Eco. Env. & Cons. 18 (4) : 2012; pp. (835-847)
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ISSN 0971–765X

Estimation of sedimentation in Karaj and Torogh Dam reservoirs (Iran) by hydrological models and comparison with actual sediment

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(Received 10 June, 2012; accepted 25 July, 2012)

ABSTRACT

The most important practical and critical problem related to the performance of reservoirs is the estimation of storage capacity loss due to sedimentation process. Sedimentation triggers several important issues such as operation and maintenance of engineering infrastructures, economical feasibility of the project, environmental problems with social aspects upstream and downstream, increasing evaporation from the surface of the reservoir and reduced flood attenuation and changes in water quality. Palmieri et al. (2001) reports, that the loss in volume capacity requires an annual replacement cost of US$ 13 billion dollars. Although suspended sediment load can be predicted using numerous developed methods including remote sensing, hydrographic survey, hydrologicy and mathematical and computer models their results often differ from each other and Every of these equations are gained based on climate or laboratory conditions in different places in the world and they have different factors for determining transporting sediment amount. These methods are cumbersome, time consuming and expensive. There is a need for developing simple methods, which require less time and are cost. In the present study, six different hydrology models were tested using measured data based on effective factor of sediment transfer such as time of measurement for determining suspended sediment load on the reservoirs of Karaj and Torogh on the Karaj and Torogh Rivers catchments area, which are located in Iran between 1961-2007 and 1978-2009 respectively. At the end, the results of developed models were compared together and with actual amount of sediment obtained from primary and secondary area –volume height- curves. The Mean Squared Error (MSE), Root Mean Squared Error (RMSE), are used as error evaluation criteria to verify, and compare the results of developed models and select the best model. The results of this research demonstrated that the model B, based on a monthly data analysis, had the least root mean squares errors for the inlet hydrometrical stations of Karaj and Torogh Dams and was selected as the best model. The volume of annually sedimentation in Karaj dam between the years 1961-2007 was 4810000m^3 while the annual sedimentation by means of hydrograph was estimated 510000m^3, which confirms the high accuracy of the model. The model A based on total data analysis and without separation of data had the highest root mean squares errors in Karaj hydrometrical station and was the most undesirable model.

Key words : *Sedimentation, Dam reservoirs, Surface-volume-height curve, Karaj reservoir, Torogh reservoir, Root Mean Squared Error*

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Introduction

Sedimentation in dam reservoirs is one of the fundamental problems in water resources utilities and designing Hydraulic structures after construction of a dam. Deposit of the sediment materials, which are transferred from land surface, valleys, and mountains, in dams reservoirs not only decreases the dam volume, have a direct effect on agriculture, decrease drinking water and reservoir installations, but also forms swamps in upper lands causing more powerful erosion in downstream and consequently lower flood control of the reservoirs. Therefore, it may come to hinder the reservoir operation, besides causing several kinds of environmental problems. Reservoirs around the world are losing on average about one percent of their storage capacity annually (WCD, 2000), causing serious problems for water and electricity supply, flood control but also for ecosystem development up-and downstream of large dams.

The problems of sedimentation in reservoirs is increase throughout using this installation. Each year about 20 billion tons of sediments are transported by the rivers of the world and deposited in still water (Mirbagheri, 1989). In Iran due to lack of taking any serious action and protecting water resources, considerable damages are caused due to flooding and sedimentation so that over 100 million tons of sediment is deposited annually in reservoirs and reduces manageable capacity due to sedimentation (Masjedi, 1999).Therefore, paying more attention than before to the problems of erosion and sedimentation has been followed more seriously. According to the Iranian Committee of large dam's report, erosion and sedimentation are two of the most important problems of 21st Century.

Because of higher water rate consumption the significance of studying sedimentation in reservoirs (either directly or indirectly) is more emphasized.

Sedimentation is regarded as a very serious and important natural hazard in developing countries. The World Bank has estimated the equivalent lost capacity of dam reservoirs, only resulted by sedimentation, to be 6 billion USD per year in 1999 that, of course, will increase by construction of more reservoirs (Fan, 1999). Hence, estimation of suspended load in rivers, which constitutes the major part of sediment deposited in dam reservoirs, is of paramount importance. The performed investigations demonstrate that the annual average economic losses in America's Dam reservoirs are $50 million, but such an economical analysis has not been performed for Iran. According to a comparison that was done in 1999 between Iran's Dams and similar dams in the U.S.A., the annual average loss of reservoirs volume due to sedimentation was 6-11 times further than those of United States. The average annual percentage decrease of reservoir capacity due to sedimentation has been 0.60%, and the annual deposition yield of watersheds of Iran has been about 8 tons per hectare; and only 10% of these sediments are passed of dams and the other 90% is settled at the bottom of the dams (Montazereion and Aminnejad,2010).

The phenomenon of sedimentation is something accidental and complicated. The amount of sedimentation depends on different factors such as the surface of watershed, vegetation, geological, and rainfall time and location distribution, its duration etc. Sediment estimation in dams' reservoirs is a very complex problem due to existence of unknown factors for evaluation of reservoir's sediment and its volume. These items depend upon flow rate, total sediment load, the size of the sediment, density, trap efficiency and reservoir yield. There are different methods for estimation of sediment in the reservoirs like hydrography, using mathematics and computer methods, direct measurement of the sedimentation thickness. . But, because of techniques' differences and complexity of sedimentation and environmental conditions, one cannot recommend a comprehensive, economic, and exact method.

Miraboulghasemi (1994) studied various methods of estimating suspended loads of the rivers, and compared the obtained results with those of hydrographic studies (depth estimation) of Karoun Dam; and demonstrated that the selected method was of high accuracy. Shahidi (1995) estimated the sediment entering the dam reservoir in Khozestan province using six hydrological methods and compared it with the actual amount of sediment deposited behind Dez Dam. Using sediment rating equation and correlating the average of classes, he found that this method gave almost results as actual measurement.

Akrami (1996) investigated six hydrological methods of sedimentation in Latian(Tehran), Sefid Rood(Gilan), Esteghlal(Minab), Ekbatan(Hamadan), Mahabad (western Azarbaigan), Doroodzan(Fars), and Dez Dams(Khozestan) in different parts of the country and demonstrated that the FAO method (by means of classified data) gave a closer result to sedimentation studies.

Piri (2003) studied optimize relationship between water and sediment discharge in Emameh watershed. He found out that the common models for estimating sediment that makes use of only one equation as sediment rating equation have the most error among other models, but the model which was based on dry and wet months and discharge classification resulted in the least square errors.

Porhemmat *et al* (2005); Azami *et al* (2005), Yousefvand *et al* (2006) and Mosaedi *et al* (2005) showed that the average categories method was effective in improving relationship and the coefficient correlation of water and sediment discharge extremely increased and took into account the effect of seasons as well.

Tarkhorani (2001); Mohammadi OstadKelaye (2002), Mirzaei (2002); Arabkhedri *et al* (2005), and Heidarnejad (2006) demonstrated that the highest amount of root mean squares error was related to annual USBR.

Bayatiyani (2001) studied the amount of sediment transferring in Nabera River in 1986-1991 and found out that the relationship between sediment load and daily discharge ($Q_s = 3.72\times10^{-7} Q_w^{1.88}$) in the 99% confidence level is acceptable. Finally, he found that special sediment load, which was about 296.5 tons per square kilometer to 1287 tons per square kilometer, was changing in years 1986-1991.

Asselman (2000) evaluated the sediment rating curve as an exponential function in several locations of the Rhyn River and it branched and analyzed the errors and mistakes of this evaluation and found that unique differences in the forms of these diagrams were dependent on sediment load characteristics. He also used from root of mean squares errors to find the best model.

Horowits (2002) evaluated the Mississippi River suspended load using sediment rating curve, he found that in order to have the best investigation of the annual sediment load in 20 year data set, sediment rating curve can be used.

Benkhald *et al.* (2003) performed a qualitative analysis for the amount a and b of sediment rating curves and demonstrated that there is a strong relationship between the amount of (a) and water discharge in dry years and factor (a) showed a correspondent erosion with water discharge in dried year period, While factor (b) was correspondent to water discharge only during rainfall period. Their researches demonstrated that the relationship between sediment capacity and water discharge was under the effect of rainfall, the amount of runoff, and soil moisture.

Alexandrov *et al.* (2007) illustrated that the methods which are based on precipitation in spring and autumn that the result of flood flow are related to water discharge, and the methods based on winter rainfalls are relateted to the type of running.

Achite *et al.*(2007) firstly explained that the predicted amounts were 20-25% more than real amounts. Secondly, according to available time series, more precise predictions need longer time periods. Also, the most amounts of sediments were due to spring and autumn. They also suggested that for more accurate investigation, climatologically changes should be considered.

Shahouyee (1995) investigated the amount of sediments in Qeshlagh Dam reservoir. The amount of annual erosion was about 143 tons per square kilometer, and it was 1/3 less than the suggested amount. Rahnamaei (1995) studied mathematical - experimental methods for estimating sediment in dam reservoirs, and compared their results with field measurements for Karaj Dam.

Mutsvangwa (1999) studied sediment deposition for some dams in Zimbabwe using mathematical and experimental methods and concluded that experimental methods were give better results than mathematical method.

Syvitski *et al* (2000) studied the relationship between sediment rating parameters and environmental conditions (morphology, river, climatology …) in 59 hydrometric stations in North America and found the sediment rating equation coefficients and concluded that there is a close relationship between environmental variables and sediment rating coefficients for rivers with 20 cubic meter per second water discharge.

Ferrari *et al.* (2006) demonstrated that the shape and how the operation of the reservoir are effective on the location and type of sedimentation.

Jain (2001) developed sediment rating curves by means of Artificial Neural networks (ANN) for sediment volume in the Mississippi River and observed that the results of this method was close to the observed amounts in comparison with common techniques. Jain *et al* (2002) estimated the amount of sediments in the Bahkara Dam Reservoir in the West of Himalaya by means of remote measurement and they were comparable with the results of topography.

Jothiprakash *et al* (2009) investigated a period of 32 years statistics by means of SPSS 11.5 and Matlab and offered a very precise estimation of sediment volume in Goubidisagar Dam in India.

Hemadi (1999) investigated the sedimentation process in Shahid Abbaspour Dam (Karoun) Iran by means of HEC-6 software and found out that at intervals of about 90 years of operation Karoun's Dam, the volume of sediment is about 52% of the reservoir initial volumes.

The scope of this study is the suspended sediment estimation of Karaj and Torogh Dam using an hydrometry methods to get more accurate results compared to the other methods. Six methods are trained using measured water and sediment discharge data of Sira, Bylaghan and kartian gauging station which is located at the entrance and output of mentioned dam in Iran.

Methods and Materials

The Study Area

The researcher has selected the study area because of its reliable statistical periods and its relatively different climatic conditions. For this reason, the two Dams of Karaj and Torogh were selected. The Torogh dam is situated in Khorasan Razavi Province with over 20 years lifetime, and the Karaj dam (Amir Kabir dam), which is one of the most important dams in the country, is located in the North Eastern of Karaj. These two dams are very important because they provide drinking water and agricultural water for the surrounding areas.

Torogh Dam

The watershed of the Torogh reservoir is located in North-East of Iran and in 25 kilometers away in SouthEast of Mashhad, between latitude 36° 15' to 36° 17'North and longitude 59° 18' to 59° 36' East. This reservoir is used as a seasonal flood regulating structure, for irrigation of some 1700 ha of agricultural lands downstream of Torogh Dam.

The Torogh Dam is a concrete dam and is located on the Torogh River. The dam height from the foundation is 81 meters and its crest length 322 meters. The useful volume of the dam between levels 1160-1217 is about 35 million cubic meters. The Torogh River is the most important permanent river in the southern part of Mashhad city, which controls the main drainage system in the region. It rises from North Binalod Mountains and flows from southwest to southeast along the Mashhad Plain and the seasonal rivers such as Ardameh flow during winter and spring when the precipitation was at its peak .The result of review the last 38 years record showed that available surface water in Torogh Dam area is

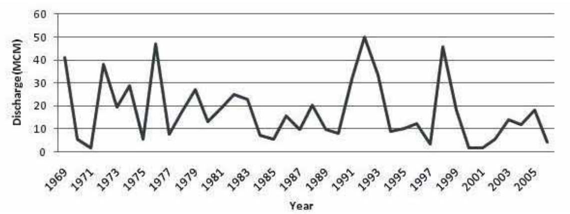

Fig. 1. The Discharge Variable in Torogh Dam Watershed (MCM)

very much depended on climate condition. Figure 1 shows that amount of discharge difference between 1969 until 2005 is very high and also this period is include some drought period in this region. The estimated water supply for agricultural consumption was 8.5 MCM but water demand in this area for agricultural consumption was about 10.5 MCM. Therefore agriculture section in this region has been 2 MCM water deficits in summer. Hydrographic survey of this in 2002 and 2008 has been reported.

Karaj Dam

This dam is located on the Karaj River. The initial studies for Amirkabir Dam took 22 years until 1956 when formal proceedings began and the dam was constructed in the period from 1957 to 1961. The Amir kabir Dam was built as a multi-purpose dam to provide tap water for Tehran alongside agricultural development in Karaj. It supplies the irrigation demand of over 50,000 hectares of farm land near Karaj. The power plant has been connected to the national electricity network for over 46 years and has a capacity of 90 megawatts. The ecliptic concrete structure is 180 meters high, with 30 meters length on bottom and 390 meters on top and its watershed is 764 kilometers long. The average annual water inflow to its reservoir is 472 million cubic meters. The total capacity of the dam's reservoir is 202 million cubic meters. The bottom elevation of reservoir and normal water surface elevation of reservoir are 1545 meters and 1610 meters respectively.This was the first multi-functional dam in the country. Its spillway discharge capacity is 1450 cubic meters per second. The highest point of the watershed is about 4200m and The lowest point is the location of the dam, 1600 m the watershed for Karaj Dam is bordered in the north by the watershed of Mazandaran, Lar and Taleghan River and in the south, east and west by watershed of the Jajrood, Kardan and northern Tehran River. The climate of the region is influenced by weather fronts from across the Mediterranean sea. The river is 66.2 km, which enters the Karaj Dam in Sira location (Ministry of power1991). This dam has got two input and output hydrometric stations which are called Sira and Beylaghan whose flow and sediment discharge measurements have been started from the years 1954 and 1967 respectively, and also in Beylaghan station the flow discharge measurement was started in 1947 and its sedimentation sampling in 1968.

Specific gravity

Computation of the storage useful life requires the knowledge of sediment trapping efficiency, the sediment unit weight or bulk dry density, the incoming flow and sediment. Unit weight, specific weight and bulk density are all used to express the dry weight per unit volume of a bulk sediment sample.

The dry bulk density of sample is estimated based on intact dried sample and its Initial volume. The amount of this quantity depends on the depth of sediment, aggregation, and … which is derived from this equation:

$$P = \frac{m}{v} \quad \text{... (1)}$$

For estimating a Bulk density one can use a similar equation but considering that the wet weight of the sample is replaced with dried sample.

Sediment Rating Equation

The changes of sediments suspended load has a close relationship with flow discharge. Unless sediment concentration is constantly recorded, hydrologists uses of the Sediment Rating Equation for estimating the sediment load.

The relation that one can establish between sediment discharge and flow discharge is as follows:

$$Q_S = aQ_w^b \quad \text{.. (2)}$$

Q_S: sediment discharge, usually in terms of tons per day (ton/day)
Q_w: flow discharge usually in terms of m^3/s
a and b: equation constant coefficient

In fact, by measuring the flow discharge, sampling the deposited particles and experimental viscometry and preparing different curves and related calculations, one can find out the values of water and sediment crossing the sediment measurement station over long periods of time.

Hydrologists, based on researches, have come to this conclusion that there is a moderately good relationship between suspended sediment concentration and discharge, i.e. the higher the discharge the higher the suspended sediment concentration. However, this relationship is to a high degree of variability and error, especially when the suspended sediment is comprised mainly of silt + clay.

In order to change sediment concentration to sediment discharge is used from the following equation:

$$Q_S = 0.0864 Q_W C \quad \text{.. (3)}$$

Q_s: sediment discharge (ton/day)
Q_w: flow discharge (m^3/s)
C: the average concentration of suspended sediment (mgr/lit)

In this study, the first based on equation (3) sediment concentrations was converted to sediment discharge. Then, the regression relationship was established between corresponding data of water discharge and suspended sediment discharge based on the investigated models, and then the coefficients of sediment rating equation (b, a) were obtained, while considering the factors affecting sediment transport that may produce errors , such as measurement time or flow condition, for this purpose five models were examined as follows:

Model A, This model is the simplest method of estimating sediment discharge. The sediment flow is estimated based on all measured data and without consideration of the time of measurements other classification of the data.

Model B, In this model, the sediment discharge can be studied based on monthly separations of data and for each month of the year due to their long - term data, sediment rating curve and its equation is obtained.

Model C, the estimation of sediment flow is performed based on a seasonal separation of data (spring, summer, autumn and winter) and then the sediment rating curve is estimated.

Model D, the separation of data is based on high water and low water flow months. A high water month has higher mean monthly flow rates than mean annual discharge rate or is equal to it. A low water month has a lower mean monthly discharge rate than the mean annual flow rate.

Model E, the sediment and flow rates are divided into the following three groups, based on daily flow rates:

Amounts less than mean annual discharge

Amounts greater than or equal to mean discharge but less than twice the mean annual flow rate.

Amounts greater than or equal to twice the mean annual discharge.

Model F: This model is known as the median of groups. In this model discharges are arranged based on flow volume (from smaller to large), then these data are divided into category (nearly ten or more). In the next part, the mean discharge of each group and average sediment discharge are estimated. After that, between these data series regression relationship is fitted and it has high correlation coefficient.

To select the best model, the root mean squares errors were used .To obtain the above results, EXCEL and SPSS software was used.

Estimating Suspended Load, Total load, and Sediment volume

In order to estimate the suspended load, as it was explained in the beginning, in hydrometric stations,the regression relationship was established between corresponding data of water discharge and suspended sediment discharge based on the investigated models, and then sediment rating equation and the coefficients of it (b, a ,which are the distance between the intersection of the best fitting line with vertical axis and origin and the slope of the best fitting line on the logarithmic paper, respectively) are obtained for different models, in the next step, using the investigated models and regarding the daily flow discharge, the amount of daily suspended load is estimated. Summing up the daily sediment loads, one can reckon the monthly and annual suspended load (ton/day).Finally; The annual average suspended load is estimated for the whole statistical period.

Different hydraulic and hydrologic methods are used in order to estimate bed load. In this research for estimating the bed load, Because no suitable data were available on bed load in the Karaj and Torogh Rivers, the Karaushev experimental curve was used to determine bed-to- suspended load ratios based on slope of the rivers. Its value is increased in the rivers with further slope and in the areas with less slopes this amount is decreased to a great extent. According to Karaushev theory, this ratio is different in the rivers to the topographic conditions. Research showed that the Karaushev theory is applicable in Iranian rivers. In this study, primarily, based on slopes Karaj and Torogh Rivers, the ratio of the bed load to suspended load was determined. Then, according to annual suspended loads and ratio mentioned, the annual bed loads was calculated. The total sediment load was determined by addition of bed and suspended load.

In order to estimate the sediment volume, one can make use of special density of the sediments in understudying dams. By dividing the sediment mass by the average density of the sediments, the volume of the sediment was obtained. Subtraction of inlet and outlet volume of sediment gave the volume of sediment deposited in the reservoir.

Selecting the optimal Model for estimating sediment

To fit function to a given series, the best method is using a function with least free parameters and these parameters are selected in such a way that the difference between the function and measured data becomes the least. Generally, performance of a model is evaluated based on the comparison between the computed output and actual data. The prediction of each model is evaluated using the correlation of coefficient (R^2), Mean Squared Error (MSE), root mean square error (RMSE). A RMSE is one of the most commonly used performance measures in hydrological modeling. A model with the minimum error would be the best choice.

There are different criteria for the best fitting functions which are all optional, but in the least square criteria is very frequent.

Based on mean of least squares errors index, the estimated amounts of the selected model is closer to observed values, the sum of squares error is reduced. Thus square mean errors which are obtained from dividing the squared errors to freedom degree will be less.

Formulas for calculating indexes of the sum of the square errors, mean of square errors, and correlation coefficient are given as follows:

$$SS_E = \sum_{i=1}^{n} (\log Q_{sio} - \log Q_{sic})^2 \quad .. (4)$$

$$MS_E = \frac{SS_E}{DF} \quad .. (5)$$

$$(MS_E)_M = \frac{\sum SS_E}{\sum DF} \quad .. (6)$$

$$R = \frac{\sum_{i=1}^{n} (\log Q_{si} - \log \overline{Q}_s)(\log Q_{wi} - \log \overline{Q}_w)}{\sqrt{\sum_{i=1}^{n} (\log Q_{si} - \log \overline{Q}_s)^2 \sum_{i=1}^{n} (\log Q_{wi} - \log \overline{Q}_w)^2}} \quad .. (7)$$

In theses relations:
SSE: the sum of squared errors
MSE: the mean of squared errors
$(MSE)_m$: every model's mean of squared errors
Q_{sio}: measurement suspended load discharge (ton/day)
Q_{sic}: estimated suspended load discharge (ton/day)
Q_{wi}: measurement flow discharge (m^3/s)

$$RMSE = \sqrt[2]{\frac{1}{n}\sum (Q_{sio} - Q_{sic})} \quad ... (8)$$

Q_w: the average measurement flow discharge (m^3/s)
Q_s: the average measurement suspended load (ton/day)
DF: the degree of freedom

Q_{sio}= observed sediment discharge , Qsic = calculated sediment discharge.

The closer this feature to zero, the more careful the model will be.

In this research, after separation of the data based on discharge rate and time of measurement, analyze them and determining the sediment transport equation, tables variance analysis, error squares, error square mean, the root of error square mean, data correlation coefficient, and sediment transferring equation coefficients were obtained in each case. the most suitable model was selected based on root mean square error index. In this study, in addition applying statistical features such as RMSE, estimated sediment volume of each model in the two understudying dam reservoirs was compared with actual deposited sediment volume obtained from primary and secondary area- volume curves until the accuracy of the models and optimization model is introduced.

Conclusions and Discussion

The objective of this paper was to investigate hydrology models in estimation of sediment concentration in reservoirs. In this research, the first in hydrometric stations, the regression relationship was established between corresponding data of water discharge and suspended sediment discharge rate based on the investigated models, and then sediment rating equation and the coefficients of it, the correlation of coefficient (R_2), the sum of squared errors (SSE), the Mean Squared Error (MSE), Root Mean Squared Error (RMSE) were extracted. (Table 1 as Samples in sira). The results of these rating equation for the inlet station of Karaj (Sira), which are compared in Table 1, reveal that the rating equation developed by data classification method is more accurate compared to other methods .The sediment rating curves in a monthly model were then illustrated as Samples in sira station of Karaj Dam (Fig 2 - the x-axis is water discharge in [m^3/s] and y-axis is sediment discharge in [tons/day]). In the next step, histograms of Root Mean Squared Error of the models in stations were drawn to find model with minimum error. (fig, 3 and 4). Considering the extracted equation for every model and the daily flow rates, the amount of suspended load in the input and output hydrometric stations was determined for Karaj Dam based on the investigated models. the bed – to - suspended load ratio was obtained as 2 and 0.45 for sira and Bilghan stations respectively (by means of Karaushev Graph) and by multiplying this ratio in suspended load was calculated The bed load in both station. Total sediment was obtained by addition of bed and suspended load in each model (Table 2). The difference between the total sediment in inlet (Sira) and outlet (Bilghan) stations, was calculated the weight of deposited sediment per tons.

Generally the curves of the surface-volume and height are based on volume unit; therefore, For computation of sediment volume we used from sediment weight and density of it (1.4 ton/m^3- water Research Center of Iran) and divided these two parameters together for both station under study (Table 2).

The results obtained show that in both station Sira and Beylaghan after model F, model B, in which the separation of data was made monthly, had the least root mean squares errors and was selected as the best model.

For further investigation of the accurate models and selection of an optimal model after determining the amount of error for each model, the estimated sediment of each model was compared with actual amount of sediment obtained from primary and secondary area –volume curves of surface-volume-

Table 1. Sediment rating equations and Root Mean Square Error in sira station of Karaj Dam

Model	Data Separation Measuring time	Data classification	N	DF	a	b	R^2	R	$a.Q_w^{\ b}$	SSE	MSE	$(MSE)_m$	RMSE
A	During Year	--	1358	1356	0.484	2.38	0.76	0.87178	0.484*Qw^2.38	389.2	0.287021	0.288	0.536656
B	January	--	42	40	1.911	1.716	0.7	0.83666	1.911*Qw^1.716	1.9	0.0475	0.243	0.49295
	February	--	60	58	1.278	2.07	0.66	0.812404	1.278*Qw^2.07	8.55	0.147414		
	March	--	138	136	0.396	2.51	0.76	0.87178	0.396*Qw^2.51	27.04	0.198824		
	April	--	301	299	0.17	2.72	0.71	0.842615	0.17*Qw^2.72	74.24	0.248294		
	May	--	350	348	0.078	2.919	0.76	0.87178	0.078*Qw^2.919	55.64	0.159885		
	June	--	175	173	0.009	3.33	0.77	0.877496	0.009*Qw^3.33	26.07	0.150694		
	July	--	84	82	1.217	1.658	0.13	0.360555	1.217*Qw^1.658	76.08	0.927805		
	August	--	33	31	1.87	1.93	0.36	0.6	1.869*Qw^1.931	17.16	0.553548		
	September	--	30	28	2.683	1.673	0.39	0.6245	2.683*Qw^1.673	9.002	0.3215		
	October	--	60	58	0.434	2.667	0.8	0.894427	0.434*Qw^2.667	11.68	0.201379		
	November	--	51	49	0.201	3.1	0.79	0.888819	0.201*Qw^3.1	9.87	0.201429		
	December	--	34	32	0.913	2.072	0.75	0.866025	0.913*Qw^2.072	6.19	0.193438		
C	Spring	--	826	824	0.091	2.847	0.73	0.8544	0.091*Qw^2.847	173.4	0.210437	0.261	0.510882
	Summer	--	147	145	3.221	1.419	174	13.19091	3.221*Qw^1.419	107.83	0.743655		
	Autumn	--	145	143	0.433	2.638	0.78	0.883176	0.433*Qw^2.638	30.53	0.213497		
	Winter	--	240	238	0.78	2.27	0.77	0.877496	0.78*Qw^2.27	40.23	0.169034		
D	Dry months	--	448	446	0.714	2.34	0.72	0.848528	0.714*Qw^2.34	100.26	0.224798	0.267	0.516
	Wet months	--	910	908	0.08	2.868	0.69	0.830662	0.08*Qw^2.868	259.8	0.286123		
E	During Year	1	433	431	1.36	1.94	0.32	0.565685	1.36*Qw^1.945	121.24	0.281299	0.253	0.502991
		2	306	304	0.138	2.567	0.12	0.34641	0.138*Qw^2.567	122.08	0.401579		
		3	619	617	0.05	3.03	0.63	0.793725	0.05*Qw^3.03	97.89	0.158655		
F	During Year	--	41	39	1.369	2.24	0.94	0.969536	1.369*Qw^2.24	1.8	0.046154	0.046	0.214476

height between the years 1961-2007.

According to the results, model B was introduced as the sediment appropriate transport model in the Karaj Dam hydrometric station in which the separation of data was made monthly, and was selected as the best model. In fact this model is highly in accordance with the effects of climate factors (such as rainfall) and hydrological factors (such as runoff) which were important in monthly separation of data. In figure 5 showed this fact. After the monthly model (model B), the seasonal model (model C), then classified model (model E), and after that model D could estimate the amount of sediment more precisely and respectively. The comparison of results showed that the monthly model predicted the deposited sediment volume 94% of the actual amount of sediment for the period between 1961 to 2007. Despite the fact that model F reckoned the least error square mean, it could not estimate the sediment more than 34% and relatively had the least precise capability.

Torogh Dam was the second studied case because of the climatic conditions in most summers and autumns the entering river was dry or semi- dry; and little or no sediment entered the dam this seasons. Therefore, no sediment rating curve was drawn for this seasons. The obtained results showed that sediment rating equation coefficient are a function of selected model and the way these data are separated. According to the criterion of least squares error, calculation the volume of sediment between the years 2002-2007 and comparing it with actual estimated sediment volume by means of surface-volume-height diagrams, also, in this case monthly model has the best results among all six evaluated methods and was se-

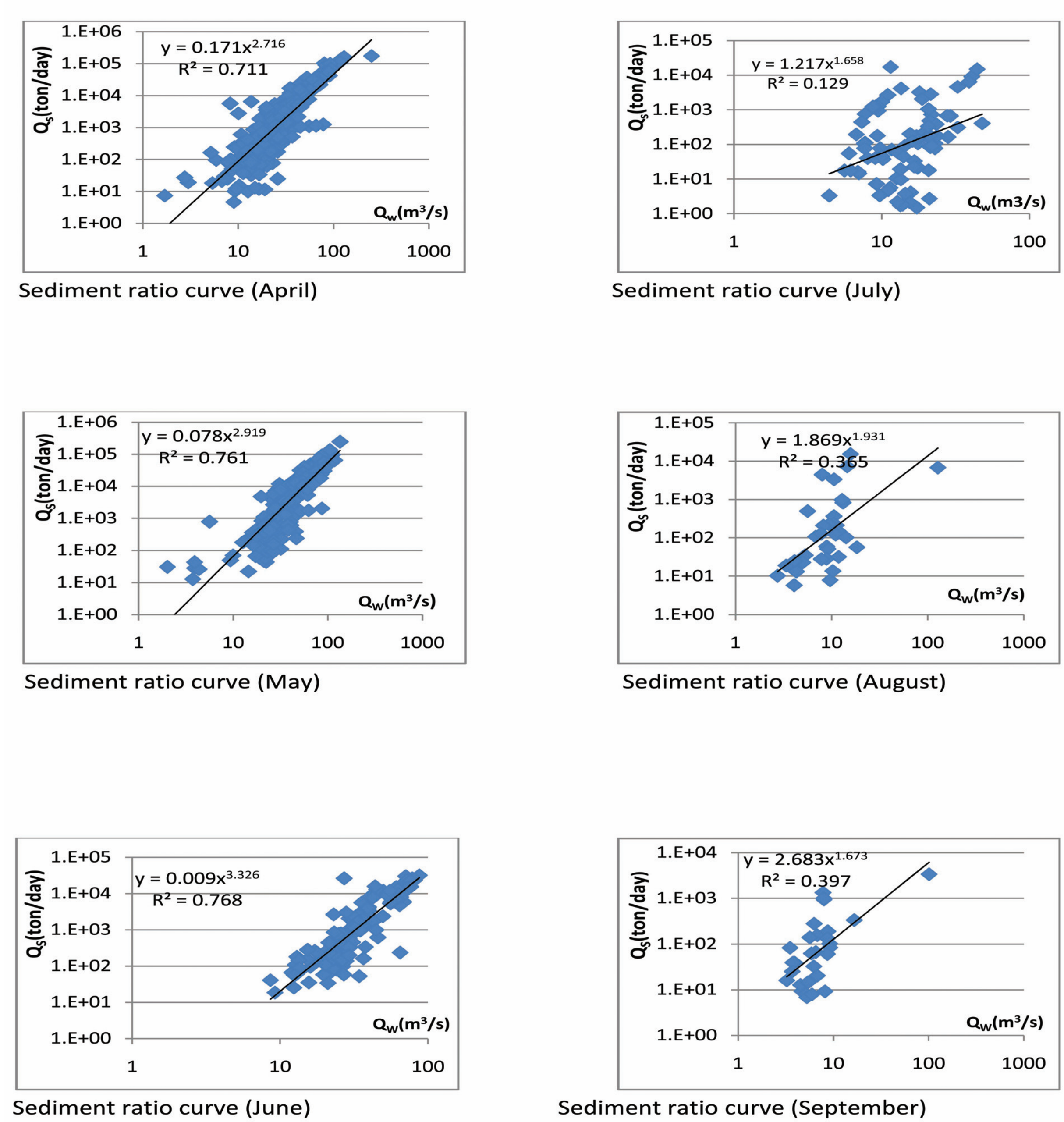

Fig 2. Sediment ratio curves (model B) in Sira station of Karaj Dam

lected as the best and efficient model that this argument approves the same results of Karaj Dam. After the monthly model, the Seasonal Model had higher exactness. The table 3 illustrates estimation of sediment volume in different models of Torogh dam. The application of different techniques for estimating the sedimentation rate in the reservoir shows that the average sedimentation rate for 6 years (2002-2007) is proximately 194.03 thousand cubic meters, whereas Results of investigation through hydrographic survey provided a sedimentation rate of 209.52 thousand cubic meters for the same period. (Fig. 6).

Based on the obtained results from both dams and comparing them with real sediment amount showed that model B was well enough to predict the amount of sedimentation in the reservoir; Classification ap-

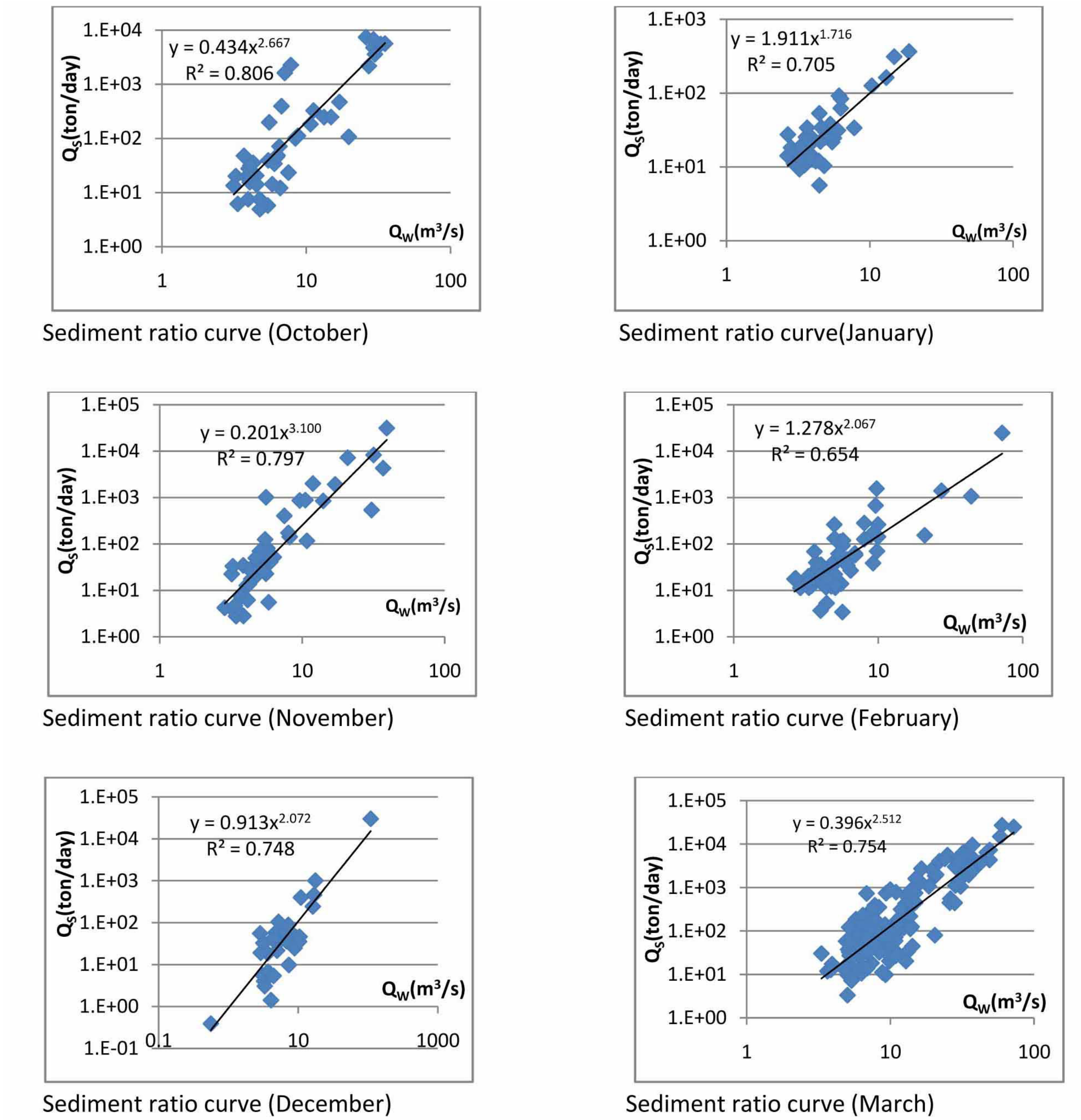

Fig 2. Sediment ratio curves (model B) in Sira station of Karaj Dam

plied on water and sediment discharge, had significant impact on the improving relation between water and sediment discharge and decreasing in RMSE. In one hand, the hydrological behavior of every understudying station was different in predicting the sediments and this demonstrated that the climatic and geological conditions and vegetation had effective impact on producing sediment; and one can conclude that it is necessary to consider other factors in transferring sediment for more precise results.

However, one should pay attention that the more precise the measurement of the water and sediment

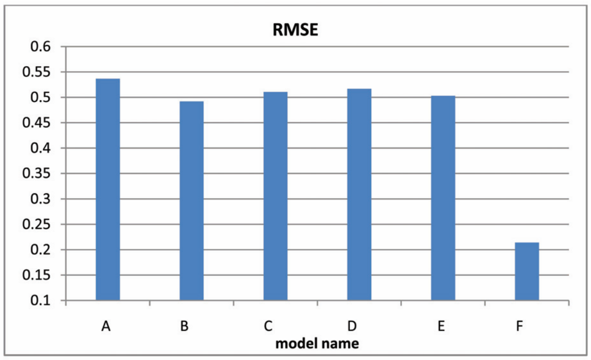

Fig 3. Root Means Square Error in sira station of Karaj Dam

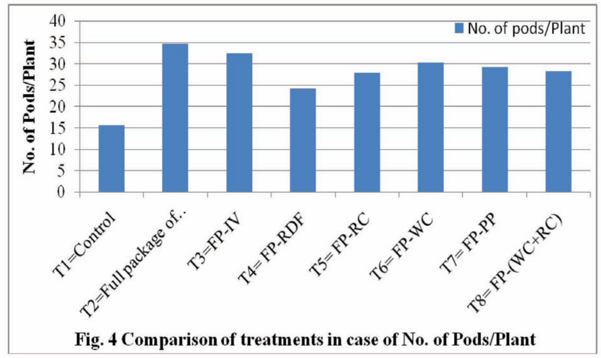

Fig 4. Root Means Square Error in Beylaghan station of Karaj Dam

Table 2. Estimated sediment volume in two station of Sira and Beylaghan with using different models from 1961 to 2007

Model	Beylaghan Hydrometric Station			Sira Hydrometric Station			Volume(m^3)
	Suspended load	Bed load	Total load	Suspended load	Bed load	Total load(tons)	
A	3085976.62	1388689.48	4474666.1	10256258.74	20512517.47	30768776.21	18781507.22
B	3728788.29	1677954.73	5407643.03	1191181.27	23823762.53	35735643.8	2166350054
C	3201950.42	1440877.69	4642828.11	11334716.19	22669432.38	34004148.56	20979275.63
D	3087058.07	1389176.13	4476234.20	11200783.8	22401567.6	33602351.4	20139720.26
E	2199781.1	9989901.49	3189682.6	12696628.05	253932256.1	38089884.15	24928715.14
F	6529465.79	2938259.61	9467725.39	17552006.75	35104013.5	52656020.24	30848782.03

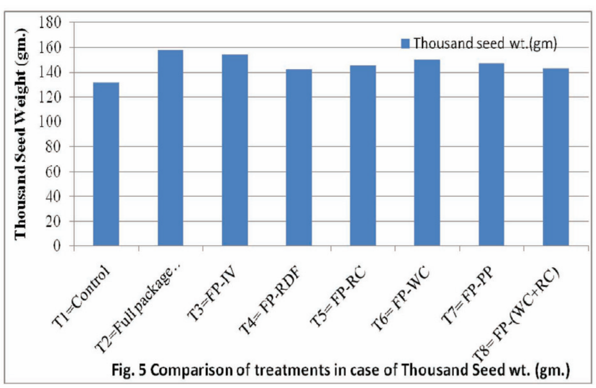

Fig 5. Estimated sediment in different model and actual sediment in Karaj Dam from 1961 -2007

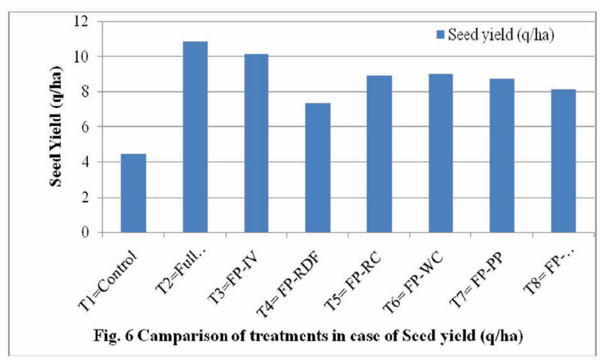

Fig 6. Estimated sediment in different model and actual sediment in Torogh Dam from 2002 -2007

Table 3. Estimated sediment volume in Torogh reservoir with using different models from 2002 to 2007.

Model	Station kartian			Volume(m3)
	Suspended load	Bed load(tons)	Total load(tons)	
A	54794.25	164382.75	219177.005	146118.004
B	72761.64	218284.9	291046.6	194031.1
C	66468.75	199406.26	265875.01	177250.009
D	62719.38	188158.15	250877.53	167251.69
E	93011	279033	372044	248029
F	137810.1	413430.18	551240.24	367493.49

discharges, accurate calibration of bed load and suspended load floor and using computing and artificial intelligence techniques can provide the more precise capability of sedimentation in the reservoirs. This matter can decrease dam hydrographic cost and leads to accurate planning in water resources management in dams. Because the bed load is coefficient of suspended load cannot provide remarkable results, it is suggested that for promoting efficiency of these methods, the climate and morphological conditions of the rivers in the different parts of the world should be studied.

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