (White 2001). The crest length is 425 m, and the reservoir capacity was 1800 MCM at the beginning of operation. Approximately 600 MCM of this capacity is allocated for dead storage. The drain facilities can drain around 6000 m^3/Sec and the annual adjustable water volume is 1650 MCM. The under cultivation area is 188000 hectares, and the installed power is 87500 m^3/Sec. The maximum and minimum discharge during a statistic period are 2300 m^3/Sec and 0.5 m^3/Sec respectively. The average discharge is 119.20 m^3/Sec and the normal storage is 1276 MCM, finally the crest storage is 1760 MCM.

Input and output stations in Sefidroud dam: Sefidroud has two entrance stations one is called Gilvan, which is on River QezelOzan, and the other is called Oshan on River Shahroud. An output station was constructed on Sefidroud River called Roudbar. The trapping coefficient can be calculated by statistics and information gotten from stations. Table 1 shows the statistic quantities of daily discharge and sampling of sediments

Table 1. Sefidroud dam stations' data

		Gilvan station	**Loshan station**	**Rodbar station**
Position	River construction site	Ghezel OzanRiver	Shahroud River	Sefidroud River
	The nearest town to the station	Manjil	Loshan	Rodbar
	Longitude	49,1'	49,31'	49,1'
	Latitude	36,5'	36,37'	36,5'
Daily Flow (m3/ s)	Maximum	2425	895	2425
	Minimum	0	1.44	0
The moment Discharge (Corresponding sediment) (m3 / s)	Maximum	2380	475	2510
	Minimum	0.62	0.34	2.02
Sampling years	Year of construction	1961	1955	1949
	The sediment water discharge	65-42	65-42	65-43
	Years of daily discharge	72-42	72-42	72-42
	No of years of daily discharge	26	23	22
Number of samples	CM cross sections	2111	1877	345
	Fixed point CF	11092	8118	7304
	Overall CM, CF	13203	10695	7649
	Average Daily	0.64	0.25	1
Sediment concentration (gr / lit)	Minimum	0.039	27	0.012
	Maximum	41	289	93

3. **Methodology**:

Different methods are used to measure sediment volume. There are also many methods used to calculate the amount of annual sediment in which one approach is to use the sediment rating curve formula.

USBR method: This method was first proposed by the US soil conservation services and was formulated by the United States Bureau of Reclamation that applied in to most development projects related to water and soil.

$$Q_s = a\, Q_w^{\ b} \qquad (1)$$

The measuring of river's suspended load and corresponding volume passing is done in a limited manner, and normally for low quantity of Qw, the amount of Qs is estimated, whereas the real discharge is considerably different. So using one or two numbers as an average discharge of the river and estimating the suspended load discharge based on the above statements cannot be reliable. USBR has suggested flood during curve.This curve which is known as a class of curves is from where the river draws a cumulative discharge in relation to time. By using this curve, it was possible to estimate the amount of water obtained based on river discharge statistics for different probabilities and this approach indicates the percentages of time that a river discharge is equal to or greater than a certain amount in the statistical period.

FAO method: From statistics point of view the distribution of data around the best fit line is asymmetrical and the distance of the upper limit of the regression line is greater than the lower limit in USBR method because in order to calculate the sediment rating curve, data logarithms are used.

This cause the estimated suspended load for discharge, Qw to get close to the minimum quantities in reality. On the other hand by substituting the average discharge, Qw during statistic period, the average sediment rating equation of suspended load, Qs was being obtained. This circumstance can be seen in arid and semi-arid regions where the data distribution is high. Therefore in order to balance the quantities and approximations of the estimated quantities to observed quantities, FAO suggested to substitute coefficient a' instead of coefficient an in water discharge equation as follows below. The other calculation of FAO is similar to the USBR approach, in other words this method is the modified form of USBR.

$$a'=\frac{\overline{Q_s}}{\overline{Q_w}^{\,b}} \qquad (2)$$

4. Results:

Depth evaluation results: Since 1962, the depth evaluation has been done several times. In this study the reports released in the year 1976 and 1970 has been used and by reviewing the reports it was understood that almost 44. 25 million tones sediments leave in dam annually .

The most sediment transportation occurs in spring. 65% of Gezel Ozan suspended load and 77% shared suspended load were transported in this Season. In addition the input flow in this season includes 65% of whole annual input flow for the reservoir.

Table 2. Calculation of the depth of deposition of different methods and results of using CM

(The average annual sediment tons per year)

Station name	**Period**				**USBR**			**FAO**		
		The daily method	Weighted average of annual sediment in depth evaluation method (million tons per year)	Visual curve fitting methods based on a concentration of lines	A correlation curve	Two correlation curves	Moderate categories	A correlation curve	Two correlation curves	Moderate categories
Gilvan	1962-1970				39144	43043	50457	146597	21194	73109
	1970-1976				34213	36620	39206	84090	107796	44478
	Entire period of operation			39774	27964	31262	39467	80106	188784	46176
Loshan	1962-1970				30412	23048	21341	191719	56380	30654
	1970-1976				7467	7678	10863	25463	2181	17308
	Entire period of operation			11719	10021	11026	12360	44768	31618	17537
Rodbar	1962-1970				1159	950	1434	23802	47614	22383
	1970-1976				1897	3555	5373	9136	14217	12036
	Entire period of operation			3208	569	683	3313	7993	9196	10366
Total input and output of total volume (thousand tons per year)	1962-1970	60785	55.46		68396	65141	70365	314514	218960	81379
	1970-1976	30339	44.9		39783	40743	44696	100116	95317	49750
	Entire period of operation	39744	44.25	48285	37415	41605	48514	116882	211206	53347

Qezel Ozan long branch and crosses from many wastelands that fight with erosion, this cause sedimentation, which contain 84% of the whole sediments that enter the Sefidroud river each year. But Shahroud watershed is much smaller than Qezel Ozan watershed. In addition, in terms of geological form, it is harder because it contains igneous rocks so that the sediments from this river are less than that of Qezel Ozan which contains 16% of the entire sediments in Sefidroud reservoir. The input sediment materials from Qezel Ozan is 68% and that from Shahroud is 6%. In fact, materials entered Qezel Ozan are 5 times more than Shahroud and sediments settles 11 times faster than Shahroud. The average amount of water entering is 4.5 billion m^3 each year. 90 % of the entire solids enter during the flood months. Flood months start from 05 March to 04 of June which carry almost 79% of the water volume.

Table 3. Results of Hydrological calculation deposition techniques using CM, and deposit figures are calculated relative to the depth values to use in CM statistics

				USBR			FAO		
	Period	The daily method	Weighted average of annual sediment in depth evaluation method (million tons per year)	One correlation curve	Two correlation curves	Moderate categories	One correlation curve	Two correlation curves	Moderate categories
Calculations of hydrological sediment methods using the results of CM, for the Sefidroud Dam	1961-1970			68396	65141	70365	314514	218960	81379
	1970-1976			39783	40743	44696	100116	95317	49750
	Entire period of operation			37417	41605	48514	116882	211206	53347
Sediment figures calculated relative to the depth valuesto use in CM statistics	1961-1970	0. 96	55.46	1.233	1.175	1.269	5.671	3.948	1.467
	1970-1976	0.676	44.9	0.886	0.907	0.995	2.23	2.123	1.108
	Entire period of operation	0.898	44.25	0.846	0.94	1.096	2.641	4.773	1.206

Table 4. Results of Hydrological calculation deposition techniques using CM, and deposits are calculated in the depth values of the statistics used in the CM, CF

		FAO			USBR			Weighted average of annual sediment in depth evaluation method (million tons per year)	The daily method
		Moderate categories	Two correlation curves	One correlation curve	Moderate categories	Two correlation curves	One correlation curve		
Sediment calculation results by applying hydrological using a combination of methods CM, CF for the sefidrud dam	1961-1970	71731	193716	310851	60789	59187	65828		57020
	1970-1976	54963	48891	65756	41898	37685	34894		32701
	Entire period of operation	36285	36853	50273	27614	26685	30365		38527
Sediment calculated by using depth evaluation values in the CM, CF mode	1961-1970	1.293	3.493	0.561	1.096	1.067	1.187	55.46	1.028
	1970-1976	1.224	1.089	1.465	0.932	0.839	0.777	44.9	0.728
	Entire period of operation	0.82	0.833	1.136	0.85	0.603	0.686	44.25	0.871

5. Conclusion:

The amount of estimated sediment measured by experimented methods in this study depends on certain factors, but accuracy, quantity, even distribution and adequate daily sampling containing flood and non-flood times are the factors that should be stronger emphasized.

Compilation of statistics for fixed-point CF and intermediate point CM, leads to more even results in terms of estimation.

In watersheds that sampling was not done during the flood or they were done a few times, the estimated sediment by USBR approach was less than the settled sediments, because in USBR approach the estimated quantity was affected by sediment minimums.

In basins that statistics were available both in flood months and non-flood months, the estimated quantities by FAO approach were more than settled sediments. That is because coefficient a' increased and the results were affected by maximum sediment estimation quantities.

It can be seen that the results of the USBR method by using two curves correlation and the results of the USBR method by using categorized data and the results of visual curve fitting method based on concentration of lines are all close to results of depth evaluation method. The first and the second mentioned methods got less and more value respectively compared to depth evaluation method values. Of course by using the visual curve fitting method, we get a value closer to what was attained in depth evaluation method. However, because this method depends on expert statement, USBR is introduced by using categorized data as the optimum method for Sefidroud watershed.

In Iran's watersheds, it is not recommended to use USBR approach by using one curve correlation because of the inappropriate sampling.

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