Optimal Heights of Small Dams Series for Rainwater Harvesting, (Iraqi Western Desert as a Case Study)

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ABSTRACT:

Small dams are a suitable tool for managing, storing and distributing water. In this paper, anew methodology has been introduced to help greatly in water resources planning. Scope of the study includes two phases, the first is to identify sites for dams in Western desert of Iraq (Horan valley) using geographical information system (GIS) according to different criteria. The second stage includes the establishment of a computer model with visual programing to evaluate the optimum height of dams according to an economic aspects based on the lowest evaporation losses and highest storage capacity through a set of equations. This computer program named Optimal Height And Location Model (OHALM). 13 proposed small dams were selected in the region and distributed on upstream, midstream and dawn stream as 3, 5 and 5 respectively. The height values for these dams ranged between 12.5 – 14 m as a maximum water storage level. The results of (OHALM) were compared with the heights of dams currently available in the valley in order to evaluate this model. The relative differences between the water levels calculated from the mathematical model (OHALM) with the water levels of existing dams in the study area area is about 10.4% in upstream , 7.2% in midstream and 7.2% in downstream.

Key words:
Small dams' series, rainwater harvesting, modeling, optimization,

1- INTRODUCTION :

One of the most important criteria that affects the sustanable development is the availability of water resources. The process of planning and managing water resources is very important, especially in regions that suffer from varying in rainfall quantity (Kamel & Mohammed, 2010) (Abdulhameed et-al 2020). According to the United Nations Environment Program (UNEP), in the year 2050 more than two billion people will live in conditions of high water stress, which confirms that water will be a limiting factor for development in many countries of the world (Sekar & Randhir, 2006). During the 20^{th} century, a large number of dams were built where it is estimated that the dams affect more than 60% of the rivers, about 19% of the electricity production in the world depends on hydroelectric power and about 40% of irrigated lands around the world depend on the dams (WCD, 2000). Small dams are a suitable tool for managing, storing and distributing water because building them requires less time, cost and effort (Blance & Strobl, 2013).

Arid and semi-arid regions constitute about 35% of the earth's surface and cover area of 50 million km^2 of the world (Naif and Abdulhameed 2021), (Ziadat etal.,2012) . The Iraqi Western Desert is one of the arid regions and covers about 32%

of the area of Iraq (Al-Muqdadi, 2012). The planning and management of water resources in this region is important for providing water and improving the quality of life. Rainwater harvesting and storing water by dams is very sutable tool to conserve water in the dry season (Abdulhameed et al 2020) and (Sayl et al.,2016).

The process of selecting dams sites in these areas faces many difficulties because the dry areas are uninhabited and suffers from severe shortage of infrastructure. Geographic Information systems (GIS) is a modern tool in planning water resources (Adham, 2016). GIS provides a simplification of the optimum dams sites selection process by a number of factors recommended by FAO (Kahinda etal.,2008). The optimum depth, surface area and storage volume of the reservoir were estimated by AVE-curve by using the Digital Elevation Model (SRTM) with GIS (GIS-SRTM) (Sayl et al.,2017). (Ahmed et al 2020).

The main objective of the present study is developing a new methodology for selecting sites of series small dams by using GIS and finding the optimum height by means of a proposed mathematical model. The computer program is constructed and named Optimal Height And Location Model (OHALM), then evaluated by comparing its results with the available dams that already constructed in the same area.

2- Materials and methods :

2.1 The study area

Horan valley is one of the largest valleys in Iraq (Figure1). Extending for a distance of 458 km from the Iraqi-Saudi border to the point where it meets Euphrates river in Al-Baghdadi city with geographical location between longitude 39˚00"00' to 43˚00"00' East and the latitude 32˚00"00' to 43˚30"00' North (Ibrahim et al.,2017). The catchment area is 13370 km^2 and the difference in elevation between the beginning and end of the valley about 600 m (Sayl et al.,2016). Horan valley region is classified as the arid region where it has a climate with hot Summers and cold Winters (Adham et al.,2018), the average annual rainfall between 75 and 150 mm, about 90 % of these rainfalls occur between December to March. The average depth of evaporation ranges between 1600 to 1900 mm and about 75% of these evaporation occur between April to September (Sayl et al., 2016). The maximum annual surface runoff rate is about 900 million cubic meters (sayl et al., 2017). Most catchment area of Horan valley content on hard limestone rocks (Alhadithi & Alaraji, 2016) and these rocks a good base for dams.

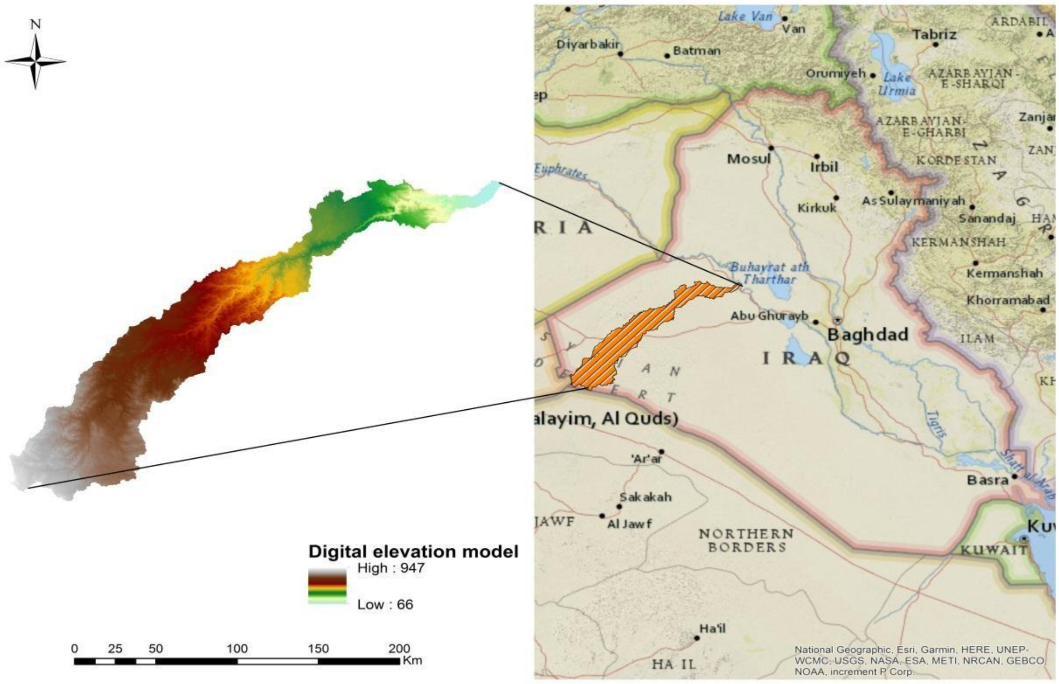

Figure 1 Location of study area

2.2 General approaches:

The research work consists of two stages, which can be summarized as follows:

1- Dams sites selection by using geographic information systems (GIS) through a set of criteria.
2- An optimization model to select the optimum height for water level by using VB software and construct OHALM.

2.2.1.a Dam location selection criteria:

Topographic data play a major role in defining the appropriate areas for the construction of dams (Stephens, 2010). The Food and Agriculture Organization (FAO) has identified six major factors when determining water storage sites: climate, hydrology, topography, agronomy, soils and socio- economics (Kahinda et-al., 2008). In this study, a number of criteria were used according to the available data.

- Stream order :

Stream order was considered as a parameter of hydrology and have been chosen as one of the criteria to find the optimal location because its effects on flood volume, as it is extremely increased in streams that have a higher stream order (Rahmati et al.,2019). The arrangement of stream order depends on connection of tributaries and allows the classification of stream orders according to their size such as the lower stream orders have higher area then higher permeability and infiltration, and vice versa (Adhem et-al.,2018). The map of stream order for study area is presented in (Figure 2), where potential dams sites are classified as very high (>7), high(7), medium (6), low (5) and very low (<5).

- Width of valley :

One of the main characteristics that should be taken into account when constructing dams is the width of the valley, the height of its walls and narrow canyon. When these properties are available, the proposed site will be reduce the dam dimensions, so the construction cost will be decreased (Hanson & Nilsson, 1985). Figure 3 shows the cross-section for suggested dam site and (Figure 4) explains the contour Lines for suggested dam site.

- Slope :

The slope is considered as a topographical parameter and was chosen as one of the basic criteria because it plays a major role in generating surface runoff and therefore will affect quantify of sedimentation, the speed of water flow and the quantity of material required to build the dam structure (Adham et-al., 2016). The slope map was considered a vital map in a runoff suitability analysis for any watershed area. When the slope of reservoir is less than 3%, the storage efficiency is better with more economical earthwork required (Al-Adamat etal., 2010). It is not recommended to collect water in area with a slope greater than 5% due to irregular distribution of runoff therefore these area are subject to high rates of erosion and large earthwork being required (Critchley & Siegert, 1991). The map of slope for study area is presented in (Figure 5).

- The series formula:

One of the characteristics that must be taken into account when constructing a series of small dams in a specific area is the location of the second dam relative to the first dam. This criterion depends mainly on the height of the first dam and which includes the maximum water level, freeboard and topographic of the valley. The maximum water level represents optimum water level that was found depending on the established criteria. Freeboard is the difference in the height between the total dam height and the maximum water level, its value should be sufficient to prevent the floods will overtop the dam as there are many dams that failed due to insufficient freeboard (Harradine,2008). United States Bureau of Reclamation (USBR) recommends that the value of freeboard used in the dams about (1.5 – 3) m (Chahar, 2004). As for the topographic conditions, it was set to add protection to the dam and prevent the effects of backwater curve (Figure 6).

$$B.L_B = Spillway\ level_A + F_b + \lambda \qquad (\ equation\ 1\ )$$

Where :

$B.L_B$ = Bottom level of the second dam (B), (m)

Spillway $level_A$ = Optimum water level of the first dam (A), (m)

F_b = Free board (m)

λ = Coefficient of topographic (m)

- Distance from main roads:

Roads are considered socio-economic parameters and have been chosen as one of the basic criteria for finding dams series locations because it is of value to the local community in the study area. People use these roads to transport their trucks and tankers from one place to another or moving with their livestock to search for water and grass. Therefore when choosing dams sites, it should not be far from the existing roads to reduce constructions costs (Al-Adamat, 2008). A 250-meter buffer zone has been used around all roads including unpaved roads to protect these roads from their selection as suitable sites for dam construction (Al-Adamat et-al., 2010). To prevent any future conflict between the constructed dams sites and roads, a threshold value of less than 5 km was chosen to include this aspect (Al-Adamat et-al., 2012) . Figure 7 shows paved and unpaved roads in the study area.

2.2.1.b Site identification:

The suitable site for series of small dams were identified by geographical information systems (GIS) represented by the Global Mapper 20 software and ArcMap 10.5 program. Used GDEM extracted from the Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data and Quick bird satellite images as input data. The identification process is done through the visual interpretation of the satellite image.

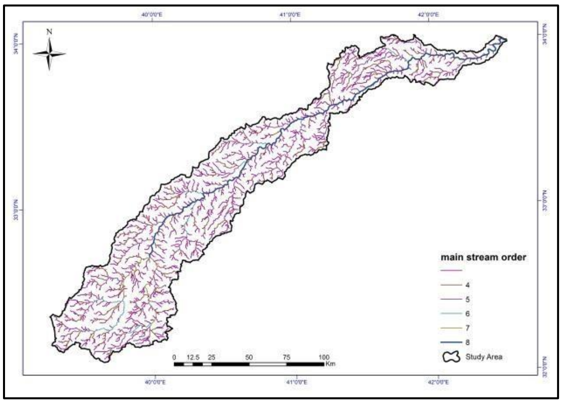

Figure 2 , stream order map

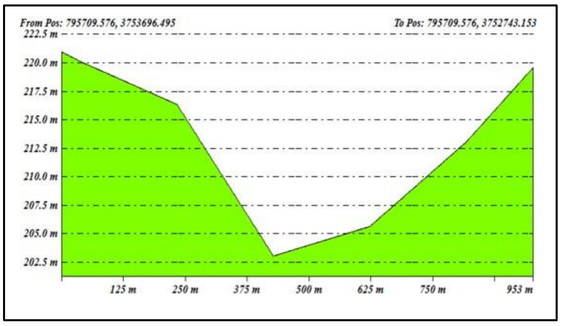

Figure 3, Cross-section for suggested site

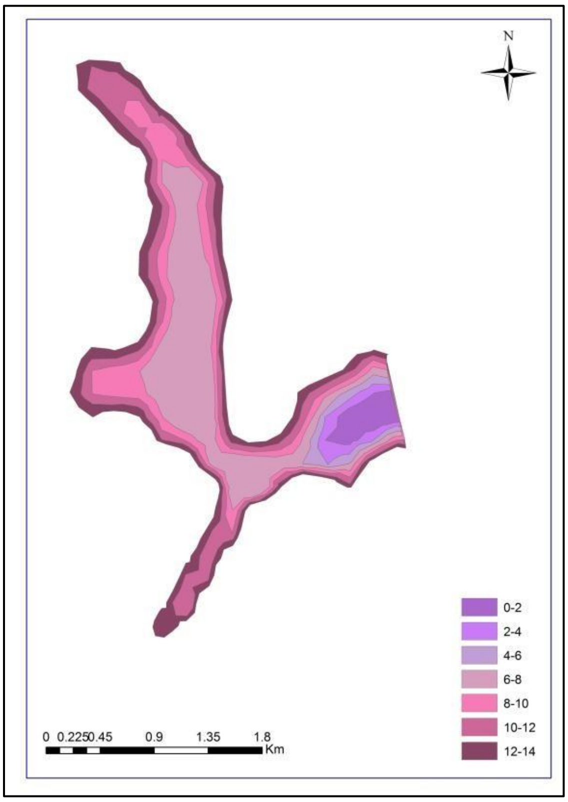

Figure 4, The contour lines for suggested site

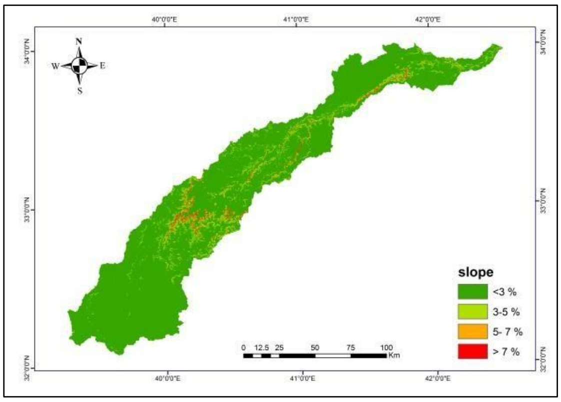

Figure 5 , slope map

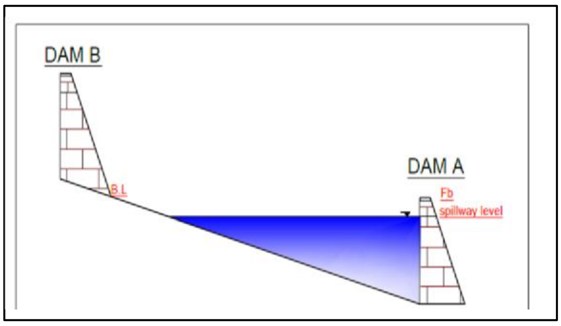

Figure 6 , The series formula description

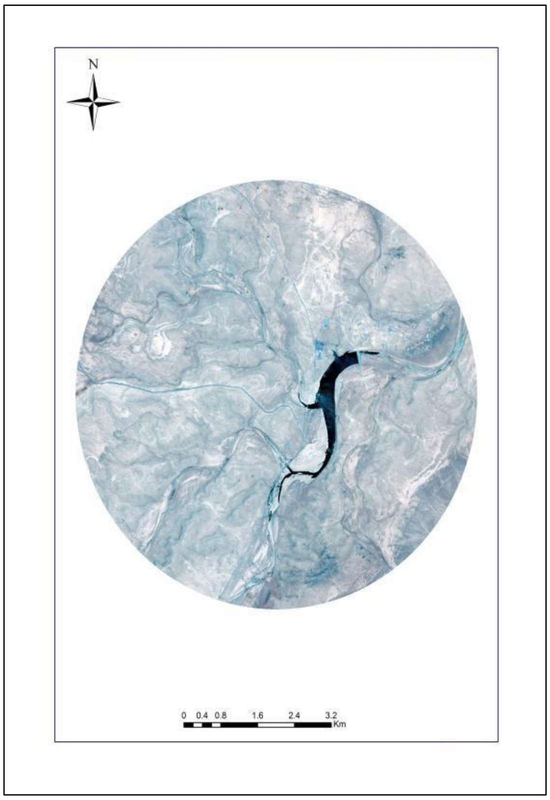

Figure 7, Paved and unpaved roads near one of the existing dams in study area

2.2.2 Formulation the optimization model and solution procedure:

2.2.2. a- Mathematical model description:

The mathematical model of the optimum water level for suggested dams can be formulated as follows:

Select {D} = dam location

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

$$F = \frac{\Delta VS}{\Delta VE} = \frac{(V_{(i+1)} - V_i)}{(S.A_{(i+1)} * d_E - S.A_i * d_E)} \qquad (\,equation\ 2)$$

where:

F = objective Function, maximizing the benefits.

$S.A_i$, $S.A_{(i+1)}$ = surface area for reservoirs at water level i & (i+1) respectively (m^2)

d_E = Evaporation depth (m)

V_i, $V_{(i+1)}$ = volume of storage for reservoirs at water level i & (i+1) respectively (m^3)

i= rank of water level

The following constrain could be used:

H_max≥W.L≥H_min

H_{max}, H_{min} = A selected maximum and minimum water level respectively (m).

W.L = the optimal water level in the reservoir.

ASTER data was used in the create of contour maps through the geographic information systems (GIS) represented by the Global Mapper 20 software and ArcView 10.5 program with the analysis and processing of spatial and descriptive data that are of great importance in the design of dams where of the volume and surface area of the reservoir were calculated. As for the depth of evaporation, it is taken from the field data that shown in the map (Figure 8) the distribution of rainfall, evaporation and temperature in the western desert, and by interpolation, the depth of evaporation was estimated for the selected locations.

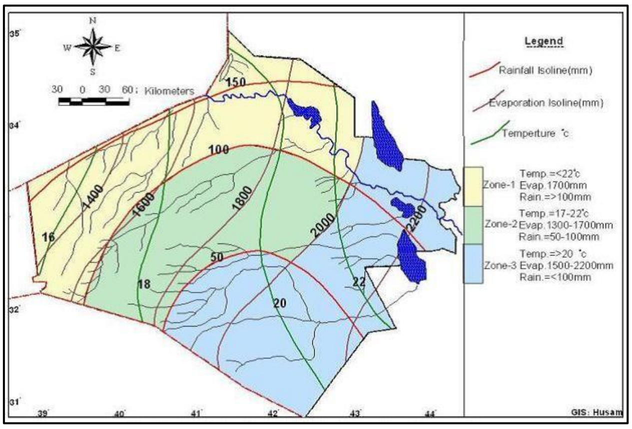

Figure 8: Rainfall Distribution, Evaporation & Temperture (HUSSEIN,2010)

2.2.2. b Visual Basic model:

The model processes to extract the optimal water level with less evaporation and high storage capacity for small dams series can be summarized in general steps described below and illustrated in (Figure 9): The model is named Optimal Height And Location Model (OHALM).

1- Selecting minimum and maximum water levels for the dam reservoirs. The minimum water level is very important to choose the location of the opening of outlet and determine the water level of the dead storage of the dams.
2- The water level will be iteratively within the chosen range of 50 cm at each step, and then the surface area and volume of storage are calculated for each water level approved.
3- The data is entered by the user, which is represented in the water level, surface area and volume of storage according to the specifications mentioned previously, while the evaporation depth is entered as one depth from the field data that are taken for each region (figure 8).
4- Calculations procedure in two paths, the first represents the change in benefit, which depends on the volume of storage for reservoir, while the second represents the change in cost, which depends on the surface area and evaporation depth.
5- Objective function is the core of the model as it is the main decision station in the system. The greater value of the benefit is chosen from the objective function, which obverse to the optimal value of the water level for the proposed dam.
6- If the calculations are completed according to the specified objective function, the model jump to the output stage, which is represented by site of dam, its height and volume of storage.
7- The pattern is iterative to (n) of the suggested dams for each region.

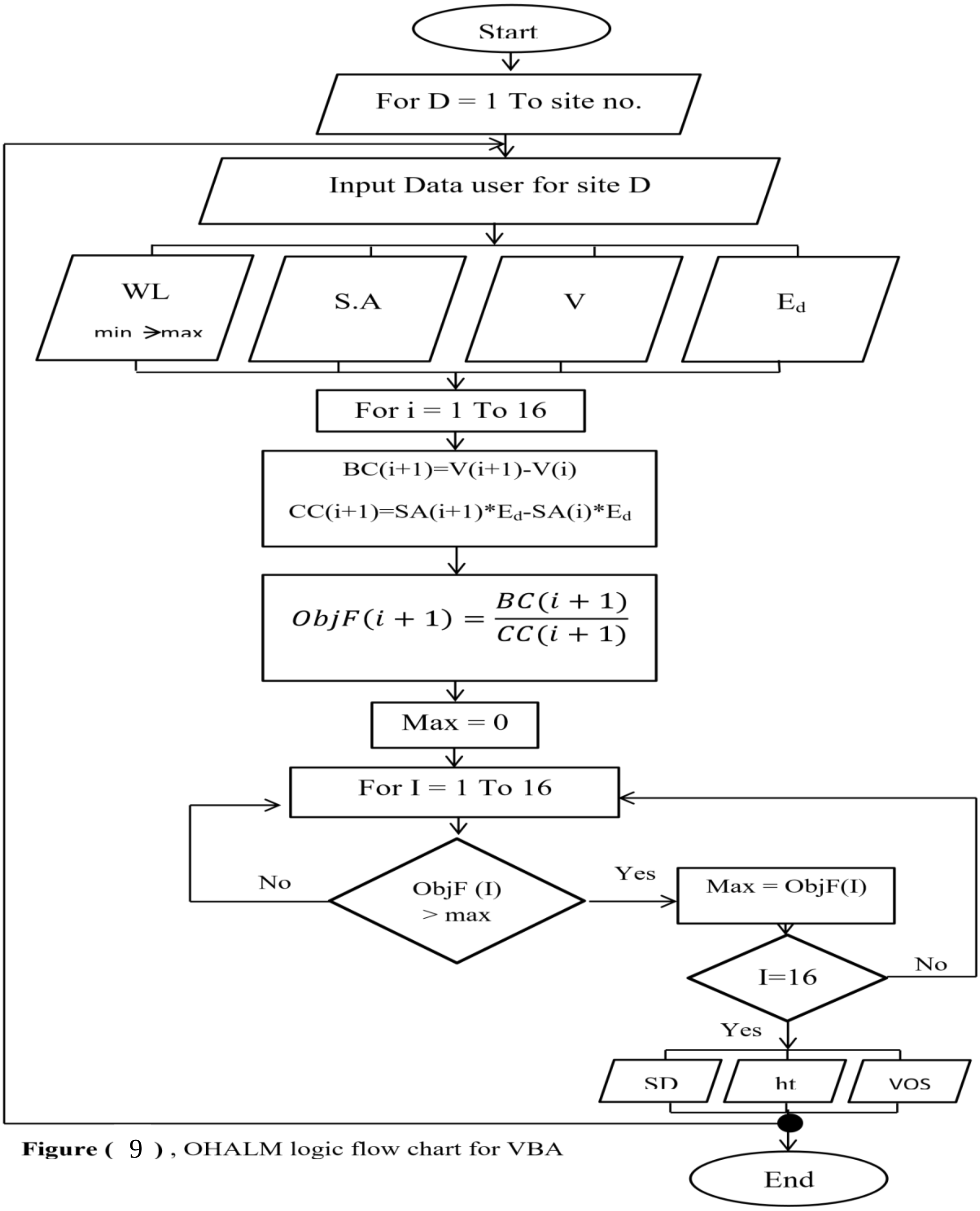

Figure (9) , OHALM logic flow chart for VBA

3- Results and discussion :

a. Division of study area:

The first step in the methodology adopted in this study and because of large study area, Horan valley has been divided into three regions depending on the area surrounding the main stream of the valley.

Zone	name	Total area km^2	Area around main stream km^2	Length of main stream km
Zone 1	Upstream	7078.15	3114.47	73.7
Zone 2	Midstream	3250.88	3250.88	108.5
Zone 3	Dawnstream	2810.85	2810.85	167.32

b. Proposed sites identification:

The most important factors affecting the selection of the small dam site can be summarized as follow:

1- The dam must be located on the main stream of the valley.

2- The cross-section of the selected sites ranges between 450-1750 m to reduce the dimensions of the dam then reducing construction costs.

3- The slope of the dam reservoir is less than 3% to provide high storage efficiency and economical earthwork.

4- The distance between the proposed dams and the existing roads whether paved or unpaved is between 250-5000 m for use in transporting materials.

5- After the first dam location is selected, the optimum storage water level is estimated using the (OHALM), then the equation (1) is applied to determine the location of second dam and so on for remainder. (Figure 10)

6- Using Global Digital Elevation Model (GDEM) and using GIS techniques, the proposed dam locations were chosen.

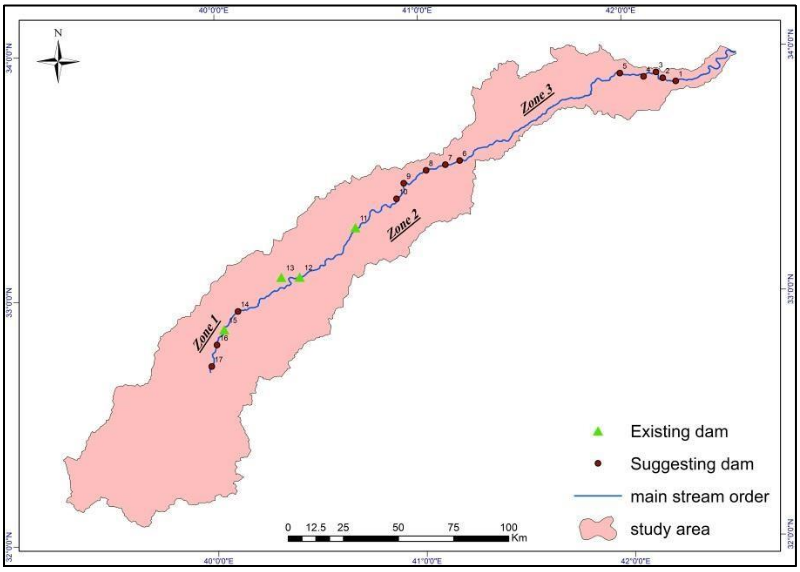

Figure 10: Dams sites identification in the study area

c. Input data for model :

After finding the proposed site for the first dam and through the contour map, the surface area and volume of storage of the reservoir are calculated. These values are entered into the visual basic form and that this value is confined from H_{min}=6m to H_{max}=14m and the iteration started from minimum value by increasing 0.5 m in each step. As for the depth of evaporation, its value was found for each region based on the field data (Figure 8), where the depth of evaporation losses in Horan valley can be classified according to field data into three regions, upstream, midstream and downstream, the annually evaporation depths in these regions were 1600 mm, 1700 mm, and 1900 mm respectively. The data is entered into the program and depending on the mathematical model that was illustrated in flowchart (Figure 9).

After running the program (OHALM) and finding the optimum water level for the first site, a free board is added (2.5 m) and value of the topographic coefficient that was used in this study (0.5 – 1) m to find the location of the second dam provided that the previous criteria are met and this applied to all selected sites.

4- Conclusions:

The results of the study showed that this method can be used to locate a series of small dams where upstream, midstream and downstream contain a system of dams consisting respectively of 3 , 5 and 5 dams with water levels ranging between 12.5 m to 14 m and different storage quantities. As shown in (Figure 11), the water level results of the proposed dams that were found from the mathematical model and the water levels of the proposed sites extracted from AVE-curve were compared with the water levels of the existing dams (AlRutba dam, Horan 2, Horan 3, Al-Ga'ra 4 and Al-Ga'ra 2) in Horan valley and the surrounding areas. The results of the study showed that the amount of the relative differences between the water levels calculated from the mathematical model with the water levels of existing dams estimated about in upstream, midstream and downstream equal 10.4%, 7.2% and 7.2% respectively, and that the amount of the relative error between the water levels obtained in AVE-curve with existing dam estimated at about 13.8%, 18.4% and 9.27 % in upstream, midstream and downstream.

the results of this model is compared with existing dams that constructed in the same area, the water levels calculated by the mathematical model OHALM are nearer to water levels for existing dams and more accurate than AVE-curve method. This indicates that the methodology can be adopted in determining the optimum water levels in arid regions as this method not require high time, effort and cost if compared to the field survey.

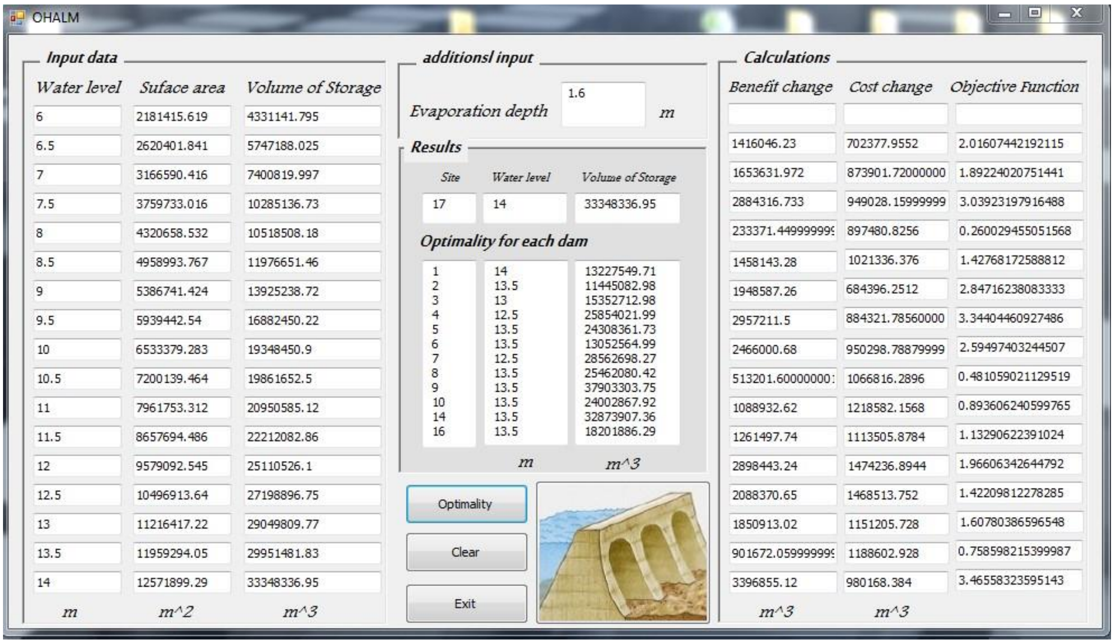

Figure 11 , OHALM model Run interface for all suggested sites

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