



# Optimal Height And Location Model (OHALM) for rainwater harvesting small dams (Iraqi western desert- case study)

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## ABSTRACT

Dams are considered as the best solution to conserve water especially in arid and semi-arid regions. This study aims to design a small dams series to conserve rainfall water. Mathematical model is proposed to optimize these dams height and locations, its named as Optimal Height And Location Model (OHALM). In this study, new method is introduced to estimate the optimal water level and volume of storage by combining between the digital elevation model generated by the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data, and the proposed model (OHALM). Two dams sites were selected for checking the validity of proposed method. The results of the present study showed that the error percentage increase or decrease from reference value by 3.5%, 13% for water level in Al-Rutba dam and Horan 3 dam respectively, and by 6.63%, 35.8% from volume of storage in Al-Rutba dam and Horan 3 dam respectively. The relative error shows a big difference from the actual data, which is a positive percentage for storing additional quantities of rainwater. That means the proposed program is better than the existing dam design, and thus the possibility of using this method to determine the optimal height of the proposed water harvesting sites.

## 1. Introduction

The increased demand of water for drinking, irrigation, hydroelectric power and other purposes has led to an increase in water use. According to the future scenario of water scarcity problem, there is a requirement to rainfall water harvesting and make surveys for new sites for constructing new reservoirs. Before choosing suitable new sites, the reservoir site must be surveyed to know the water quantities that can be stored inside the reservoir versus the different elevations.

Lately, the computer technology and the use of Geographical Information Systems (GIS) has become fundamental tools for analyzing optimum reservoirs sites [1]. DEMs are used to identify the flow directions, flow accumulations, stream orders, slopes, areas and volumes[2]. ArcGIS works to provide accurate calculations of storage volumes and surface areas of dams reservoirs through contouring and surface mapping rather than other classical methods. The storage capacity

for the reservoir at any level can be easily determined by finding the volume under each contour. With this procedure, the economic burdens, work burdens and time can be greatly reduced in the calculation of storage capacities and surface areas of reservoirs. Remote Sensing (RS) data was used to find the storage volume for the small reservoirs in Ghana. The results of this study showed that there existed relationships between the surface area, depth of water and volume of storage for the reservoirs[3]. Authors studied that the optimum depth, surface area and storage volume of dam were estimated by AVE-curve through of the Digital Elevation Model (SRTM) with GIS (GIS-SRTM) [4].

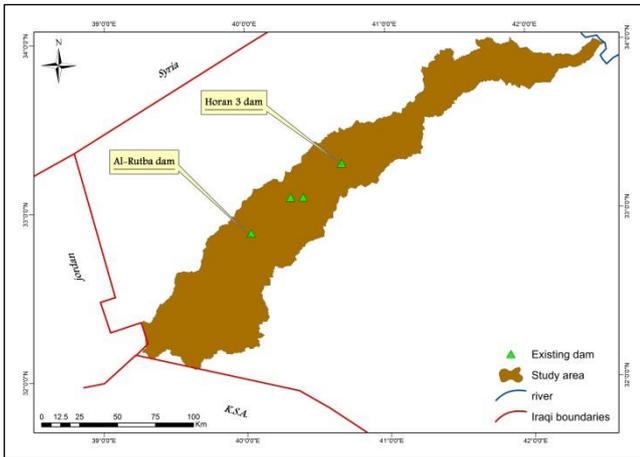
This study aims to use Geographical Information Systems (GIS) to extracting the geometric dams reservoirs properties and modeling it in (OHALM) to find the optimal water level and storage capacity. It should be noted that it is the first study that introduce evaporation losses as a fundamental component in the objective function to find the optimum water level of the reservoirs. To validate the proposed model, this model was applied on two existing dams in the Iraqi Western Desert..

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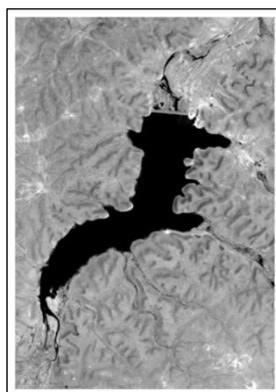
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**2. Area of the Study**

Horan valley is one of the largest valleys in Iraqi Western Desert extending for a distance of 458km from the Iraqi-Saudi borders to the point where it meets Euphrates River in Al-Baghdadi town [5]. The valley catchment area is around 13,370 km<sup>2</sup> with specific geographic coordinates 32° 10' 44" to 34° 11' 00" north and 39° 20' 00" to 42° 30' 00" east [6]. Horan valley contains four dams (Figure 1) that were constructed in different years with different heights and storage capacities. Also, there are a number of proposed dams for future development. Current study was worked on two existing dams sites [Al-Rutba dam & Horan3 dam] on Horan valley. Al-Rutba dam which was constructed in the 1970s, is located 38km southwest of Al-Rutba city (Figure 2). It is earth fill dam of 847meters length, the height is 19m and reservoir capacity of 32 Mm<sup>3</sup> [7],[8]. The geographic coordinates for Al-Rutba dam is 32.886766N and 40.035807E. Horan3 Dam [Figure 3] which was constructed in 2003 is located 58 km northeast of Al-Rutba city with 448meters length, the height is 15m and reservoir capacity of 5.3 Mm<sup>3</sup> [9]. The geographic coordinates for Horan3 dam is 33.295652 N and 40.679637E.



**Fig. 1 Locations Map of the study area dams**



**Fig. 2 Al-Rutba dam**

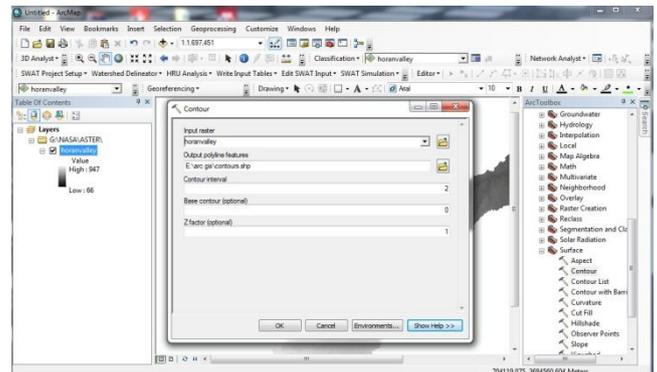


**Fig. 3 Horan 3 dam**

**3. Materials and Methods**

**Phase I.** The first step in this research is extracting geometric data for dams. This is done by using GIS and through the following steps:

- 1- Advanced Space borne Thermal Emission and Reflection Radiometers (ASTER) were used to draw the contour map for the study area by using "Contours" tool present in Spatial Analyst Tools > Surface > Contours and supply the contour interval value by 2m and 0.5m as shown in Figure (4).



**Fig.4 Contour of the study area**

- 2- Selecting the maximum dam height to find the storage volumes at different elevations of the dam lake and then the specific contour will be exported to the directory. Then, the exported contours are converted to a polygon through using of the tool "Feature To Polygon" present from Data Management Tools > Features > Features To Polygon, as shown in the figure (5). Before converting to a polygon, all open spaces must be closed, this is done through start editing for contour layer. At the end, the DEM is extracted versus this polygon by using the command "Extract by Mask" tool present in Spatial Analyst Tools > Extraction > Extract by Mask.

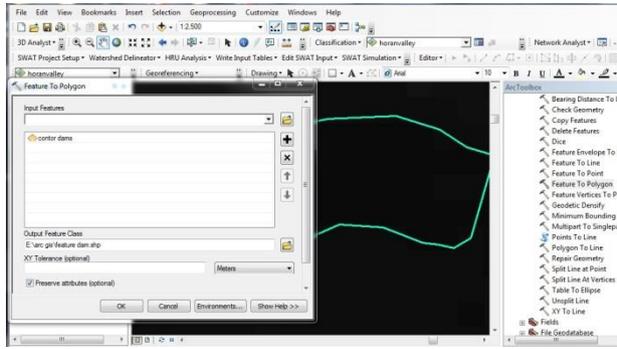


Fig.5 Feature To Polygon tool

- 3- The volume of storage and surface area for any dam can be estimated below any specified contour. This is done by using 3D Analyst Tools > Functional Surface > Surface Volume, as shown in the figure (6).

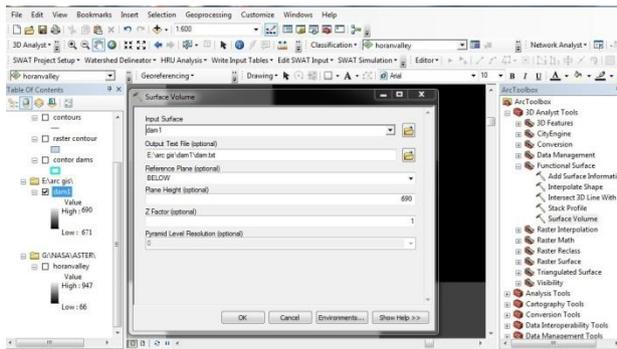


Fig.6 Surface Volume tool

- 4- Repeated the above steps for all dams sites.

**Phase II.** Estimating the optimal water level for the dams by using proposed model (OHALM). This method is suggested in this study to find the optimum water level for dams by using the Visual Basic program and can be formulated as follows:

To maximize the objective function (F), which can be written as:

$$Maximize F = \frac{\Delta VS}{\Delta VE} = \frac{(V_{(i+1)} - V_i)}{(S.A_{(i+1)} * d_E - S.A_i * d_E)} \quad (1)$$

Where:  $F$ = Objective Function of the benefits,  $d_E$  = Evaporation depth (m),  $i$ = rank of water level,  $V_{(i+1)}$ ,  $V_i$ = volume of storage for reservoirs at water level  $(i + 1)$ ,  $i$  respectively ( $m^3$ ),  $S.A_{(i+1)}$ ,  $S.A_i$ = surface area for reservoirs at water level  $(i + 1)$ ,  $i$  respectively ( $m^2$ ).

The following constraint could be used:  $H_{max} \geq W.L > H_{min}$

$H_{max}$ ,  $H_{min}$ = A selected maximum and minimum water level respectively by user. The surface area and volume of storage are calculated as shown in (Phase I). The evaporation depth was depended for each of the three regions as shown in Table (1).

Table 1- Evaporation depth for each zone [10]

Zone	Evaporation depth (mm)
Down-Stream	1900
Mid-Stream	1700
Up-Stream	1600

The model processes to design the optimal water level with minimum evaporation losses for a given reservoir capacity. The general steps for this model described below and illustrated in Figure (7), while figure (8) described the program interface.

- 1- Selecting minimum and maximum water levels for dams ( $H_{max}$  &  $H_{min}$ ) according to sediment loads and evaporation losses. The minimum water level equal to 6m, it depends on the dead storage volume of the dam.
- 2- The water level will be iteratively increased by 50cm and estimating the surface area and volume of storage for each water level approved.
- 3- The input of the program is water level, surface area and volume of storage according to the specifications mentioned previously. While the evaporation depth is entered by 1600mm and 1700mm (Table 1) for Al-Rutba dam and Horan3 dam respectively, where Al-Rutba dam and Horan3 dam is located in Up-stream and Mid-stream respectively.
- 4- Calculations procedure went through two paths; the first represents the change in benefit which depends on the volume of storage, while the second represents the change in cost which depends on the evaporation losses which varies directly with the surface area of the stored water in a reservoir.
- 5- The ratio between the benefit change and the cost change is the main limitation of the model and it is the main decision station in the system. The greater value is chosen from the objective function, which obverse to the optimal value of the water level for the dam.
- 6- When the calculations are completed according to the specified objective function, the model jump to the output stage represented by site of dam, optimal water level and storage capacity.
- 7- The pattern is iterative to (n) of the suggested dams.

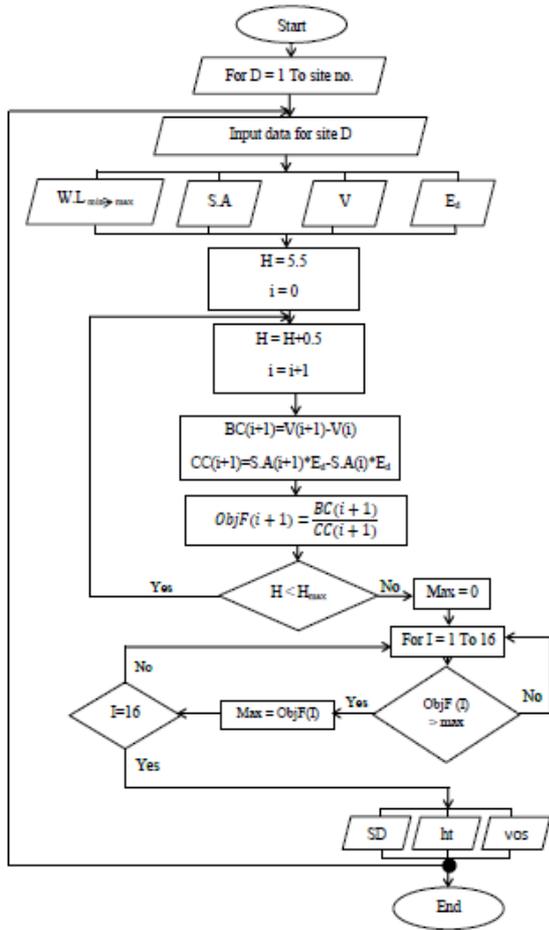


Fig. 7 OHALM logic flow chart

Where: WL=water level in the dam (m), S.A= surface area for the dam reservoir (m<sup>2</sup>), V= volume of storage for the dam reservoir(m<sup>3</sup>), Ed= evaporation depth (m), BC= Benefit Change (m<sup>3</sup>), CC= Cost Change (m<sup>3</sup>), Objf= Objective function, i= rank, SD=dam site, ht= Optimal water level (m), VOS= optimal volume of storage (m<sup>3</sup>)

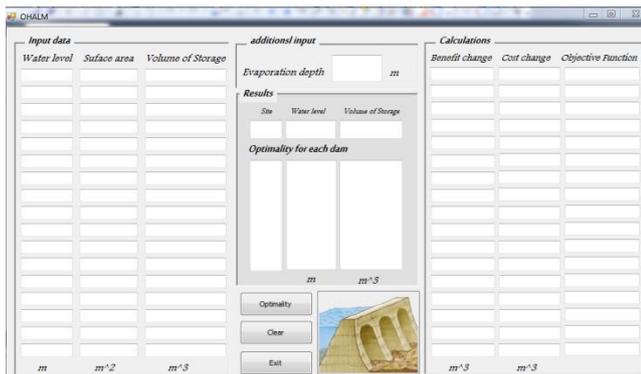


Fig. 8 OHALM interface

**Phase III. Model Validation**

The proposed model (OHALM) is applied to redesign two small dams

constructed to stored rainfall surface runoff in Horan valley are Al-Rutba dam and Horan 3 dam. The performance efficiency of the present model is appointed by using Relative Error (ER)[11]. ER is defined as

$$RE = \left( \frac{V_m - V_a}{V_a} \right) * 100\% \tag{2}$$

Where:  $V_m$ = measured value,  $V_a$ = actual value

The actual values for the two studied dams illustrated in Table (2)

Table 2-The actual data for the dams[12]

Dam	Water Level m	Volume of storage Mm <sup>3</sup>
Al-Rutba dam	14	32
Horan 3 dam	11.5	5.3

**4. Results and Discussions**

Extraction of reservoirs properties through GIS is a very convenient approach. In this study, OHALM was developed by using the GIS-ASTER data to find the optimal water level and volume of storage and compared with the actual data for dams reservoirs.

After finding the surface area and volume of storage for dam lake. The values are entered in to (OHALM), as shown in Figure (9). these value is confined from  $H_{min}$ = 6m to  $H_{max}$ =14 m and the increase is every 0.5m. The maximum water level height  $H_{max}$ =14 was chosen for two reasons. First, when applying this model on  $H \geq 14$ m, there are no significant difference between the objective function values. Secondly, the rate height of the existing small dams in the Western Desert =14m. As for the depth of evaporation, its value was found for each region based on (Table 1) where Al-Rutba dam and Horan3 dam is located in Up-stream and Mid-stream respectively. The data is entered into the program, running the program and optimum value of water level will appear for this dam as shown in Figure (10). This is applied to both selected sites.

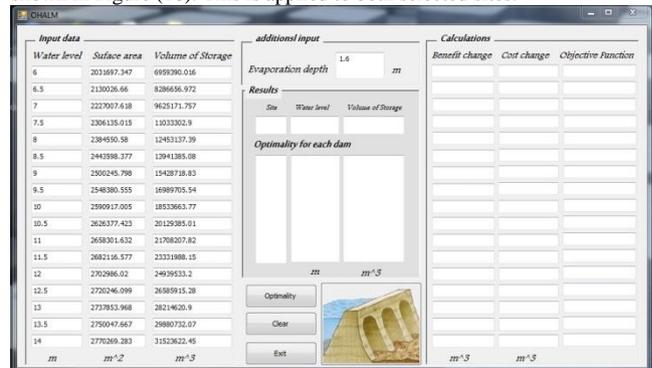


Fig. 9 Input Water level, Surface area, Volume of storage & Evaporation depth



Fig. 10 OHALM Run interface for dams

The validation process of measured data from OHALM is done by measuring the performance of each result and comparing with actual data, depending on the relative error between the actual and measured data. The results of the relative error is shown in Table (3).

Table 3- Percentage increase or decrease from reference values.

Dam	Real data		OHALM data		RE %	
	W.L (m)	V (Mm <sup>3</sup> )	W.L (m)	V (Mm <sup>3</sup> )	W.L (%)	V (%)
Al-Rutba	14	32	13.5	29.88	3.5	6.63
Horan 3	11.5	5.3	13	7.2	13	35.8

Figure (11) and Figure (12) shows the graphical representation developed for volume of storage versus water level for two dams.

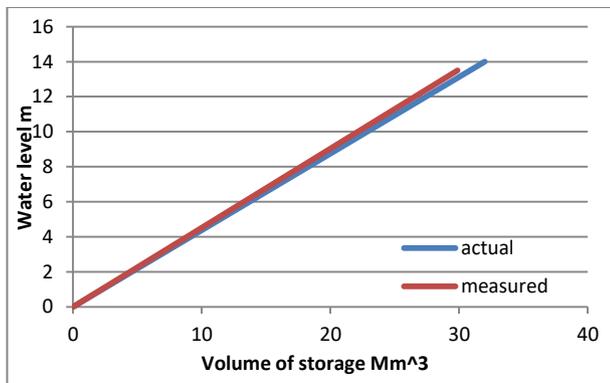


Fig. 11 Graph of difference between actual and measured data for Al-Rutba dam

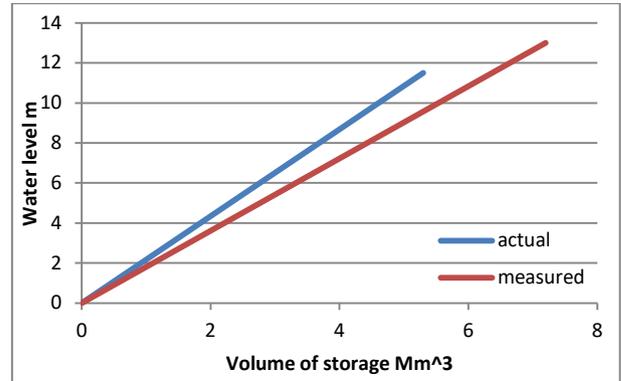


Fig. 12 Graph of difference between actual and measured data for Horan 3 dam

The results of the present study showed that the error percentage increase or decrease from reference value by 3.5%, 13% for water level in Al-Rutba dam and Horan3 dam respectively, and by 6.63%, 35.8% from volume of storage in Al-Rutba dam and Horan3 dam respectively.

In Al-Rutba dam, the existing water level height equal to 14m, while the water level height extracted from the proposed model (OHALM) equal to 13.5m for the same dam. The proposed model reduced the surface area by about 18% and thus reduced the evaporation losses by 18%. On the other hand and in the case of comparison with the real data of the dam, the evaporation losses are increasing by (18%) while the stored volume increased by (6.63%), that means the increasing in evaporation ratio is the greater than the increasing in stored volume ratio.

As for Horan 3 dam, the relative error value of 13% for the optimum water level was observed and 35.8% for the storage volume. The source of this error because of the rugged terrain in this part of the study area. As it is known, the DEM data are affected by the topography and thus causes some error in the measurement. But at the same time, an increase in the storage volume of 35.8% was obtained by using the proposed model (OHALM) , which is a good percentage for storing additional quantities of rainwater.

In general, the relative error shows a big difference from the actual data and that leads to storing additional quantities of rainwater, and thus the possibility of using this method to determine the optimal height of the proposed water harvesting sites.

**conclusion**

Geo-spatial techniques, i.e. Geographical Information System (GIS) assists the user to find the reservoirs properties without physically visiting the dams sites. It was concluded from this study that OHALM model works to reduce evaporation losses by reducing the surface area in Al-Rutba dam. Also, OHALM is better than the existing dams design and leads to storing additional quantities of rainwater in Horan 3 dam.

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