Abstract
One of problems that affects the hydro-installation and reduces the useful life of dams, is sedimentation in the reservoir, which is unavoidable. In estimating reservoir sedimentation and accumulation, a number of uncertainties arise. These are related to the quantity of streamflow, sediment load, sediment particle size, and specific weight, trap efficiency, and reservoir operation. To evaluate suspended sediments and bed load in some hydrometric stations, separating the field data into wet and dry time periods and total time periods are used. Harr’s method is used to quantify the uncertainty of accumulated reservoir sedimentation through time. To examine the importance of various factors on the uncertainty of accumulated reservoir sedimentation, sensitivity analysis was conducted. In this study, the effect of each uncertain factor, on the uncertainty of accumulated reservoir sedimentation through time has been examined for Shahar Chai Dam in northwestern Iran. The results show that in Harr’s method, the uncertainty of accumulated reservoir sediment volume is 0.384 in total time periods and 0.244 for wet and dry time periods.

Keywords: Reservoir sedimentation, Harr’s method, Uncertainty analysis.

چکیده
پیشینه نشان داد که رسوایی ورودی به مخازن خود و ناحیه توسعه و حجم آن دارای اهمیت و پیچیدگی‌ای‌یابی در طرح و هیدرودزایی مناسبی سازنده‌ای بی‌ای‌است. روشهای مختلف و تحلیل متمد و پیچیده‌ای برای شناخت فرآیند رسوایی و برآورد رسوایی ورودی و حجم رسوایی‌کارانی در مجاران سد هر کدی است. تحلیل رسوایی در مجاران سد‌های تأمین پایین به طراحی مدل کم‌پرسی‌گر رسمونی می‌باشد. در این شرایط، تحلیل اثر نامی‌آبی به رسوایی جهت افزایش حجم می‌باشد خواه آگاهانه، میزان رسوایی، نغمه رسوایی و ... به مخزن باشد. در این تحقیق از چهار روش در حجم رسوایی (Harr) بهره‌مندی می‌گردد. در این مطالعه حجم رسوایی، شیت بدون رسوایی و سد در مجاران سد طول زمان (10، 20 و 35 سال بعد از ساختن و نصب) در آماری تحلیل نشان داده است. با این حال، اثر حسابی و ساختار اهمیت گفته می‌شود. همچنین، رسوایی حجم از نظر اکثریت، سبب ناشی از اثر افزایش حجم می‌شود. در این مطالعه نشان داده شد که در جهت تحلیل این روش پیچیدگی می‌باشد. در این مقاله نشان داده می‌شود که این روش در کنار مدل کم‌پرسی‌گر رسمونی، تحقیق و تحلیل جزئی به مخزن‌ها باشد.

کلمات کلیدی: رسوایی، حجم رسوایی، حجم رسوایی، تحت‌الحمی، تحلیل حجم رسوایی.

References
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1-Introduction

Uncertainties may arise due to natural variations in the phenomenon being considered, or to an incomplete understanding of mechanisms. Uncertainties may also arise from inaccurate characterization of important parameters or variables. Thus, engineering practice is frequently associated with decision making under uncertainty and physical or numerical models developed and used to simulate natural phenomena are often in reality probabilistic, and hence, subject to analysis by rules of probability theory. Identifying the components of uncertainty related to physical phenomenon and quantifying them can, therefore, improve decision making and the results (Huang 1986; Mercer and Morgan 1975).

Reservoir sedimentation varies with several factors such as sediment production, sediment transportation rate, sediment type, mode of sediment deposition, reservoir operation, reservoir geometry, and streamflow variability. Sediment is transported as suspended sediments and bed loads by streams and rivers entering a reservoir. The deposited sediments may consolidate by their weight and the weight of overlying water through time. The correct prediction of the amount of accumulated sediment behind the dam is one of the most important problems in hydraulic engineering. An empirical model, based on surveys and field observations, has been developed and applied to estimate annual reservoir sedimentation load (RSL), accumulated reservoir sedimentation load (ARSL) and accumulated reservoir sedimentation volume (ARSV) after a given number of years of reservoir operation (Strand and Pemberton 1982; Morris and Fan 1998). Likewise, several mathematical models for predicting reservoir sedimentation have been developed based on the equations of motion and continuity for water and sediment [see, for instance, Chen et al. (1978), Soares et al. (1982), and Morris and Fan (1998)]. However, empirical methods are still widely used in actual engineering practice (Butler 1987; Ruddy 1987; Shen and Julian 1993). To estimate reservoir sediment inflow, reservoir sedimentation, and reservoir sediment accumulation, a number of uncertainties arise: 1- quantity of streamflow; 2- quantity of sediment inflow into a reservoir; 3- sediment particle size; 4- specific weight of the deposits; and 5- reservoir size and operation [(USBR 1987) p.529]. Fan (1988) obtained information on 34 streams, 18 watersheds, and 12 reservoir-sedimentation models and stated that different models may give significantly different results even when using the same set of input data. Such an additional factor is known as "model uncertainty" and may be quite a large component of the overall uncertainty (Salas 1999).

Several methods have been developed and applied for uncertainty analysis in water resource engineering, the most widely used of which are first-order variables estimating (FOVE), Harr's Probabilistic Point Estimation method, Monte Carlo simulation (MCS) (Ang and Tang 1984). FOVE is based on linearizing the functional relationship that relates a dependent random variable and a set of independent random variables by Taylor series expansion (Yeh et al., 1986). This method has been applied in several water resources and environmental engineering problems involving uncertainty. Examples include: storm sewer design (Tang and Yen 1972); ground-water flow estimation (Dettinger and Wilson 1981), prediction of dissolved oxygen (Burges and Lettenmaier 1975; Chadderton et al. 1982), subsurface flow and contaminant transport estimation (Sitar et al. 1987), and water surface profile of buried stream flowing under coarse material (Hansen and Bari 2002). In Harr's method, average and variance of probabilistic variables and their correlations are used (More details are introduced in Tung 1993). If there are n variables, the number of cases (points) will be 2n which is considered an important advantage compared to the point estimate method proposed by Rosenblueth (1981). In cases in which obtaining the derivatives are too complicated, Harr's method is considered a good substitute of the FOVE method. This method has been used for uncertainty analysis of sediment transport relationships (Yeh and Deng 1996), in studying the spatial variation of river bed scouring (Yeh and Tung 1993), and for uncertainty analysis incorporating marginal distribution (Chang and Yang 1997). In Monte Carlo Simulation (MCS), stochastic inputs are generated from their probability distributions and are then entered into empirical or analytical models of the underlying physical process involved in generating stochastic outputs. Then, the generated outputs are analyzed statistically to quantify the uncertainty of the output. Several examples of uncertainty analysis by MCS can be found in water resources and environmental engineering (Salas 1993; Hipel and Mcleod 1994; Melching 1995). Some of them include ground-water flow estimation (Smith and Freeze 1979; Jones 1989) and water quality modeling (Warwick and Cale 1986; Brutsaert 1975), and in studying the spatiotemporal stochastic open-channel flow (Gates and Al-Zahrani 1996). Scavia et al. (1981) made a comparison of MCS and FOVE for determining uncertainties associated with eutrophication model outputs such as plankton, zooplankton and nitrogen forms. They concluded that both FOVE and MCS agree extra in estimating the mean and variance of model estimates. However, MCS has the advantage of providing better information about the frequency distribution. Latin hypercube sampling (LHS) is used to generate random stochastic inputs in a stratified manner from the probability distributions. This way the number of generated inputs can be reduced considerably as compared to MCS (see McKay et al. (1979)). Chang et al. (1993) used LHS to perform...
sensitivity and uncertainty analysis in his research. Yeh and Tung (1993) applied FOVE, the point estimate method proposed by Rosenblueth (1981), and LHS to analyze the uncertainty of migration of a pit. They pointed out the point estimate method yields a larger mean and variance than those obtained by FOVE and LHS methods. Furthermore, in studying the importance of stochastic inputs on the output by sensitivity analysis, LHS yields more information than the other two methods.

In this study, uncertainty analysis based on Harr's method is conducted to obtain the accumulated reservoir sedimentation volume. Then sensitivity analysis is performed to show the relative importance of stochastic inputs in estimating ARSV.

2-Methodology
The incoming sediment load and the streamflow discharge are usually measured at hydrometric gauging stations, and a sediment rating curve is constructed. Incoming sediment is generally composed of suspended sediment and bed load. When the bed load cannot be obtained by measurements, it can be estimated by formulas [(Vanoni 1975) p.190]. The annual sediment rating curve is the relation between annual sediment load and annual streamflow discharge. Two methods can be considered for determining annual sediment rating curve from the daily sediment rating curve (Colby 1956). To evaluate suspended sediment and bed load for a number of hydrometric stations, the field data is divided into wet and dry time periods. The data separation improves the results compared to the one when the whole data is used. The division into wet and dry time periods is based on the incoming daily streamflow discharges and their monthly average. Wet time periods are those with a daily streamflow discharge that is bigger than the average, while dry time periods are those with a daily streamflow discharge that is smaller than average. Then the other calculations have been performed for wet and dry time periods, as well as the total time periods. In estimating reservoir sediment inflow, the Food and Agricultural Organization method (Food and Agricultural Organization, 1981) and its coefficients give the best estimate compared to real data for annual average suspended and bed load.

For the estimation of ARSV, the following steps have been performed:
1- Calculating the daily rating curve of suspended sediment and bed load:

\[ \log_{10} QSD = a_1 + b_1 \log_{10} QWD \]  
\[ \log_{10} QBD = a_2 + b_2 \log_{10} QWD \]  

Where QSD = daily suspended load (tons/day); QBD = daily bed load (tons/day); QWD = daily average streamflow discharge (m³/s); \( a_1, b_1, a_2, b_2 \) = rating curve coefficients for suspended sediment and bed load respectively.

2- Calculating the corresponding annual rating curves of suspended sediment and bed load:

\[ \log_{10} Q_{S\text{r}} = a_1 + b_1 \log_{10} Q_{W\text{r}} \]  
\[ \log_{10} Q_{B\text{r}} = a_2 + b_2 \log_{10} Q_{W\text{r}} \]  

Where Q_{S\text{r}} = annual average suspended load (tons/day) in year t, Q_{B\text{r}} = annual average bed load (tons/day) in year t; Q_{W\text{r}} = annual average streamflow discharge (m³/s) in year t and \( a_1, b_1, a_2, b_2 \) = rating curve coefficients for annual average suspended and bed load, respectively.

3- As in FAO method coefficient (a) replaces (a') where \( (a') \) is defined as: \( a' = \frac{Qs}{(QW)^b} \), where \( Qs \) = daily average suspended load (tones/day) for suspended load and daily average bed load (tones/day) for bed load, \( QW \) = daily average streamflow discharge (m³/s) and therefore Q_{S\text{r}} and Q_{B\text{r}} are calculated with the new (a).

4- Calculating total sediment inflow in year t, QT = Q_{S\text{r}} + Q_{B\text{r}}

5- Calculating trap efficiency using Brune's (1953) data: [several empirical methods have been developed to estimate trap efficiency (Churchill 1948; Brune 1953; Brown 1958)]

\[ TE_i = a_3 + b_3 [\log_{10} (C_{i,1}/IW_{i})]^2 \]  

Where \( TE_i \) = trap efficiency (%) in year t, \( C_{i,1} \) = useful reservoir capacity (m³) at the beginning of year t, \( IW_{i} = 31.536 \times 10^6 \) QW_i streamflow (m³) in year t and \( a_3, b_3 \) = regression coefficients.

6- Calculating the total sediment load trapped in a reservoir in year t:

\[ RSL_i = 3.65 QT_i \times TE_i \]  

Where RSL is in tons; and the accumulated sediment in reservoir after t years is calculated as:

\[ ARSL_i = ARSL_{i,1} + RSL_i \quad t = 1, 2, \ldots \]  

Where ARSL_0 = 0
7- Estimating the average specific weight of sediments deposited after t years, using Miller (1953) formula:

\[ W_t = W_i + 0.4343K \left[ \frac{1}{t - 1} \ln t - 1 \right], \quad t > 1 \]  

(8)

Where \( W_i \)=average sediment specific weight (kg/m^3) after t years; \( W_i \)=specific weight of sediment in the first year; and \( K \)=consolidation constant alternatively, both \( W_i \) and \( K \) are functions of the type of reservoir operation and the size of sediment. (Lane and Koelzer 1943); Table 1 shows values of \( W_i \) and \( K \). For a mixture of sediment, a weighted average of specific weights and consolidation constant must be used as (Lara and Pemberton 1965):

\[ W_i = 0.01[W_i(c)P(c) + W_i(m)P(m) + W_i(s)P(s)] \]  

(9)

\[ K = 0.01[K(c)P(c) + K(m)P(m) + K(s)P(s)] \]  

(10)

Where \( W_i(c), W_i(m) \) and \( W_i(s) \)=initial specific weight; \( K(c), K(m) \) and \( K(s) \)=consolidation constants; and \( P(c), P(m) \) and \( P(s) \)=percentages of clay, silt, and sand, respectively.

8- Calculating ARSV_{t}:

\[ \text{ARSV}_{t} = 1000 \frac{\text{ARSL}_{t}}{W_i} \]  

(11)

9- Estimating C_{t}:

\[ C_{t} = C_{0} \times \text{ARSV}_{t} \]  

(12)

Where \( C_{0} \)=initial useful reservoir capacity.

3-Stochastic inputs

In the empirical models, the various uncertain factors that affect reservoir sedimentation may be categorized as follows:

-Inputs associated with annual sediment inflows such as regression coefficient \( a_1, b_1 \) and \( a_2, b_2 \) of step (3) and (4) respectively;
-Inputs associated with the type of the incoming sediment such as the percentage of clay, silt and sand;
-Inputs associated with the regression equation for estimating the trap efficiency of the reservoir; and
-Inputs associated with the variability of the water inflows to the reservoir.

Harr's method does not take into account the probability distribution of variables which might be considered as a disadvantage (Soleimani 2003). The uncertainty of annual streamflow is an important factor affecting the uncertainty of reservoir sedimentation. Stochastic time series models have been widely used in literature for many water resources problems (Loutk et al. 1981; Salas 1993). Auto regressive models (AR) have been the most commonly used models for annual streamflow simulation [see, for instance, Mcleod and Hipel (1978) and Salas et al. (1980)]. AR(1) model is defined as:

\[ QW_t = \mu + \phi_1(QW_{t-1} - \mu) + \varepsilon_t \]  

(13)

Where \( \mu \)=mean; \( \phi_1 \)=lag-1 autoregressive coefficient; and \( \varepsilon_t \)= normal random variable with mean zero and variance \( \sigma^2 \). Then we have 10 sources of uncertainty for studying reservoir sedimentation; \( \{a_1, b_1, a_2, b_2, a_3, b_3, P(c), P(m), P(s) \} \).

Harr's method is a simple, effective, and precise method. It uses the two first order moments of stochastic variables and not the probability distribution but it is easy in terms of calculation efforts. Harr's method is considered a good substitute for other methods. Different stages of Harr's method can be summarized as:

-Identifying input physical parameters of each of the relationships and calculating its correlation matrix
-Decomposition of the correlation matrix (CO) to Eigen vectors matrix and Eigen diagonal values matrix

Table 1- Initial specific weight \( W_i \) (kg/m^3) and consolidation constant [Strand and Pemberton (1982)]

<table>
<thead>
<tr>
<th>Type of reservoir operation</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( W_i(c) )</td>
<td>( K(c) )</td>
<td>( W_i(m) )</td>
</tr>
<tr>
<td>Sediment always submerged(under continuous of water head) or nearly submerged</td>
<td>416</td>
<td>256</td>
<td>1120</td>
</tr>
<tr>
<td>Moderate to considerable reservoir drawdown</td>
<td>561</td>
<td>135</td>
<td>1140</td>
</tr>
<tr>
<td>Reservoir normally empty</td>
<td>641</td>
<td>0</td>
<td>1150</td>
</tr>
<tr>
<td>Riverbed sediments</td>
<td>941</td>
<td>0</td>
<td>1170</td>
</tr>
</tbody>
</table>
CO = VLV'  

(14)

Where V = (v₁, v₂, ..., vₙ) is Eigen vectors matrix and L = λ₁, λ₂, ..., λₙ is Eigen value diagonal matrix.

-Calculating 2N intersection points:

\[
X_{is} = \mu \pm \sqrt{N} \sigma_i, \quad V_i, \quad \ldots, \quad \sigma_N
\]

(15)

Where μ=mean; σ=standard deviation of ith stochastic input; N=number of inputs; V=Eigen vectors matrix

-Calculating Y_is=g (X_is) and Y_is²=g² (X_is) for (i=1, 2, ..., N) where Y=model output and then calculate $\bar{Y}_i = \frac{Y_{is} + Y_{is} -} {2}$ and $Y_i^2 = \frac{Y_{is}^2 + Y_{is}^2} {2}$

-Calculating the average and variance of different model outputs:

\[
E(Y) = \frac{\sum_{i=1}^{N} Y_i}{N} \quad E(Y^2) = \frac{\sum_{i=1}^{N} Y_i^2}{N}
\]

(16)

(17)

Var(Y) = E (Y²) - E² (Y)

(18)

Computing model uncertainty with the coefficient of variation. For an elaborate discussion on Harr's method, the reader is referred to Hosseini (2000).

Sometimes when a large number of stochastic input is involved in determining the output, sensitivity analysis may be carried out to determine the degree of influence of each stochastic input on the output uncertainty, C_i.

In Harr's method a linear regression relationship between x’s, input parameters, and output, Y can be considered, as the following:

\[
Y = a_0 + \sum_{i=1}^{N} a_i x_i + e
\]

(19)

Where a₀ is the interception value of the line with y axis, a_i refers to regression coefficients that show the sensitivity coefficients, and e is indicating the model error. Due to the dimensional problems, it is recommended to centralize the output parameter and then by standardizing (Y-Y) and input parameters, the regression can be conducted. In this case, coefficients will indicate the output variation for a variation of input parameters equal to one standard deviation. Then C_i values which indicate the uncertainty of the input parameter can be calculated from the following relationship:

\[
C_i = \frac{SSR_i}{SSR} R^2 \quad \text{For } i=1,2,\ldots,N
\]

(20)

In which SSR_i is the summation of square values of the ith input stochastic parameter from the regressed line and SSR is the summation of SSR, for the independent input parameters. For more details the reader is referred to McKay (1988).

The concept here is that by sensitivity analysis stochastic input more important to output uncertainty is selected for detailed analysis.

4-Procedural steps

The uncertainty in predicting accumulate sediment in a reservoir is an important aspect in the design and management of the reservoir. In this section, the uncertainty of accumulated sediment in the reservoir throughout a number of years of operation is considered by Harr's methods. The procedure steps are summarized here:

1- Generate annual flows Q_w (t=1,..,M) from (13) model where M=simulation run years, n times. 2- Generate the other set of stochastic inputs (a₁, b₁, a₂, b₂, a₃, b₃, P(C), P(M), P(S)) 2n intersection points based on Harr's method described in the previous section. 3- Using the obtained stochastic input, determine the stochastic output namely, the ARSV, and useful capacity at the end of year t, C from (6), (7), (11) and (12) respectively. 4- Obtain an array of n output for each t. 5- Determine the statistical characteristics of the array ARSV, such as the mean, variance, coefficient of variation, and coefficient of skewness.

5-Application

Uncertainty analysis of reservoir sedimentation is applied to the Shahar Chai reservoir, located in the Urmia Lake Basin. Shahar Chai Dam was constructed in 2005. The reservoir capacity for Shahar Chai is 221 $10^6$ m$^3$. The basic information about streamflow and sediment data was obtained from West Azarbayjan Water Bureau in Iran (West Azarbayjan Water Bureau 2002). The incoming suspended sediment load and the streamflow discharge are usually measured at hydrometric gauging stations and so, based on expert's local estimation bed load calculated 10-30% of suspended load. The streamflow data at the Band gauging Station in Shahar Chai River are available for...
the years 1949-2001 and the suspended sediment load for the years 1964-2001. This is the nearest gauging station to Shahar Chai Reservoir. Table 2 shows the basic statistics of the streamflow data at the Band Station and the basic statistics of the suspended sediment load are listed in Table 3.

The corresponding annual rating curve equations are listed in Table 4. Mean values and standard deviations of annual rating curve parameters \((a_1, b_1)\) and \((a_2, b_2)\) in dry and wet time periods and total time periods are listed in Table 5. In addition, the annual rating curve for both suspended sediment and bed load in wet and dry time periods and total time periods are constructed in logarithmic coordinates as shown in Figs 1 and 2. The correlation coefficient between regression coefficients are -0.9393 and -0.974 for suspended sediment and bed load in total time periods and -0.9177, -0.9597 in wet and dry time periods. The lower and upper bounds for each fraction which are denoted as \(P(c), P(m)\) and \(P(s)\) listed in Table 5 were taken from field measurements and soil texture diagrams. The estimated mean and standard deviation of each regression coefficient, \((a_1, b_1)\) are listed in Table 5 as well. The correlation coefficient between \(a_1\) and \(b_1\) is -0.694. In summary, the 9 stochastic inputs have been characterized.

For Harr’s method the correlation matrix are shown in Table 6. For calculating ARSV the algorithm described in previous sections was used. Moreover, the parameter uncertainty of the annual flows has been considered.

### 6-Results

For calculating ARSV, \(t=1,\ldots, 60\), that is for each \(t\), 9 values of ARSV\(_t\) for Harr’s are obtained that are used for statistical analysis, (except annual stream flow that generated 60× 9 values).

Table 7 shows the result of uncertainty analysis of ARSV for \(t=1,\ldots, 60\), from Harr’s method. In addition, the result of the sensitivity analysis for each input based on Harr’s are shown in Fig 3.

### Table 2- Basic statistics for streamflow data at the Band Station

<table>
<thead>
<tr>
<th>Station</th>
<th>Length of record</th>
<th>Mean flow (m³/s)</th>
<th>Standard deviation</th>
<th>Frequency of measurement</th>
<th>Sample of streamflow data points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band</td>
<td>52</td>
<td>5.325</td>
<td>2.095</td>
<td>Every day</td>
<td>18250</td>
</tr>
</tbody>
</table>

### Table 3- Basic statistics for the suspended sediment load at the Band Station

<table>
<thead>
<tr>
<th>Station</th>
<th>Length of record</th>
<th>Mean and Minimum Maximum</th>
<th>Frequency of measuring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band</td>
<td>37</td>
<td>2906.21 and 30013.7</td>
<td>Two or three per month</td>
</tr>
</tbody>
</table>

### Table 4- Annual rating curve for wet and dry time periods and total time periods and trap efficiency curve

<table>
<thead>
<tr>
<th>Types</th>
<th>Regression equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual suspended sediment(wet and dry periods)</td>
<td>(QS_t=23.381QW_t^{2.3019})</td>
</tr>
<tr>
<td>Annual bed load(wet and dry periods)</td>
<td>(QB_t=11.785QW_t^{1.7082})</td>
</tr>
<tr>
<td>Annual suspended sediment(total periods)</td>
<td>(QS_t=41.863QW_t^{2.8275})</td>
</tr>
<tr>
<td>Annual bed load(total periods)</td>
<td>(QB_t=15.978QW_t^{1.8277})</td>
</tr>
<tr>
<td>Trap efficiency</td>
<td>(TE_t=99.508-13.547[\log_{10}(C_{t-1}/IW_t)]^2)</td>
</tr>
</tbody>
</table>

\(QW_t=\) annual average streamflow discharge (m³/s) in year \(t\); \(QS_t=\) annual average suspended load (tons/day) in year \(t\); \(QB_t=\)annual average bed load (tons/day) in year \(t\); \(TE_t=\)trap efficiency (%) in year \(t\); \(C_{t-1}=\)useful reservoir capacity (m³) at the beginning of year \(t\); \(IW_t=31.536\times10^6\) \(QW_t=\) stream flow (m³) in year \(t\)
Table 5- Statistical properties (mean, standard deviation and type of distribution) of inputs

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Lower bound</th>
<th>Upper bound</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a_1) (wet and dry periods)</td>
<td>—</td>
<td>—</td>
<td>29.831</td>
<td>12.460</td>
<td>Bivariate</td>
</tr>
<tr>
<td>(b_1) (wet and dry periods)</td>
<td>—</td>
<td>—</td>
<td>2.104</td>
<td>0.316</td>
<td>Normal</td>
</tr>
<tr>
<td>(a_1) (total periods)</td>
<td>—</td>
<td>—</td>
<td>42.015</td>
<td>20.613</td>
<td>Bivariate</td>
</tr>
<tr>
<td>(b_1) (total periods)</td>
<td>—</td>
<td>—</td>
<td>2.106</td>
<td>0.352</td>
<td>Normal</td>
</tr>
<tr>
<td>(a_2) (wet and dry periods)</td>
<td>—</td>
<td>—</td>
<td>12.942</td>
<td>3.406</td>
<td>Bivariate</td>
</tr>
<tr>
<td>(b_2) (wet and dry periods)</td>
<td>—</td>
<td>—</td>
<td>1.669</td>
<td>0.179</td>
<td>Normal</td>
</tr>
<tr>
<td>(a_2) (total periods)</td>
<td>—</td>
<td>—</td>
<td>15.530</td>
<td>4.147</td>
<td>Bivariate</td>
</tr>
<tr>
<td>(b_2) (total periods)</td>
<td>—</td>
<td>—</td>
<td>1.668</td>
<td>0.178</td>
<td>Normal</td>
</tr>
<tr>
<td>(a_3)</td>
<td>—</td>
<td>—</td>
<td>99.508</td>
<td>1.541</td>
<td>Bivariate</td>
</tr>
<tr>
<td>(b_3)</td>
<td>—</td>
<td>—</td>
<td>-13.547</td>
<td>0.5168</td>
<td>Normal</td>
</tr>
<tr>
<td>(P(c))</td>
<td>12</td>
<td>28</td>
<td>26</td>
<td>—</td>
<td>Uniform</td>
</tr>
<tr>
<td>(P(m))</td>
<td>50</td>
<td>72</td>
<td>54</td>
<td>—</td>
<td>Uniform</td>
</tr>
<tr>
<td>(P(s))</td>
<td>20</td>
<td>50</td>
<td>20</td>
<td>—</td>
<td>Uniform</td>
</tr>
<tr>
<td>(QW)</td>
<td>—</td>
<td>—</td>
<td>5.325</td>
<td>2.095</td>
<td>Log normal</td>
</tr>
</tbody>
</table>

Fig 1- Annual sediment rating curve for bed load in a: wet and dry time periods and b: total time periods

Fig 2- Annual sediment rating curve for suspended sediment in a: wet and dry time periods and b: total time periods
### Table 6- Correlation matrix between input parameters (Harr’s method)

<table>
<thead>
<tr>
<th></th>
<th>a1</th>
<th>b1</th>
<th>a2</th>
<th>b2</th>
<th>A3</th>
<th>b3</th>
<th>p(c)</th>
<th>p(m)</th>
<th>p(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a1</td>
<td>1.00</td>
<td>-0.968</td>
<td>0.963</td>
<td>-0.974</td>
<td>0.456</td>
<td>0.385</td>
<td>-0.405</td>
<td>0.405</td>
<td>-0.405</td>
</tr>
<tr>
<td>b1</td>
<td>-0.968</td>
<td>1.000</td>
<td>-0.922</td>
<td>0.970</td>
<td>-0.481</td>
<td>-0.385</td>
<td>0.471</td>
<td>-0.471</td>
<td>0.471</td>
</tr>
<tr>
<td>a2</td>
<td>0.963</td>
<td>-0.922</td>
<td>1.000</td>
<td>-0.983</td>
<td>0.358</td>
<td>0.314</td>
<td>-0.363</td>
<td>0.363</td>
<td>-0.363</td>
</tr>
<tr>
<td>b2</td>
<td>-0.974</td>
<td>0.970</td>
<td>-0.983</td>
<td>1.000</td>
<td>-0.358</td>
<td>-0.287</td>
<td>0.401</td>
<td>-0.401</td>
<td>0.401</td>
</tr>
<tr>
<td>a3</td>
<td>0.456</td>
<td>-0.481</td>
<td>0.358</td>
<td>-0.358</td>
<td>1.000</td>
<td>0.984</td>
<td>-0.513</td>
<td>0.513</td>
<td>-0.513</td>
</tr>
<tr>
<td>b3</td>
<td>0.385</td>
<td>-0.385</td>
<td>0.314</td>
<td>-0.287</td>
<td>0.984</td>
<td>1.000</td>
<td>-0.453</td>
<td>0.453</td>
<td>-0.453</td>
</tr>
<tr>
<td>p(c)</td>
<td>-0.405</td>
<td>0.471</td>
<td>-0.363</td>
<td>0.401</td>
<td>-0.513</td>
<td>-0.453</td>
<td>1.000</td>
<td>-1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>p(m)</td>
<td>0.405</td>
<td>-0.471</td>
<td>0.363</td>
<td>-0.401</td>
<td>0.513</td>
<td>0.453</td>
<td>-1.000</td>
<td>1.000</td>
<td>-1.000</td>
</tr>
<tr>
<td>p(s)</td>
<td>-0.405</td>
<td>0.471</td>
<td>-0.363</td>
<td>0.401</td>
<td>-0.513</td>
<td>-0.453</td>
<td>1.000</td>
<td>-1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

### Table 7- Statistical characteristics of ARSV for 15, 30 and 45 years of reservoir operation (Harr’s method) for wet and dry time periods and total time periods

<table>
<thead>
<tr>
<th>Time in Years</th>
<th>Periods</th>
<th>Mean</th>
<th>Standard deviation</th>
<th>Coefficient of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>wet and dry</td>
<td>6977646.006</td>
<td>1576590.42</td>
<td>0.226</td>
</tr>
<tr>
<td></td>
<td>total</td>
<td>6236902.22</td>
<td>2406155.08</td>
<td>0.384</td>
</tr>
<tr>
<td>30</td>
<td>wet and dry</td>
<td>11605907.16</td>
<td>2420181.26</td>
<td>0.209</td>
</tr>
<tr>
<td></td>
<td>total</td>
<td>13919347.65</td>
<td>3700629.88</td>
<td>0.266</td>
</tr>
<tr>
<td>45</td>
<td>wet and dry</td>
<td>22584853.63</td>
<td>5513099.27</td>
<td>0.244</td>
</tr>
<tr>
<td></td>
<td>total</td>
<td>24151160.66</td>
<td>6065491.06</td>
<td>0.251</td>
</tr>
</tbody>
</table>

![Fig 3- Comparison of sensitivities for all inputs (Harr’s method)](image-url)
Also, total time periods show larger coefficients of variation (uncertainty) than do wet and dry time periods. In this method annual streamflow and annual sediment inflow are the most important factors that affect the uncertainty of ARVS, especially the annual streamflow. The two other factors are less important. This result illustrates that a complete uncertainty analysis can provide a more realistic evaluation and better optimization of reservoir design life. So, Harr’s method shows that the CV is 38% for t = 15 in total time periods and 23% in wet and dry time periods and decreases to 25% for t = 45 for all periods. In addition, sensitivity analysis shows that suspended sediment and bed load followed by annual streamflow are the most important factors influencing ARSV, in both total and wet and dry time periods. Trap efficiency and the percentage of different sediment type rank as the less important factors. In this study the percentage of silt is a less significant factor.

In this study, the result of uncertainty analysis with Harr's method shows good agreement with Monte Carlo simulation and LHS results employed by Salas (1999).

7-Conclusions
1- Annual streamflow and annual sediment inflow are the most significant factors that influence accumulated reservoir sedimentation, trap efficiency and percentage of sediments are less important factors.
2- In Harr’s method, the uncertainty of accumulated reservoir sediment volume is 37% in total time periods and 31% for wet and dry time periods.
3- Sensitivity analysis shows that suspended sediment and bed load followed by annual streamflow are the most important factors influencing ARSV, in both total and wet and dry time periods, and trap efficiency and percentage of different are less important. In this study percentage of silt is the least significant factor.
4- Wet and dry time periods estimate the uncertainty less than total time periods but to estimate sediment reservoir, wet and dry time periods have better correspond with real data.
5- Harr’s method is a very simple method that estimates uncertainty and does not take into account the probability distribution of variables which might be considered as a disadvantage. This method is recommended in water resources problems.

8-References


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