A Developed Model for Selecting Optimum Locations of Water Harvesting Dams Using GIS Techniques

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ABSTRACT

An integrated GIS-VBA (Geographical Information System – Visual Basic for Application), model is developed for selecting an optimum water harvesting dam location among an available locations in a watershed. The proposed model allows quick and precise estimation of an adopted weighted objective function for each selected location. In addition to that for each location, a different dam height is used as a nominee for optimum selection. The VBA model includes an optimization model with a weighted objective function that includes beneficiary items (positive) , such as the available storage , the dam height allowed by the site as an indicator for the potential of hydroelectric power generation , the rainfall rate as a source of water . In addition to that (negative) penalty items are also included such as surface area, evaporation rate.

In order to obtain precise results, an Artificial Neural Network (ANN) model was formulated and applied to correct the elevations of the Digital Elevation Model (DEM) map using real and DEM elevations of available selected control points.

The application of the model is tested using a case study of a catchment area in Diyala and Wasit Governorate. The DEM file was corrected for elevations, using the developed ANN model .This model is found using SPSS – software. The correlation coefficient of this model is found to be (0.97) , with 3- hidden nodes and hyperbolic tangent and identity activation functions. Different weight scenarios for the objective function of the optimization model were adopted. The results indicate that different optimum dam locations can be observed for each case. Results indicate also that sometimes equal objective can be obtained but each has different reservoir volume and surface area.

KEY WORLDS: Water harvesting - Dam location- Geographical Information System – Visual Basic for Application – ANN model- DEM

تطوير نموذج لاختيار المواقع المثلى لسدود حصاد المياه بأستخدام تقنية نظم المعلومات الجغرافية

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الخلاصة:

تم بناء نوذج تكاملي باستخدام برامجيات نظم المعلومات الجغرافية وبرمجة فيجوال بيسك لاغراض التطبيق يمكن استخدامه لايجاد الموقع الامثل لسدود حصاد المياه من المواقع العديدة المحتملة في جابية معينة . يقوم النموذج بحساب دالة هدف موزونة باوزان معينة ولمواقع عديدة لوديان بالجابية وكذلك لعدة ارتفاعات للسدود في كل موقع بطريقة دقيقة وسريعة . يتضمن النموذج معايير ايجابية (موجبة) واخرى سلبية

(سالبة) موزونة باوزان يمكن للمستخدم ان يختارها حسب اهمية كل معيار . من هذه المعايير الموجبة قابلية الخزن المتوفرة ، ارتفاع السد الممكن كمؤشر لقابلية انتاج الطاقة الكهربائية ، معدلات الامطار كمصدر للمياه . ومن المعايير السالبة استخدمت كجزاء مثل المساحة السطحية**.** وأوضحت النتائج بأن المواقع المثلى تتغير عند الاوزان المختلفة.احيانا يتوفر حلين مثالين لدالة هدف واحدة متساوية رغم اختلاف قيم حجم الخزان والمساحة السطحيةو لغرض ان تكون النتائج اكثر دقة تم بناء نموذج اخر هو نموذج الشبكات العصبية الذي يجب تطبيقه على خارطة نموذج الارتفاعات الرقمية .لتصحيح مناسيب النقاط اعتمادا على العلاقة بين الارتفاعات الحقيقية والارتفاعات التي يعطيها نموذج الرقمية.(DEM)الارتفاعات لنقاط الضبط الارضي المتوفرة في المنطقة.

الكلمات الرئيسية: حصاد المياه –مواقع السدود –نظم المعلومات الجغرافية – نموذج الارتفاعات الرقمية- نموذج الشبكات العصبي

INTRODUCTION:

Our planet is known as the blue planet, due to its extensive reserves of water. The three fourth of the Earth's surface is covered by water. Unfortunately, 98% of this surface water is in the oceans, the remaining 2% accounts for the fresh water supplies of the world. More drastically, 90% of this fresh water supply is either in the poles or remains under the ground. As fresh water resources, humans make up only0.26%, which is available to consumption.**Jhon,2000**.

As it is well known now everywhere the water needs is growing up, coupled with the decrease of availability. This problem has an increased importance in arid and semi-arid regions .Rain-water harvesting dams is one of the solutions that could be adopted in such areas to store water during rainy season to be used later during dry season for agriculture,domestic and mini-power generation uses . For a large watershed different valleys may exist that could have a feasible potential for building a water harvesting dam. In such problem engineers or water resources planners may face the difficulty of selecting the proper location or locations of such dams that must be the most beneficiary for optimum storage and use of the harvested rain water. For such large watershed the use of Geographical Information System (Arc GIS ver.9.3) can simplify the process used to evaluate each valley and each location in this valley in the watershed and then to put these location in descending order according to it's evaluation score.This will be a useful tool for water recourse planners to use this evaluation process for deciding the optimum locations to build these dams ,with consideration to the available budget for building them.

Weerasinghe et. al, 2010, Had described a comprehensive and convenient method to optimize the locations of proposed dams, to implement integrated water management strategies efficiently and effectively. To illustrate this routine methodology, they develop a spatially explicit spatial analysis model: Geographic Water Management Potential (GWAMP). they focus on the aspect of using GIS, to find adaptation- and mitigation- strategic solutions for water management, by applying GWAMP at global scale. These solutions are important towards ensuring- and improving- agricultural land productivity at climate initiated water related drastic events**. Al-Ayyash et.al, 2012**: Had carried a major research project in the Jordanian Badia on site selection criteria for rain water harvesting systems based on the integration between indigenous knowledge and the use of Geo-infor- matics. This work was followed by conducting a geophysical and soil investigation for five potential sites. In this study, GIS was used to investigate the potential of having enough runoff in the five selected sites to establish water harvesting dams based on rainfall, evaporation data and catchments' areas for the selected sites. It was found that the estimated runoff that could be harvested on annual basis at these sites varies between 0.2 Million Cubic Meters (MCM) in Alaasra site to 0.82 MCM in Al-Manareh (Al-Ghuliasi) site. This indicates that these sites have the potential for small scale water harvesting that could be utilized by local livestock owners in the area.

THE DEVELOPED MODELS.

The work in the research consists of two models which can be summarized as follows :

1- An Artificial Neural Network model For enhancement of the digital elevation model (Vertical accuracy enhancement)

2- An optimization model to select the optimum locations of water harvesting dams, in a certain multi-valley, catchment.

These two developed models are used in conjunction with GIS software .as shown in **Fig.1** Schematic representation of the developed models.

DIGITAL ELEVATION MODEL (DEM)

Digital Elevation Models are data files that contain the elevation of the terrain over a specified area, usually at a fixed grid interval over the surface of the earth. The intervals between each of the grid points will always be referenced to some geographical coordinate system. This is usually either latitude-longitude or UTM (Universal Transverse Mercator) coordinate systems. The closer together the grid points are located, the more detailed the information will be in the file. **Lynn,2009**

WATER HARVESTING

Water harvesting means capturing rainwater where it falls or capturing the runoff. Measures should be taken to keep that water clean by not allowing polluting activities to take place in the catchment. Water harvesting can be undertaken through a variety of ways:

• Capturing runoff from rooftops.
• Capturing runoff from local catchments.
• Capturing seasonal floodwaters from local streams.
• Conserving water through watershed management.

These techniques can serve the following purposes:

• Provide drinking water.
• Provide irrigation water.
• Increase groundwater recharge.
• Reduce storm water discharges, urban floods and overloading of sewage treatment plants.

Rain is the first form of water that is known in the hydrological cycle, hence is a primary source of water. Rivers, lakes and groundwater are all secondary sources of water. In present times, human depend entirely on such secondary sources of water. In the process, the rain is the ultimate source that feeds all these secondary sources and remain ignorant of its value**.ER-ING,2008.**

OPTIMIZATION PROCEDURE

Optimization means maximizing or minimizing an objective function which represents the criteria adopted to define *best dam's location*. Generally, the quality of a dam location is characterized by dam's height, reservoir volume and economy……etc.

In the general view, optimization problems are made up of three basic items**:**

1. An objective function, which should be minimized or maximized. For instance in fitting experimental data to a user-defined model, we might minimize the total deviation of observed data from predictions based on the model.
2. A set of unknown or variables, which affect the value of the objective function. In fitting-the data problem, the unknowns are the parameters that define the model.
3. Sets of constraints that allow the unknowns to take on certain values but exclude others.

So generally the optimization problem defined as, finding values of the variables that minimize or maximize the objective function while satisfying the constraints, these variables are known as the decision variables. **Kiamehr, R.,2003.**

STUDY AREA DESCRIPTION:

A DEM file has to be observed and prepared for application of case study, Diyala and Wasit Governorates extend to the north-east of Baghdad. They are cover an area of 34,838 square kilometers. Its location (32^o 1' 10 "- 34^o 54' 10 " N). (44^o 16' 15 "- 46^o 3' 51"E) A large portion of Diyala is drained by the Diyala River, a major tributary of the Tigris river .The Hemrin Mountains pass through the governorate. Wasit Governorate location in the central part of Iraq,to the east lies Iraq's international border with Iran . **Fig.2,** shows the location of the case study.

ENHANCEMENT OF THE DEM MODEL USING ANN MODELING.

Improvement of DEM means corrections of the elevations given by the DEM file using ground control points.
The procedure of the improvement of the digital elevation model contains the following phases:

- Conversion of the original digital elevation model from raster file system to shapefile feature class format, using Arc GIS 9.3 software.
- Locating the Ground Control points(164) on the study area.
- Calculation of the elevations (Z values) from the original digital elevation model (Zdem) and (Ztrue) for the Ground Control points.
- Computation of a relationship between the (Zdem) and (Ztrue) , using Artificial Neural Network model,by using statistical program called Statistical Package for the Social Sciences (SPSS 16.0).
- Programming a software for computing the new corrected elevations (new Z value),using the matlab software .
- Conversion of new data (new Z) to a new Digital elevation model , using the Arc GIS V.9.3 program .

The architecture of the ANN model has three input nodes in the input layer and one output node in the output layer. The input nodes represent the coordinates (X,Y,Zdem) for Ground Control Points. The output node represented the (Ztrue) for Ground Control Points, and three hidden node in this model as the required number of hidden nodes for the ANN model as obtained by the SPSS software .With single layer neural network.

FORMULATION OF THE OPTIMIZATION MODEL FOR DAM LOCATION SITE SELECTION AND SOLUTION PROCEDURE.

The mathematical model of the optimum location of water harvesting dam's location can be formulated as follows:

select {X} = {dam location}

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

$$F(V,S,T,R,E,H) = (V/Vmax * Wv) – (S/Smax * Ws) – (T/Tmax * Wt) + (R/Rmax * Wr) - (E/Emax * We) + (H/Hmax * Wh) \quad (1)$$

Where :
F(V,S,T,R,E,H) = objective function of the benefits.
V = reservoir volume.
Vmax = maximum reservoir volume , given by a site .
S = reservoir surface area.
Smax = maximum reservoir surface area, given by a site .
T = temperature, in the dam location .
Tmax = maximum temperature.
R = rainfall, in the dam location .
Rmax = maximum rainfall.
E = evaporation, in the dam location .
Emax = maximum evaporation.
H = dams height.
Hmax = maximum height, given by a site .
Wi = weights for each items, i= V,S,T,R,E,H.
The following constrains could be used:
$H\ min \leq H \leq H\ max$
Where :
H max : maximum elevation available in the valley.
H min : A selected minimum height by the user .

THE DESIGNED (VBA) SOFTWARE FOR THE OPTIMIZATION MODEL.

The operation of the designed model is presented by the overall flow chart, which shows its components and it's logic sequence of operations, as shown in **Fig.3**.

MODEL DESCRIPTION.

The developed (VBA) code is inserted inside the active tool bar of the GIS software, as shown in **Fig.4.** Inside ArcMap operation window. The code item is shown in one of the tool bars of the GIS software.

The following steps should be performed; then.

- Open the ArcMap
- Clicking on the (VBA) code, the window shown in **Fig .5,** will appear to the user.

MODEL OPERATION.

The developed software was applied using the explained case study. Different locations and Dam heights for each location were tried for purpose of presentation, one of the locations selected will be shown in the model operation. Starting the model operation using the VBA code shown in **Fig .5,** the software will analyze these data and **Fig.6,** appears which shows the first drainage point after which a dam was drawn manually, as a red line. shown in the **Fig.6,** Example of a dam drown in a certain drainage point.The lake boarders will appear immediately as shown in **Fig.7,** for the maximum dam height. Entered in the VBA code input window.Then the internal code will start the estimation of the objective function variables. (volume , area , … etc) , and the weighted objective function accordingly. There calculation will be adopted for the same dam location but for different heights, starting from the max. Height and down according to user selection**.Fig.8,** shows the calculations of the objective function for the selected dam with 3 – different heights (H = 20,18,16) .**Fig.8,** shows also the borders of the lake for the first height dam heights selection H = 20 (blue solid line) . As the user assign the mouse cursor to the sectional row and click it , the borders of the lake with the second height value will appear as shown in **Fig.9,** simitary for any height the lake border can be shown, as in **Fig.10** compare these **Figures.8,9,10,** shows the reduction in the lake area .

Then the procedure can be repeated for any other location as shown in **Fig.11**. In this figure, the green color indicate the lake and for the new location . The user can keep the layer of the first location for visual comparison (shown in blue.)

The procedure is further repeated for many locations for each location different dam height values are selected . All the results of the objective function of these locations and heights will be stored in descending order of the objective function as shown in **Fig.12**

RESULTS PRESENTATION AND DISCUSSIONS.

The results obtained from different sites selection each with different dam heights varied from it's minimum height to the maximum height offered by each locations are presented in tabulated view in descending order of the objective function as shown in **Fig .12.** Recalling that those results obtained are for equal weights values of each item of the
presenta
will be indicated later .

If the user select the first row it's data can be presented in many ways, for example the dam profile can easily draw as shown in **Fig.13**.

The selected optimum dam location and the corresponding lake can be presented in the georeference map of the case study as shown in **Fig.14.**

To present changes in storage and surface area
and/or height
ws the storage
and surface area and the objective function respectively for the list (33) site, with their location and heights shown in for equal weights.

In order to check the effect of items weights on the solution, different weight scenarios were used as shown in **Table .1.**

In general, changing the weights can affect the optimum solution as shown in **Table .2.** shows the first 3- optimum solution for each scenario. In order to simulate effect of weight the differences should be more than 1.

The objective function is plotted against location number for each scenario.

CONCLUSIONS.

The following conclusions can be deduced from the work conducted in this research:

1- The best data division required for the ANN model used for elevations corrections is 67% ,18% ,15% for training, testing and holdout sub – sets respectively.
2- The required hidden nodes is (3) with a hyperbolic tangent and identity activation functions for the hidden and output layer respectively.
3- The ANN model can predict the corrected elevations with a correlation coefficient is (0.9).
4- The developed integrated GIS- optimization model can be used easily, and can produce the optimum results of many selected locations very quickly.
5- The results indicated that even though the differences in the objective functions of different locations are seemd to be small, the corresponding differences in storage and surface area are significantly different.
6- Among the 33-sites and heights combinations selected as a nominee for dam construction in the watershed case study, site number (6), followed by sites number (9) and (18) represent the most optimum locations with storage capacities of (150353686.466 , 2145519.15142, 46045984.5662)m^3, and surface areas (15743356.479, 499543.130235, 5366985.41692) m^2, respectively. For the case of equal weights adopted for the different items of the objective function.
7- Adopting different weights for each items in the objective function have considerable effect on the optimum dam location.
8-In some weight scenarios, the models gives the maximum objective functions of the first two solution as an equal value.
8- However the storage and surface area are different. The first solution gives higher storage than the second one, but with lower surface area. This means that the benefits gained from the difference in storage, is equalized by the penalty of evaporation given by the increase in evaporation less due to increase in surface area. For example for scenario (A), the first two solutions gives both an objective function value f1=f2= 0.3333. but with S1 = 149177957.309 , S2 = 246679790.58 m^3 and A1 = 15651355.098 , A2 = 24065080.3 m^2.

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Table (1) Different weight scenarios

scenarios	Volume weight	Dam height weight	Surface area weight	Rain &temp. &evap.
A	3	2	1	1
B	5	3	1	1
C	7	4	1	1
D	1	2	3	1
E	1	4	7	1
F	1	3	2	1
G	2	3	1	1

Table (2) The first 3- optimum solution for each scenario.

scenario	Equal weight	A	B	C	D	E	F	G
First 3- optimum Dams	6 9 18	6,21 22 7	6,15 16 7	6,21 22 7	9 24 12	24 9 25	24 9 12	6,21 22 0

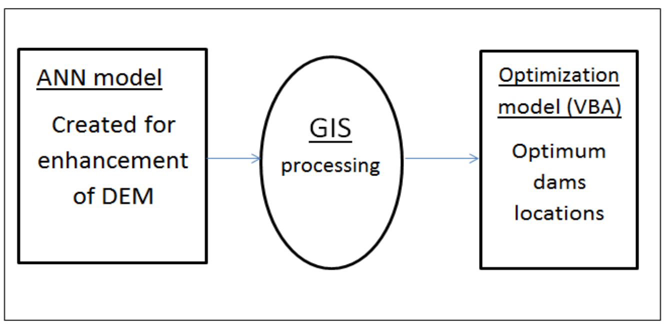

Fig. (1) Schematic representation of the developed models

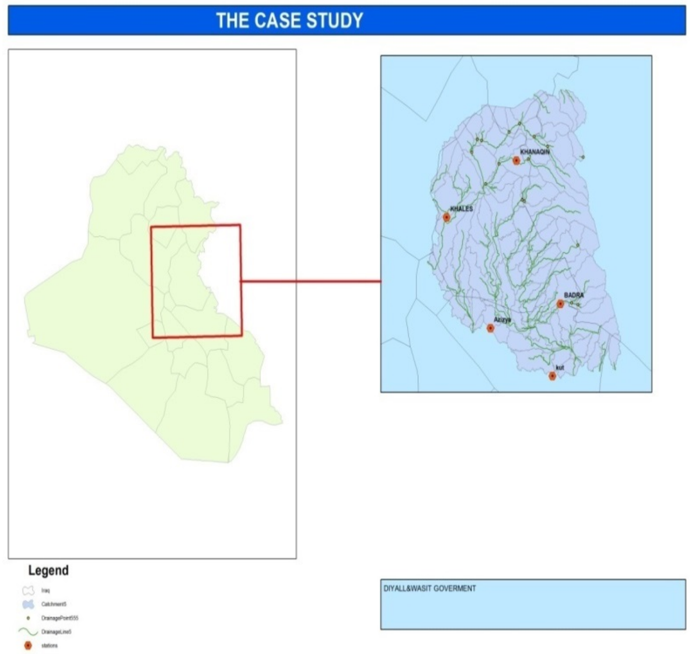

Fig. (2) Location of the case study area.

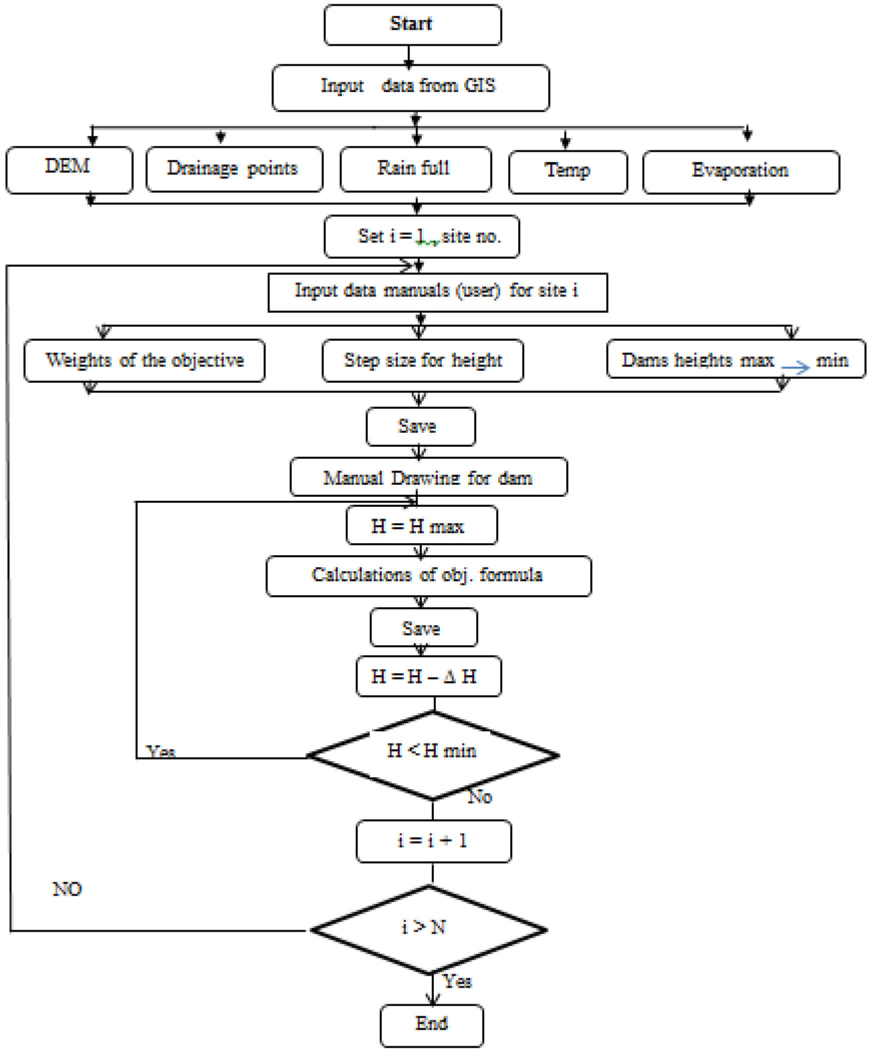

Fig.(3) Model flow chart.

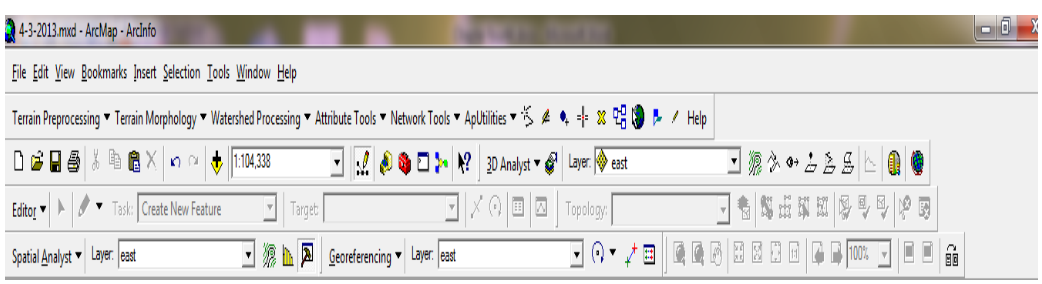

Fig.(4) VBA model code insertion
in the active tool bar of the GIS software.

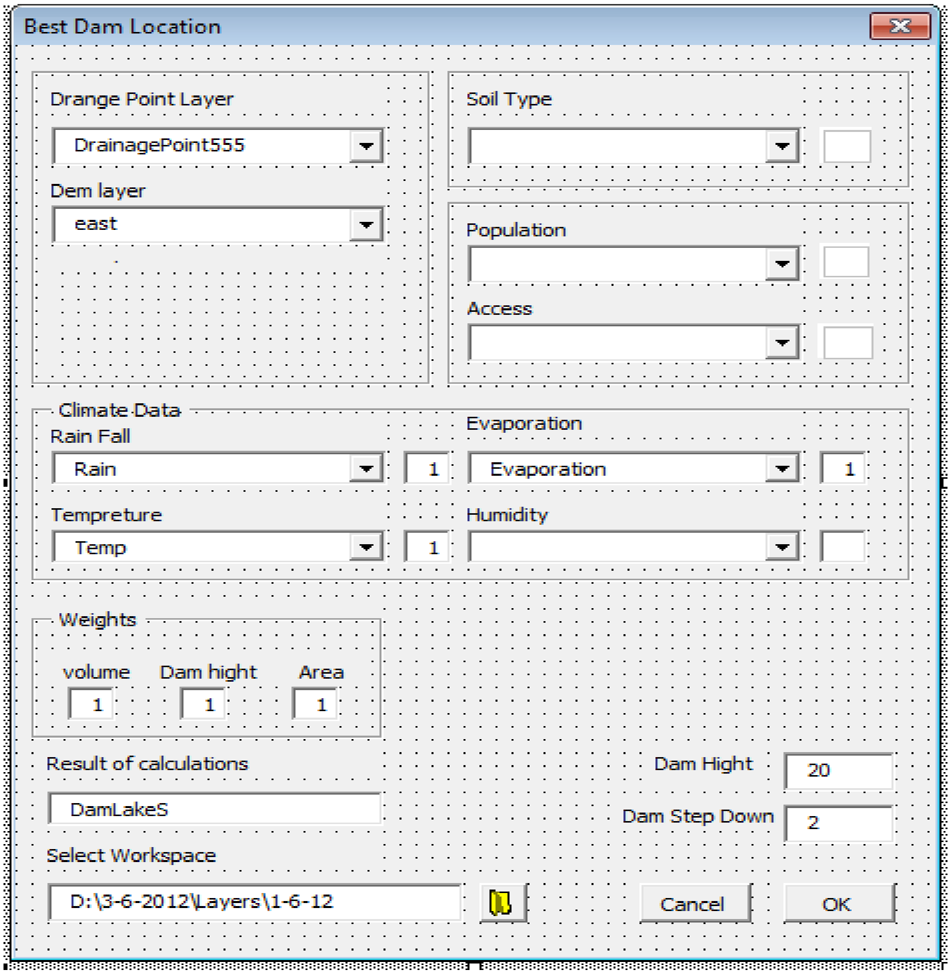

Fig. (5) Main VBA program window, Data inputs.

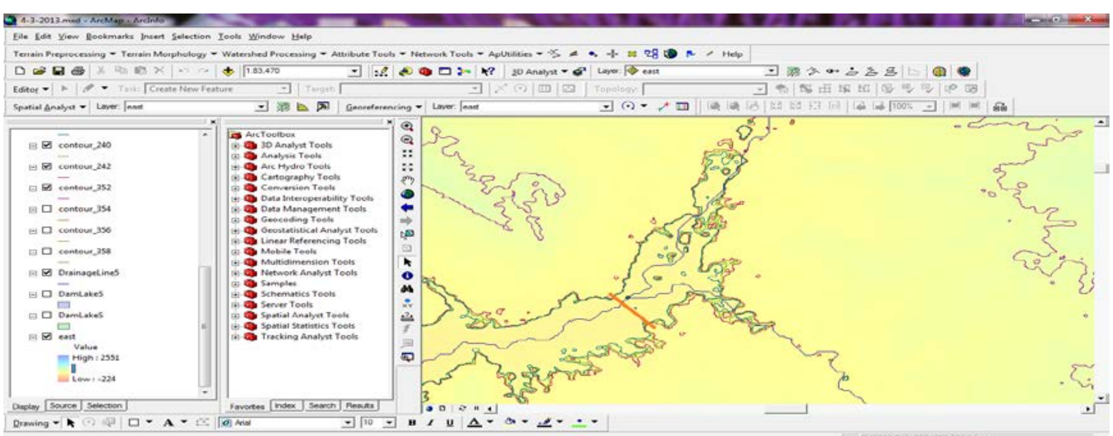

Fig. (6) Example of a dam drown in a certain drainage point .

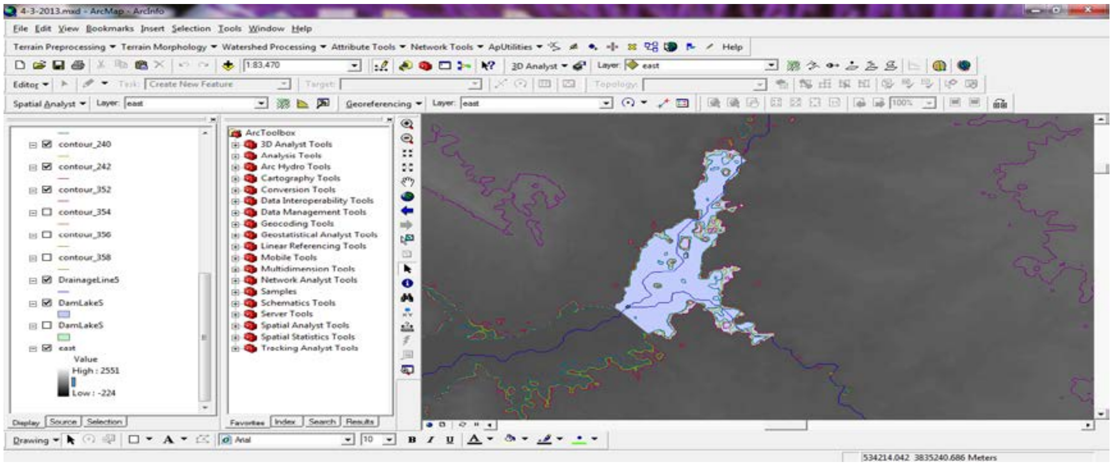

Fig. (7) The lake borders of the selected dam.

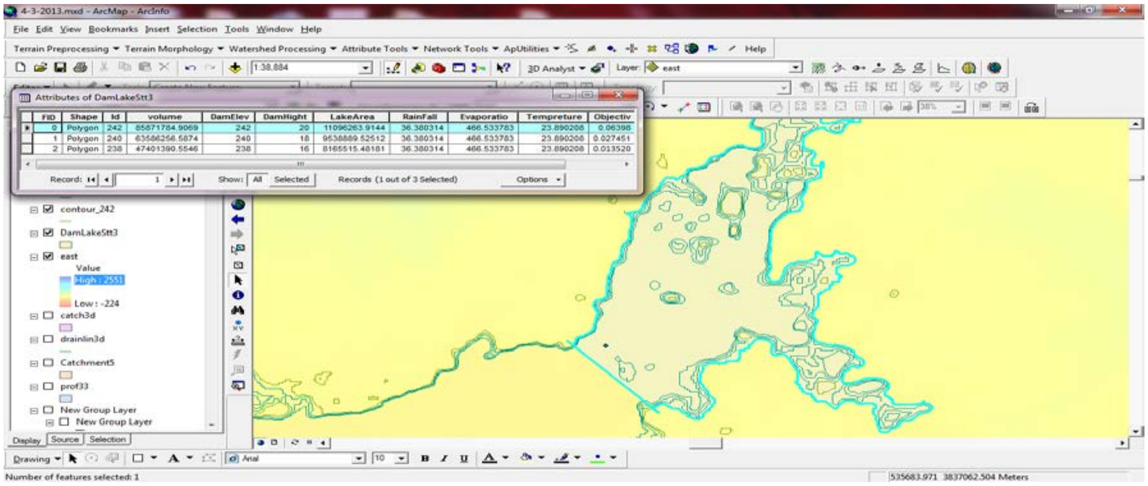

Fig. (8) The objective function calculation results for the selected dam.

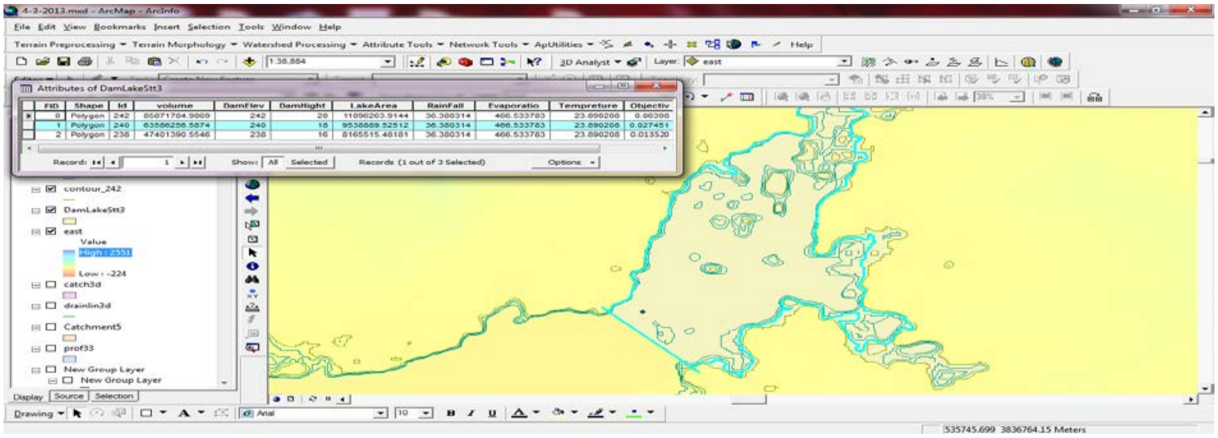

Fig. (9) Calculation for the second lower dam.

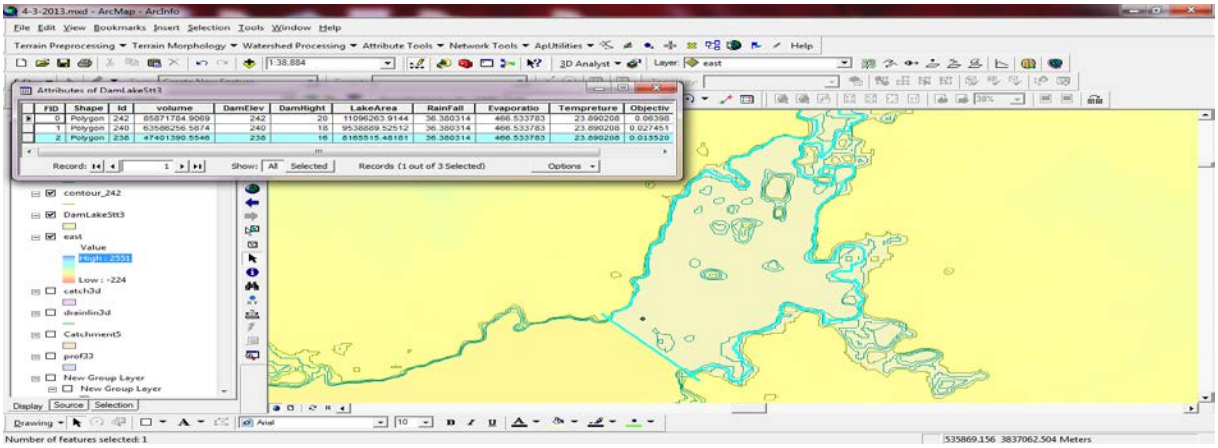

Fig.(10) Calculation for the third lower dam.

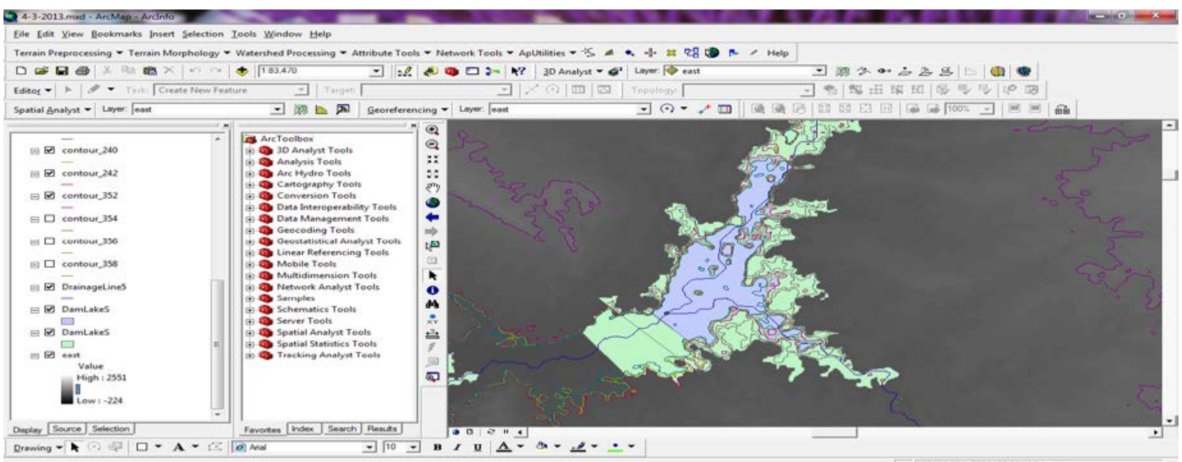

Fig. (11) Selection of another location.

Attributes of DamLakeS111

Dam	* Shape	Id	volume	DamElev	DamHight	LakeArea	RainFall	Evaporatio	Tempreture	Objectiv
6	Polygon	242	150353686.466	242	20	15743326.479	36.380314	466.533783	23.890208	0.067128
9	Polygon	358	2145519.15142	358	20	499543.130235	36.380314	466.533783	23.890208	0.064218
18	Polygon	502	46045984.5662	502	20	5366985.41692	36.380314	466.533783	23.890208	0.061352
12	Polygon	502	2925708.54299	502	20	869370.617218	36.380314	466.533783	23.890208	0.061167
15	Polygon	502	12501221.3831	502	20	2040538.26184	36.380314	466.533783	23.890208	0.059383
10	Polygon	356	1266079.93782	356	18	401416.397122	36.380314	466.533783	23.890208	0.047615
13	Polygon	500	1543448.65197	500	18	556396.96759	36.380314	466.533783	23.890208	0.046282
0	Polygon	242	85821663.6326	242	20	11080888.7793	36.380314	466.533783	23.890208	0.044953
19	Polygon	500	35999801.6801	500	18	4328768.96663	36.380314	466.533783	23.890208	0.04454
16	Polygon	500	9081337.67657	500	18	1598791.97586	36.380314	466.533783	23.890208	0.043602
3	Polygon	242	73650224.9826	242	20	9973784.08164	36.380314	466.533783	23.890208	0.043182
21	Polygon	252	245333693.433	252	30	23980992.9241	36.380314	466.533783	23.890208	0.043131
24	Polygon	368	2309591.25902	368	30	577491.772973	36.380314	466.533783	23.890208	0.040687
7	Polygon	240	121138466.92	240	18	13802820.7226	36.380314	466.533783	23.890208	0.038619
30	Polygon	511	65272818.4152	511	30	7497552.23834	36.380314	466.533783	23.890208	0.035367
27	Polygon	511	21662804.089	511	30	3676492.60704	36.380314	466.533783	23.890208	0.032297
11	Polygon	354	609924.989408	354	16	250659.6917	36.380314	466.533783	23.890208	0.031817
14	Polygon	498	724190.77288	498	16	320944.165635	36.380314	466.533783	23.890208	0.0312
25	Polygon	366	1439641.17967	366	28	323015.586161	36.380314	466.533783	23.890208	0.030753
17	Polygon	498	6314775.71936	498	16	1246204.98523	36.380314	466.533783	23.890208	0.027601
20	Polygon	498	28785692.6999	498	16	3602571.18056	36.380314	466.533783	23.890208	0.027565
22	Polygon	250	198238184.777	250	28	20129901.9295	36.380314	466.533783	23.890208	0.026791
31	Polygon	509	52977208.0246	509	28	6346468.76845	36.380314	466.533783	23.890208	0.023903
28	Polygon	509	15324852.1367	509	28	2846152.48073	36.380314	466.533783	23.890208	0.022651
4	Polygon	240	54563682.6756	240	18	8495269.71454	36.380314	466.533783	23.890208	0.02101
1	Polygon	240	63541478.7038	240	18	9523865.51276	36.380314	466.533783	23.890208	0.020072
26	Polygon	364	862277.018689	364	26	282066.470836	36.380314	466.533783	23.890208	0.019535
29	Polygon	507	10397872.1941	507	26	2133718.62605	36.380314	466.533783	23.890208	0.013144
32	Polygon	507	41356100.9954	507	26	5319360.56601	36.380314	466.533783	23.890208	0.012035
8	Polygon	238	95395339.7267	238	16	12102526.7949	36.380314	466.533783	23.890208	0.011417

Record: 1 Show: All Selected Records (1 out of 33 Selected) Options

Fig. (12) The results of (33) locations selected , each of different dam height values .

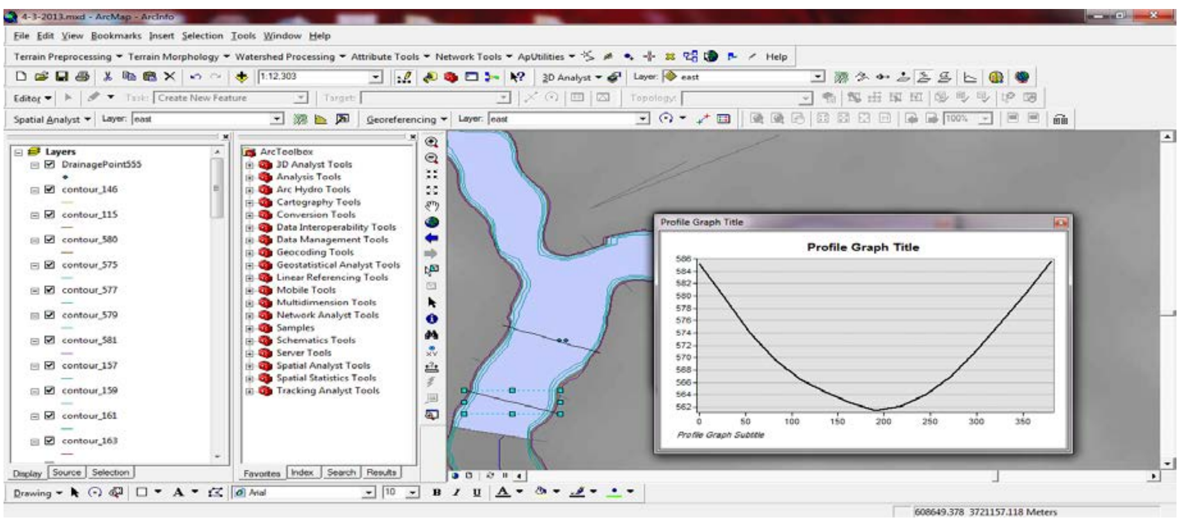

Fig. (13) The profile of the dam site.

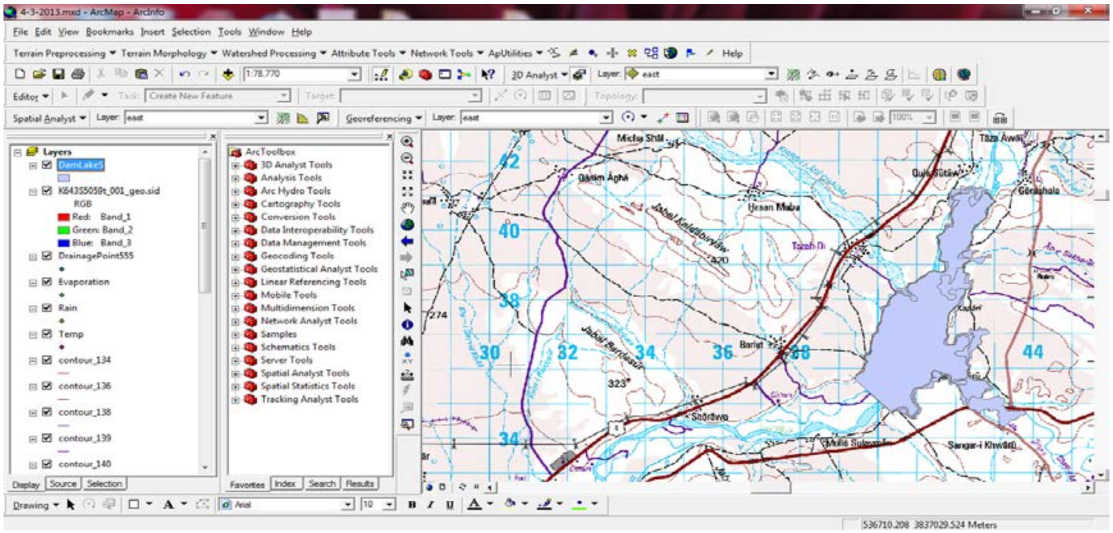

Fig (14) Selected optimum dam location and its corresponding lake present on the georeferenced map of the case study.

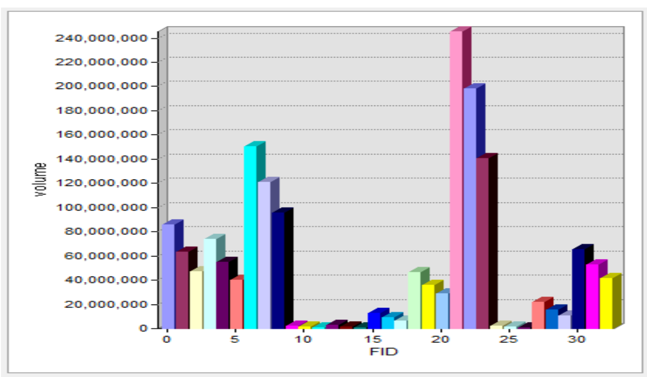

Fig.(15) Change in storage with the 33 sites

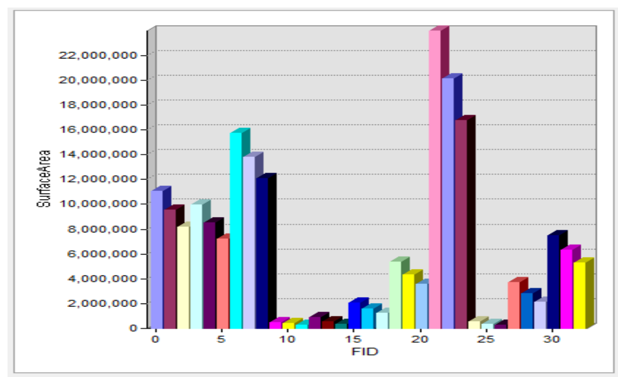

Fig (16) Change in surface area with the 33 sites

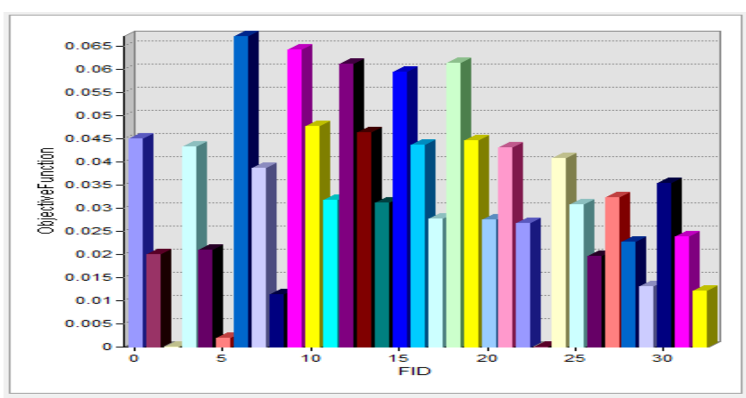

Fig. (17) Change in the objective function with the 33 sites.

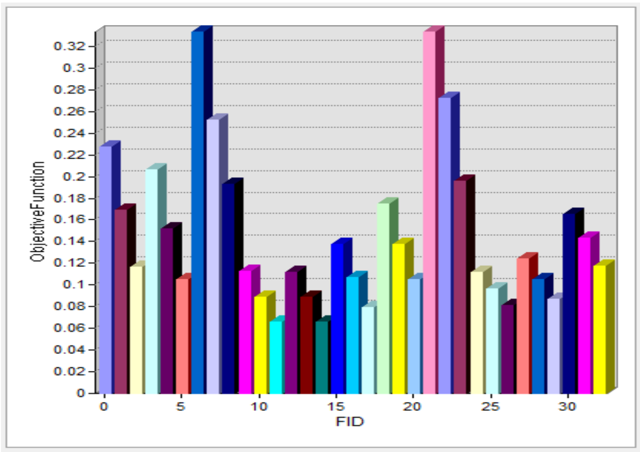

Fig.(18) Objective function and dams numbers for scenario (A).

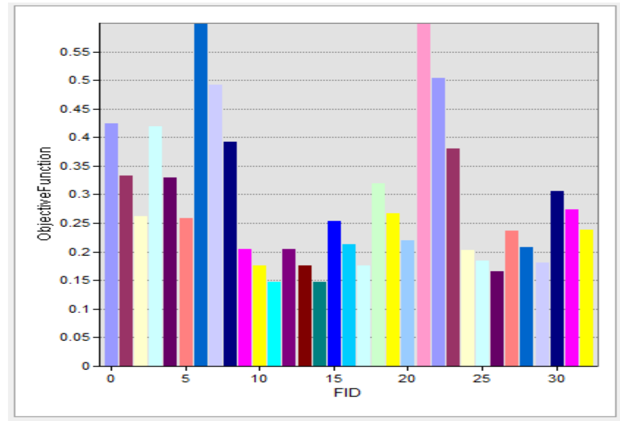

Fig.(20) Objective function and dams numbers for scenario (C).

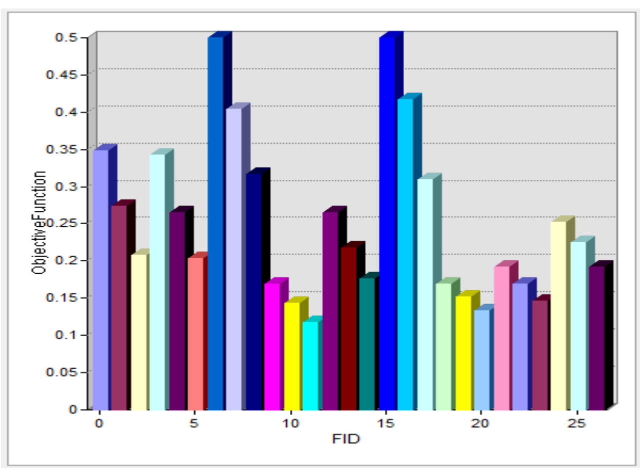

Fig.(19) Objective function and dams numbers for for scenario (B) .

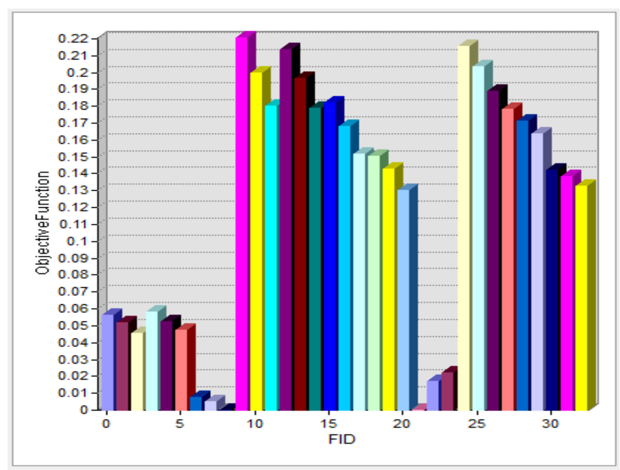

Fig.(21) Objective function and dams numbers scenario (D).

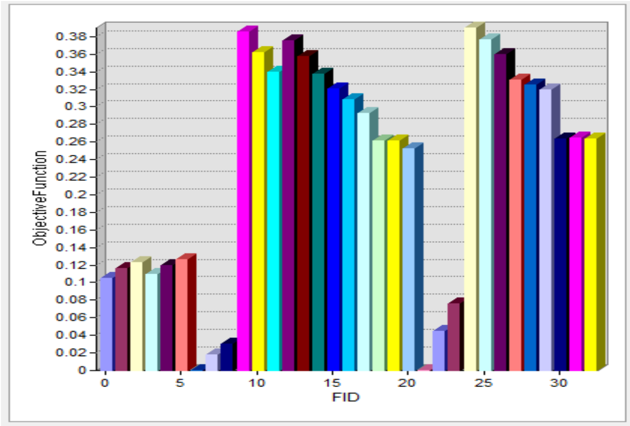

Fig.(22) Objective function and dams numbers for scenario (E).

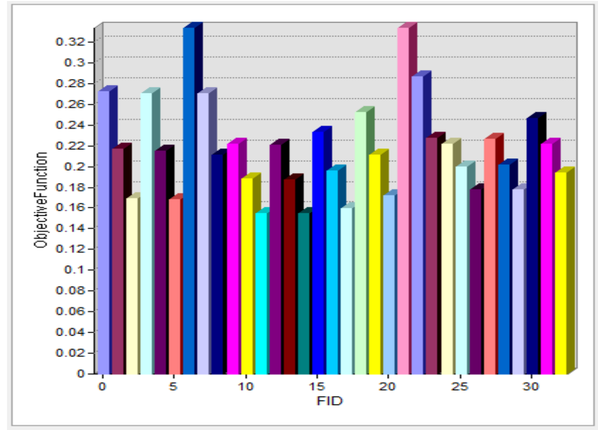

Fig.(24) Objective function and dams numbers for scenario (G).

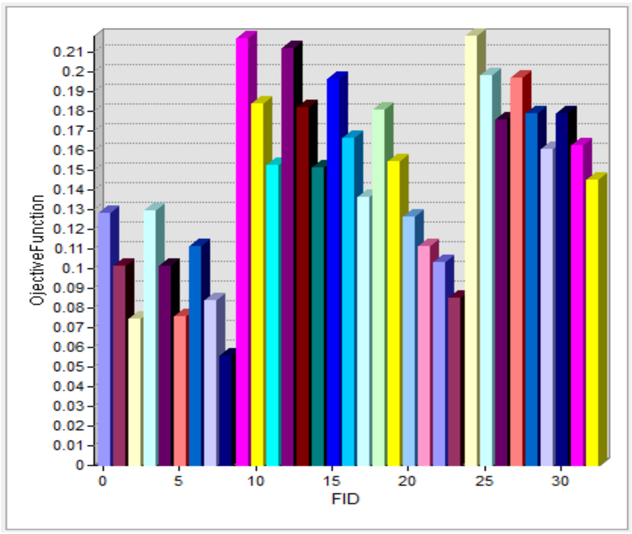

Fig.(23) Objective function and dams numbers for scenario (F).