**Bulletin of Environment, Pharmacology and Life Sciences**
Bull. Env. Pharmacol. Life Sci., Vol 3 (4) March 2014: 120-126

Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
Global Impact Factor 0.533
Universal Impact Factor 0.9804

**ORIGINAL ARTICLE**

# Investigation and calibration of area-reduction and area-increment empirical methods in Sediment distribution type of Maroon reservoir dam in Khuzestan, Iran

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**ABSTRACT**
*In this research, the sediment distribution in Maroon reservoir dam situated in Iran, Khuzestan province was investigated through empirical methods of area-increment and reduction. In order to perform calculations, primary area-volume-height data of reservoir and information obtained through hydrography in years following exploitation were used. Using both methods, sedimentation in reservoir was calculated and compared to actual values obtained of hydrography in year 2005. Results showed that, area-reduction method by error decrease of 7 percent is preferred to area-increment method regarding Maroon reservoir dam. Afterwards, parameters used in area-reduction (c,m,n) were calibrated and this method was optimized to about 34 percent. Eventually and upon the base of calibrated parameters, sediment distribution was predicted for coming 30 and 50 years.*
***Key words**: area-reduction, area-increment, Maroon reservoir dam, calibration of parameters, sediment distribution.*

*Received 21 /12/2013 Accepted 10/02/2014* 

## INTRODUCTION

When a dam is constructed on a river to store water, sediments transported by the water flow are also stored and reservoir capacity is gradually reduced by sediment accumulation. Prediction of sediment distribution in reservoirs is an important issue for dam designers to determine the reservoir active storage capacity, outlet sill elevation, dam stability, recreational facilities, and backwater conditions [1]. Considering great plans regarding construction of reservoir dams and great investments in this part, awareness of status and a precise estimation of sedimentation in such dams is necessary. The pioneer of calculating non-uniform sediments was Einstein [2]. Khodhal and Ghiaci (2010), using area-reduction and modified area-reduction, predicted Karaj dam reservoir sedimentation in duration of 46 years in different levels with relative error of 6 percent [3]. Shafiee and Safamehr [4], has a search about Sediments Water Resources System of Zayanderud Dam. In this study, the different aspects of Zayandehrud dam's lake utilization and the Investigation of Sediments Water Resources System of Zayanderud Dam through Area increment and Area reduction Methods are evaluated]. Mousavi and et al [5], in a study the accuracy of area-increment and area-reduction empirical methods to predict the sediment distribution of Dez, Dorudzan and Shahid Abbaspour reservoirs was evaluated. Kargar and Sedghi [6] investigated sedimentation in Sefidroud dam reservoir using empirical area-reduction and area-increment methods and empirical method of Galay and Advance and hence, concluded that output of these methods is greatly different from hydrographic values and hence, these methods should be calibrated. Mohammadzadeh-Habili and Heidarpour (2010), are used of original and secondary area-capacity data of 40 reservoirs in the United States and a new empirical method is proposed for the prediction of sediment distribution in

reservoirs. In the proposed method, reservoir sediment distribution is related to the sediment volume and original reservoir characteristics [7]. Gharegozlu et al, (2011), optimized area-reduction method to about 30 percent by calibrating parameters of c,n,m in order to estimate and forecast Doroudzan dam sediments [1].
In this research, sediment distribution concerning reservoir dam of Maroon was estimated by area-reduction and area-increment methods regarding primary area-volume-height information of dam and hydrography performed in 2004 (Hydrography data of Maroon dam, 2004). Finally, empirical method of area-reduction was chosen which estimates the sediment amount in this dam with lowest level of error.
Although empirical method of area-reduction is one of the most common methods of estimating sediment distribution, but survey of previous researches show that, since parameters used in this method are obtained from information under study by Berland and Miller on 30 dams in America, which, in most of the dams, these parameters were not the best parameters to estimate sediment distribution method and needs to be calibrated .Following this, empirical method parameters of area-reduction concerning Maroon reservoir dam were calibrated and this method was optimized. Eventually and through the optimized method, a more precise estimation of sediments amount was predicted for coming years.

## MATERIALS AND METHODS

### A. Dam characteristics

Maroon dam is located on a river with the same name, which is one of Khuzestan's main rivers. This river originates from 2300 meter heights of Zagros Mountains located in 19 kilometers northeast of Behbahan City. Basin area of this river is about 3824 square kilometers and mean annual yield of the river is 50 cubic meters per second. Primary area-volume-height curves of Maroon dam and its technical characteristics are shown respectively in table 1 and figure 1.

**Table1.** Maroon dam specifications.

| | |
|---|---|
| Dam Type | Rock fill with a clay *core* |
| UTM | 438336 and 3398950 |
| Height above foundation (m) | 165 |
| Crest length(m) | 345 |
| operation time (year) | 2000 |
| First hydrography time | 2005 |
| Reservoir primary volume (MCM) | 1200 |
| 50 year sediment volume (MCM) | 160 |

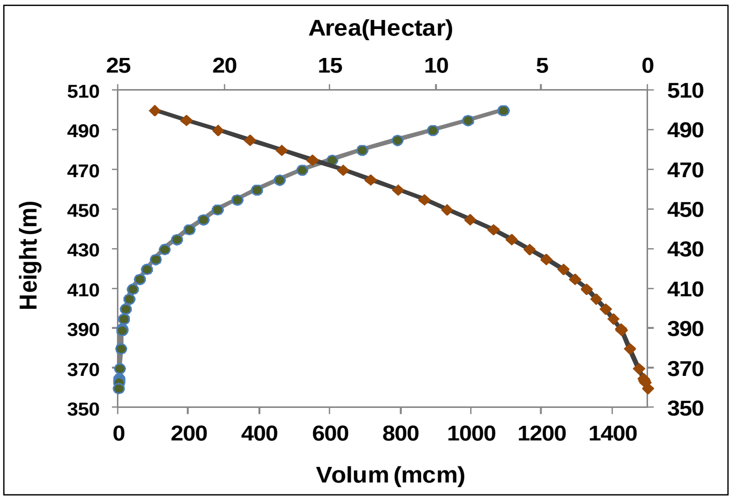


**Figure 1.** Primary area-volume-height curves of Maroon dam.

 

In this research, sediment distribution type was calculated through two methods of area-reduction and area-increment using area-volume-height data for year 2005. Then, sediment distribution type was estimated upon the base of primary area-volume-height information and sediment estimation results obtained of both methods were compared to actual value (hydrography) in year 2005 and hence, the error rate and standard deviation were calculated. In the end, area-reduction method was chosen as the appropriate option and then, by calibrating parameters of c, m, and n by a program written in Matlab software, sediment distribution type was estimated according to primary area-volume-height information. Finally and by using area-reduction method, dam sediment distribution was forecasted for coming years (2035 and 2055).

**B. Area-increment method**

Area-increment method was proposed by Christiphano in 1953. Principle of forecasting sediment deposit in reservoirs by this method is based upon calculation of areas-reduction in each height as a result of definite amount of sediment accumulation. It is supposed in this method that, sediment level all heights is constant and sediment volume is distributed evenly in height above zero. The mathematical relation is as follows:

$$K = \frac{A_0}{a_0}$$

Where, $V_s$ is total sediment volume per square meter, $A_0$ is area correction coefficient in hectare which equals to reservoir area in new zero digit, $V_0$ is sediment volume below new zero digit in cubic meters, H is reservoir height above stream bed to the maximum normal digit per meter, $h_0$ is the elevation of reservoir filled with sediment in new zero digit per meter.

$$V_s = A_0(H - h_0) + V_0$$

In this method we should first guess a level concerning the new elevation and then, with regards to primary reservoir area-volume-height table of the reservoir, area and volume values of the reservoir are defined. Then, as for the area-increment relation, total volume is calculated and compared to predicted total volume at the time of design. In case these two values be the same, initial conjecture regarding new zero height is correct, otherwise, another new zero height will be guessed and the whole procedure is repeated until equality of two volumes is reached [8].

**C. Area-reduction method**

One of the empirical methods in estimating sediments amount behind dams is area reduction method. This method was proposed by Berland and Miller in 1958 to field's reclamation committee of America and is obtained through studies of actual results of 30 great reservoirs in America. This method was modified by Lara in 1962 [9]. The results show that accumulation and distribution of sediments in different reservoir heights has a specific relation with reservoir shape (according to table 2) and the reservoir shape is defined and categorized according to the relation between reservoir height and capacity.

**Table 2.** Different reservoirs gradation according to shape.

| Reservoir gradation | Reservoir Type | M |
|---|---|---|
| I | Lake | 3.5 – 4.5 |
| II | Flood Plain | 2.5_3.5 |
| III | Hill | 1.5_2.5 |
| IV | Gorge | 1_1.5 |

Following steps must be followed in the area-reduction method in order to define sediment distribution type [8]:

***First step***: Definition of reservoir type according to factor m. Factor m is reverse slope of best graphic representative line of reservoir height per reservoir capacity drawn on a full logarithm paper in which, vertical axis is the depth and horizontal axis is the volume. M classification is according to table 2.

***Second step***: Defining different values of comparative depth P. Comparative depth is calculated through dividing reservoir depth in definite level by reservoir depth in normal level.

***Third step***: Relative sediment area ($a_p$) is calculated through substituting different values of P relative depth in the equation relating reservoir type. Finally and by use of proportionality coefficient of K (according to the equation), sediment relevant area is converted to actual area and new zero will be defined.

In this relation, $A_0$ is the reservoir area in height $h_0$ (bed - building stage), $a_0$ is the relative area of sediment in new zero height. Relative area is calculated through following formula in which c,m,n are constant coefficients which are defined according to table 3 with regards to reservoir type. Of course, these are modified values of Berland and Miller method (7). It's favorable to optimize these values for each reservoir.

$$a_p = Cp^m(1-p)^n$$

**Table 3.** Reservoir type modified values of Berland and Miller method.

| Sediment detention limit | N | M | C | Reservoir type |
|---|---|---|---|---|
| High | 0.36 | 1.85 | 5.074 | I |
| Higher than average | 0.41 | 0.57 | 2.487 | II |
| Lower than average | 2.32 | -1.15 | 16.967 | III |
| Low | 1.34 | -0.25 | 1.486 | IV |

**Fourth step**: Using depth-capacity curve of the reservoir, sediment volume below reservoir zero level is defined and then, sediment volume in different depths is estimated. It should be noticed that, this is a trial and error method and if calculated volume of sediments be greatly different from input sediments, proportionality coefficient should again be modified.

$$K_2 = K_1 \frac{S}{S_1}$$

In which $K_2$ and $K_1$ are new and previous proportionality coefficient respectively and $S_1$ is the cumulative volume of sediments. Afterwards, these values are compared to values obtained of hydrography and subsequently, error rate and standard deviation are calculated according to the following relations:

$$e = \sqrt{\sum_{i=1}^{n} (v_i - \overline{v_i})^2}$$

In which, $v_i$ and $\overline{v_i}$ are measured volume and actual volume of the reservoir in different levels, **σ** is the standard deviation and e is the error rate.

$$\sigma = \sqrt{\sum_{i=1}^{n} (v_i - \overline{v_i})^2 / (n-1)}$$

## RESULTS AND DISCUSSION

### A. Determine Dam Type & Empirical method

Primary area-volume-height curves of Maroon dam shown in figure 1 are based upon information of year 2000 (Exploitation time)[10]. Also, by depicting volume-height data in a logarithmic coordinate system (figure 2), reservoir type was defined of type II.

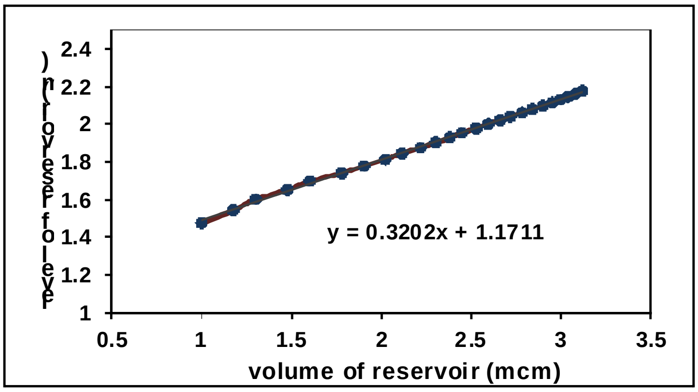


**Figure 2.** Line and equation of Maroon dam reservoir type definition.

 

After defining reservoir type and considering 50-year average input sediment to the reservoir equaling 160 million cubic meters, sediment amount and distribution type were calculated regarding year 2005 by use of area-reduction and area-increment methods based upon volume-area-height information of year 2000. Finally, sediments volume calculation results of both cases in year 2005 were compared to reservoir hydrography results in that year and hence, error rate and standard deviation were defined. Summary of calculations and comparison of volumes are presented in table 4 and figure 3, respectively.
Using level increment and reduction methods, new zero height was calculated 364.5 and 369 respectively.

**Table 4.** Error rate and standard deviation of level reduction and increment.

| | Level reduction method | Level increment method |
|---|---|---|
| Error (percent) | 33 | 40 |
| Standard deviation | 45 | 49 |

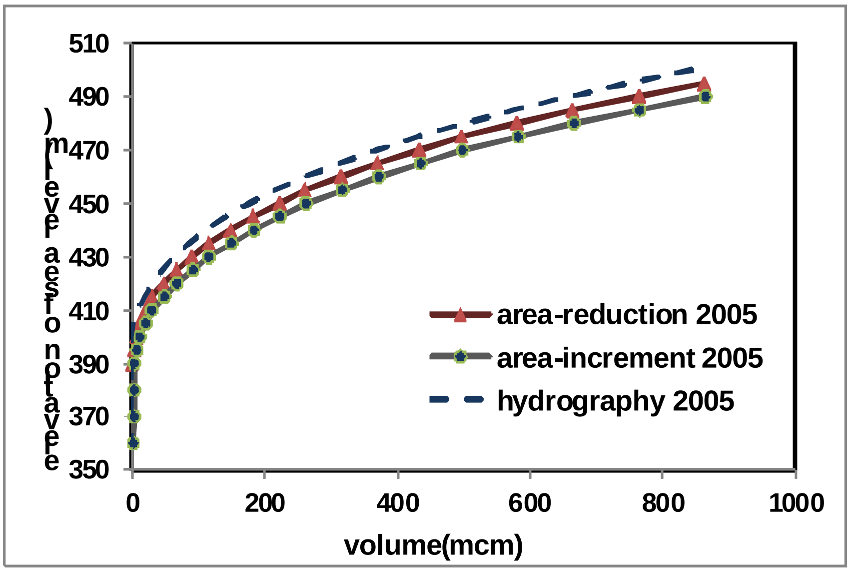


**Figure 3.** Maroon dam sediments distribution using area-reduction and area-increment empirical method compared to hydrography in year 2005.

**B. Calibration of area-reduction method & Forecast**

First, the amount and type of sediments distribution for year 2005 was calculated through area-reduction method (area-reduction with usual parameters) based upon volume-area-height information of year 2000. Then, the mentioned parameters were calibrated through "Matlab" software and hence, the amount and type of sediments distribution were again estimated for year 2005.
Eventually, the results of sediment volume calculation regarding year 2005 was compared to reservoir hydrography results for both cases (usual parameters and calibrated parameters) and error value and standard deviation was identified. The calculation summary and volumes comparison are exhibited in table 5 and figure 4, respectively.

**Table 5.** Error value and standard deviation with calibrated and regular values of c,m,n.

| Parameter | n | m | c | Error value | Standard deviation |
|---|---|---|---|---|---|
| Regular | 0.41 | 0.57 | 2.487 | 33.90 | 44.20 |
| Calibrated | 0.4 | 0.75 | 3.9 | 23.24 | 21.61 |

 

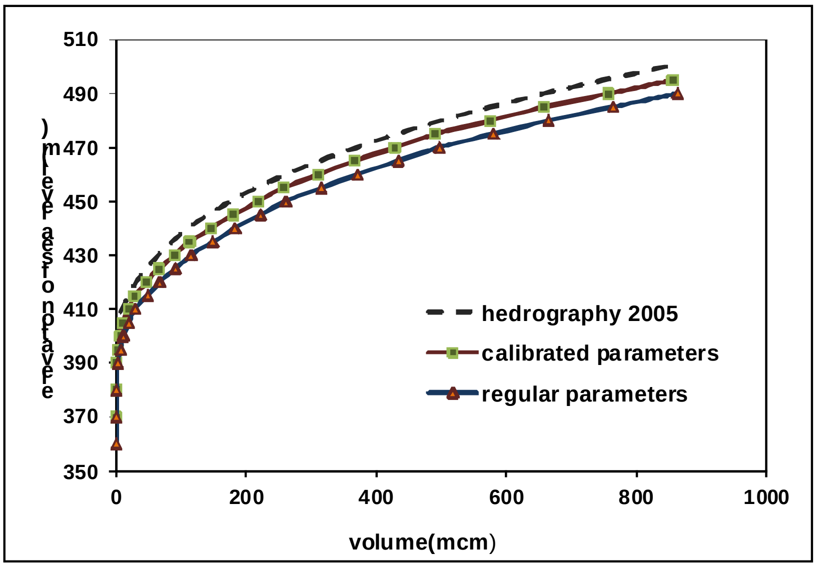


**Figure 4.** Sediment distribution using empirical method of area-reduction with calibrated and regular parameters in comparison with hydrography of year 2005.

As it is seen in figure 5, the volume-height graph obtained through calibrated parameters shows better conformance to measured values (hydrography). It's also shown in table 5 that, the error rate of estimating Maroon dam sediments distribution type is declined to about 10.5 percent by calibrating parameters (c,m,n). It should also be mentioned that, in case of long interval between dam exploitation time and first hydrography, optimization of parameters will be more precise and error value will show greater decrease.
Figure 5 shows the sediment distribution type of 35 years later using calibrated parameters upon the volume-area-height information of year 2005.

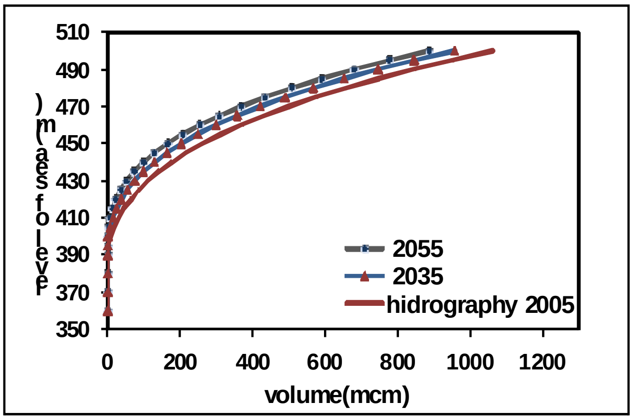


**Figure 5.** Forecast of sediments distribution type for years 2035 and 2055 using calibrated parameters.

## CONCLUSION

Results showed that:
1. Both method of area-reduction and area-increment can be used with a little difference, in estimating dam sediments.
2. Finally, area-reduction method shows closer results to dam hydrography values compared to area-increment method.
3. The error rate in estimating Maroon dam sediments by use of area-reduction method is 34 percent.
4. The error rate in estimating Maroon dam sediments by use of area-increment method is 40 percent.

5. By calibrating parameters in area-reduction method, error rate in estimation of Maroon dam sediments decreases from 34 to 23 percent. In other words, through decreasing error by 10.5 percent, the mentioned method is optimized to about 31 percent.
6. Forecasts regarding method and amount of sedimentation in Maroon dam reservoir in years 2035 and 2055 were predicted through calibrated area-reduction method and the results obtained may be advantageous in water resources planning.
7. Considering that area-reduction is one of the most applicable methods of estimating sediments distribution at the time of dam design (due to lack of information), and by taking into account that this method is based upon information gained from a limited number of dams (30 dams in America), it should be calibrated regarding other dams in the world.

## ACKNOWLEDGEMENT

Hereby, we would like to express our appreciation due to their kind supports, towards department of drainage and irrigation standards and researches of water and power organization in Khuzestan & Young researchers and elite Club & Agricultural Sciences and Natural Resources University of Sari in Iran.

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**How to cite this article:**
Niayesh F, Samaneh A, Mohammad G, Sajjad R. Investigation and calibration of area-reduction and area-increment empirical methods in Sediment distribution type of Maroon reservoir dam in Khuzestan, Iran.Bull. Env.Pharmacol. Life Sci. 3 (4) 2014: 120-126