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GIS-BASED MULTICRITERIA DECISION MAKING TO ASSESSMENT OF POTENTIAL WATER HARVESTING DAM SITES

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ABSTRACT

Selection of water harvesting dam site involves a complex array of decision criteria that may have conflicting values. Finding the optimum location requires integration of the capacities of Geographic Information Systems (GIS) and Multi-criteria Decision- Making (MCDM). In this research, a GIS-based multi-criteria decision analysis approach is used to solve this problem. The approach is based on the extension of Analytical Hierarchy Process using fuzzy quantifiers-guided Ordered Weighted Averaging operators (GIS-based AHP-OWA). This approach is applied to determine the optimal site of a water harvesting dam in Qassim region, Saudi Arabia. Several factors affect the selection of the best location of the target water harvesting dam. The results showed that using a combination of GIS-based AHP–OWA is proper approach for optimal water harvesting site selection, where this approach provides a generic powerful decision-making tool that allows decision-makers to define a decision strategy on a continuum between pessimistic (risk-averse) and optimistic (risk-taking) strategies.

Keywords: *Site selection, GIS, MCE, AHP, OWA, water harvesting.*

1. INTRODUCTION

Water is fundamental to life on this planet; it is the most crucial for maintaining an environment. Water plays a vital role not only in basic human need but in socio-economic development also. As the rainfall is primary source of water, so it becomes necessary for us to harvest it effectively. Water harvesting techniques have received growing attention, especially in arid and semi-arid regions like Saudi Arabia. Water Harvesting and Conservation, is the activity of direct collection of rain water to be stored for direct use or can be recharged into the Ground Water, it is the best means to get water when other water sources are not available. Selection of the water harvesting site is one of the most important and complex problems in different countries. A large amount of information should be gathered, combined, and analyzed to develop a correct criterion that may affect the final decision. The traditional method of determining these sites is using Geographic information systems (GIS), where GIS is a great tool for handling physical suitability analysis, but it has limited capabilities of incorporating the decision maker's preferences into the problem solving process. Recently multicriteria decision making (MCDM) technique is tools employed to solve these problems; it lacks the capability of handling spatial data (e.g., buffering and overlay) that are crucial to spatial analysis. So the need for combining the strengths of these techniques has prompted researchers to seek integration of GIS and MCDM.

(Ramakrishnan, 2009) determined the site suitability for different water harvesting structures by considering spatially varying parameters like runoff potential, soil type, slope, drainage network and land use, using the overlay and decision tree concepts in GIS. (Nihila, 2012) conceded runoff coefficient, land use, soil, slope, drainage and stream order, soil permeability in site selection for runoff harvesting/recharging structures using overlay tool of GIS. (Majdh, 2014) studied the Qassim region, she found the map of suitable site of water harvest, through the overlay method of the geology, soil, slope, rainfall, landuse, distance to roads, distance to cities criteria using Raster Calculator operation in GIS, and adopting Equal Weight Approach. In general, previous studies show the use of GIS overlapping for choosing suitable sites for a rain water harvest.

2. Methodology of water harvesting dam site selection

Geographic Information Systems (GIS) and Multi Criteria Decision techniques (MCD) are the two common tools employed to find the suitability site of water harvesting dam.In this paper both the Analytic Hierarchy Process (AHP) and Ordered Weighted Averaging (OWA) methods are suggested in GIS environments as a powerful multicriteria decision making tool for solving this problem.

2-1 Analytical Hierarchy Process (AHP) based GIS

The Analytical Hierarchy Process(AHP) was developed by (Saaty, 1980) which is a powerful tool in applying MCDA. The concept of this method isdividing the water harvesting site problem into a hierarchy structure, in each hierarchical level the weights of the elements are calculated based on pair wise comparison method. Where the pair wise comparison method employs an underlying scale with odd values from 1 to 9 to rate the relative preferences for two elements of the hierarchy developed by Saaty (1980). The decision on the final goal is made considering the weights of criteria and alternatives. Although AHP is widely used, one of the major issues of AHP is its inability to address the uncertainty in the decision maker's judgments (Deng, 1999).

2-2 Ordered Weighted Averaging (OWA)

To overcome the shortcomings of the AHP, OWA is used. OWA is a family of multi-criteria aggregation procedures developed by (Yager, 1988) as a tool for decision-making in a fuzzy environment.OWA involves two sets of weights: importance weights and order weights. The critical element of the OWA procedure is the method for obtaining the order weights. There are several methods for obtaining the order weights; this study uses a fuzzy linguistic quantifier approach. OWA can generate a wide range of decision scenarios.

3. Application of Method

Qassim occupies a middle position in the Arabian Peninsula, as it is located in the northern center of the Kingdom of Saudi Arabia between longitudes of 41° 30' and 45° 54' East, and latitudes in 24° 25' and 28° 15' north. It is the link between Riyadh area and Haael to the North, and the city of Medina in the West direction. Figure (3) shows the Location of AL-Qassim case study.

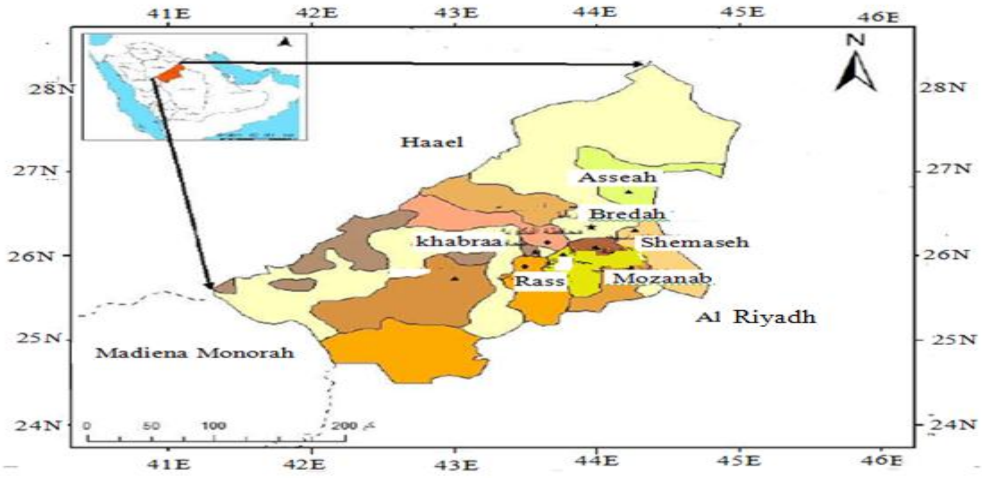

Fig.1. Location of AL-Qassim region

Eight criteria considered as factors affecting the location of harvesting dam were adopted in this study. All the suggest criteria of rain water harvest are (slope, geology, rainfall, drainage, soil, landuse, distance from roads, distance from cities) generated using functions in GIS, and convert to raster having the same cell size of pixel and number.

4. SYSTEM IMPLEMENTATION

To implement the proposed GIS-based MCE approach for dam site selection, a researcher had modified an present tool [5] to be used for dam site selection, using Visual Studio 2008 (C# Programming Language), as a toolbar within ArcGIS desktop to help the GIS analysts to solve complex dam site selection problems. As shown in Figure (2) a dam Site Selection Toolbar is comprised of three main menus (data preparation, data standardization, and MCE Tools)

Fig.2. Dam Site selection using GIS-based MCE toolbar

4-1- Data Standardized

After defining the criteria, select the standardized methods from Dam Site Selection toolbar and determine which criteria is maximum to goal or minimum as in figure (3). The first three criteria (geology, soil, landuse) are to be maximized. The dam must build in minimum slope. The distance from stream criteria is to be minimized; the suitable site is where maximum rainfall, the distance from cities, and distance from roads criteria are to be minimized. There is different standardization methods are applied on the maps. Here we used the linear standardization which called the maximum score procedure.

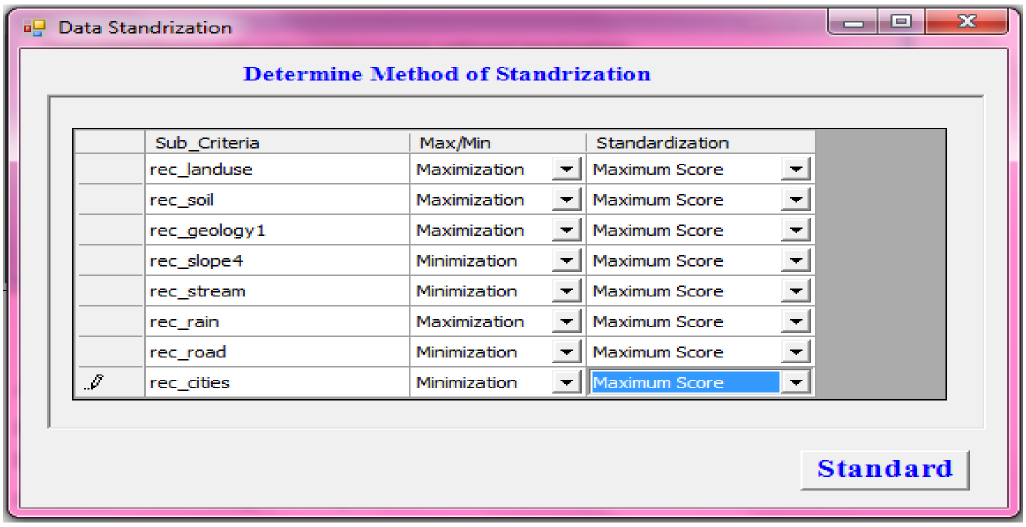

Fig.3. Data standardization

After preparing the standardized criterion maps, the next step is using the available MCE methods (Analytical Hierarchy Process (AHP), and Order Weighted Averaging (OWA) to identify the most suitable locations for the water harvesting.

4-2 Ordered Weighted Averaging (OWA)

It has been developed in the context of fuzzy set theory. In OWA method a criterion weight is assigned to a given criterion or attributes to indicate its relative importance, according to the decision-maker. OWA is used and the criteria are ranked as follows: the most important criterion ranked first, and the least important criterion ranked last as shown in Fig (4). Then estimating the criterion weight can be defined as follows equation (1) (8)as shown in fig (5)

$$W_j = \frac{n - r_j + 1}{\sum_{k=1}^{n} n - r_k + 1} \qquad (1)$$

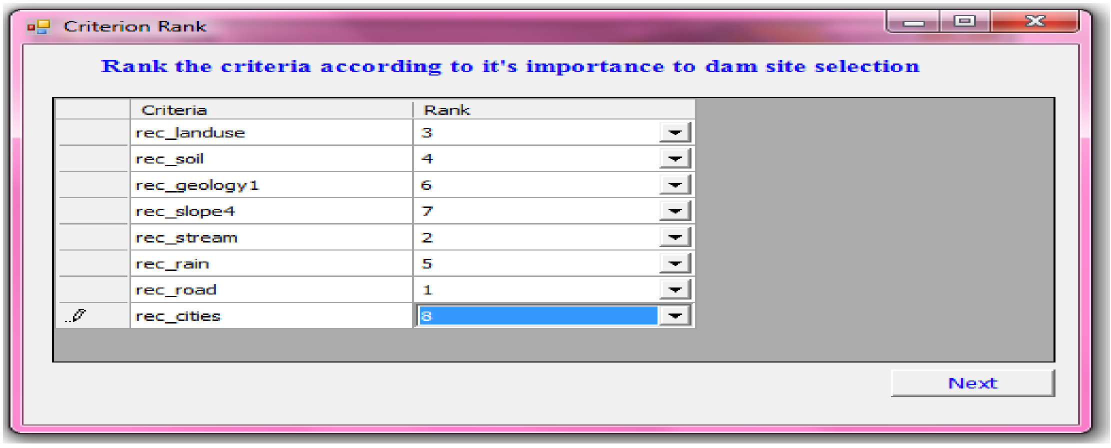

Fig.4. Criterion ranking

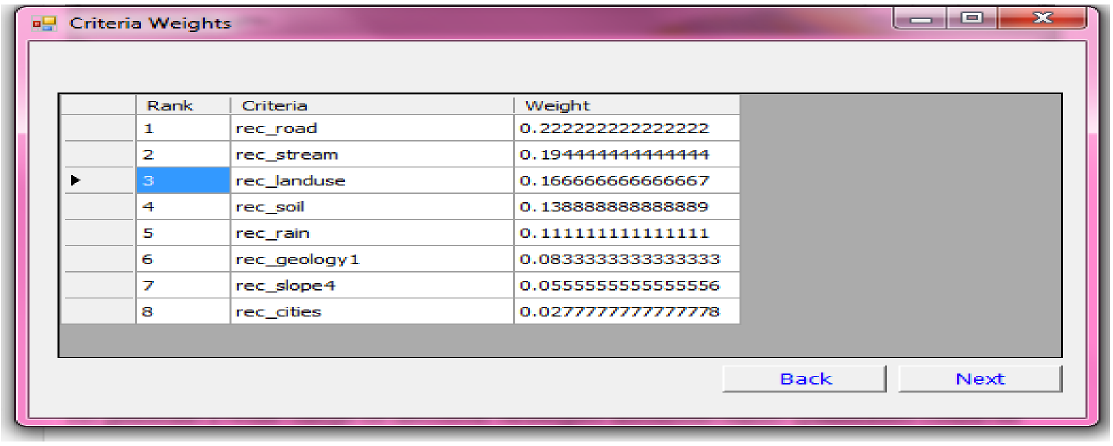

Fig.5. **Criterion weight**

To generate a wide range of decision strategies different fuzzy quantifiers could be used as shown in Fig (6).

Fig.6. Fuzzy quantifier

In this problem, three different quantifiers are selected (All Most, and some). Figures 7, 8 and 9show the Site suitability for dam site, each pattern is associated with a givenquantifier.

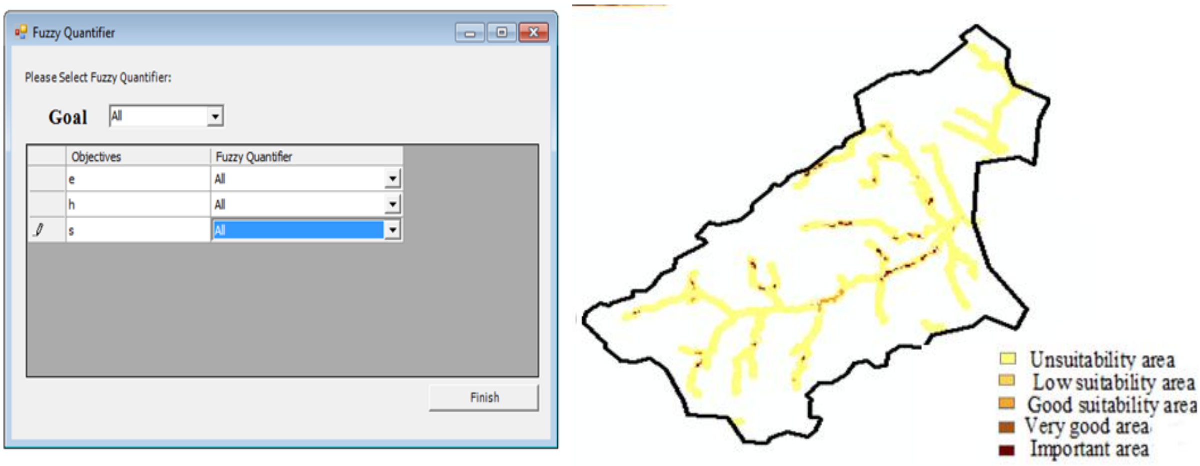

Fig.7. **Site suitability for dam site using Linguistic Quantifier (all)**

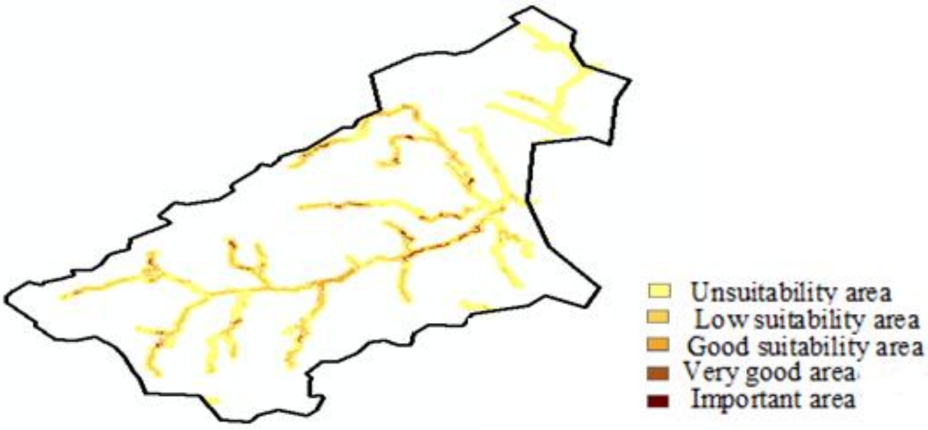

Fig.8. **Site suitability for dam site using Linguistic Quantifier (most)**

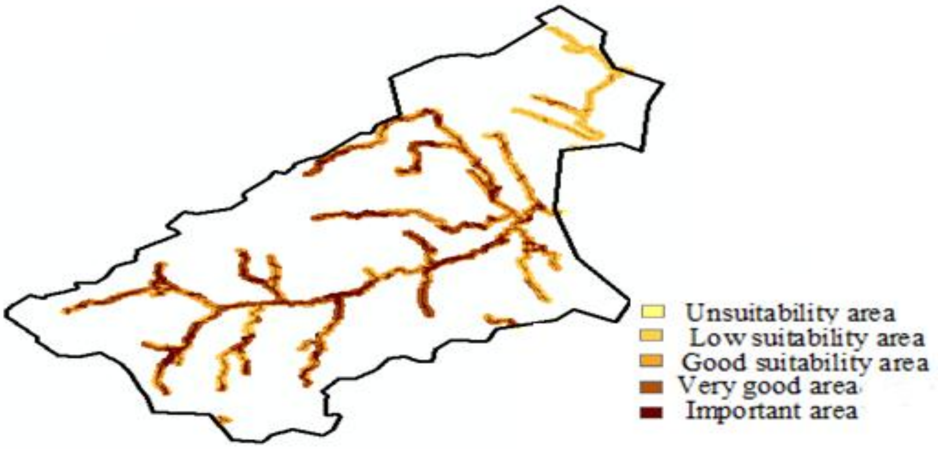

Fig.9. **Site suitability for dam site using Linguistic Quantifier (some)**

4-3 Analytic Hierarchy Process (AHP)

First we start building the hierarchy of water harvest and determining the main criteria under the goal and sub criteria associated with the main criteria, here in this study three main groups; environmental, hydrological, and socio-economic factors are adopted and each associated sub criteria Figure (10).

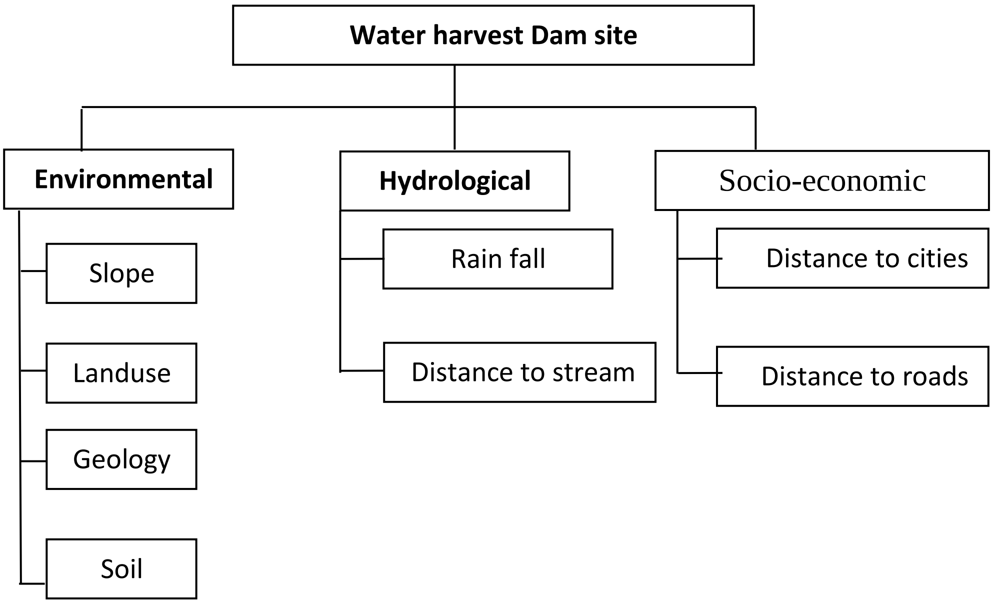

Fig.10. Hierarchy structure of rain water harvest site

Choosing the AHP method from the tool bare, and then assigning each sub-criterion to relative main criteria as in Figure 11, 12.

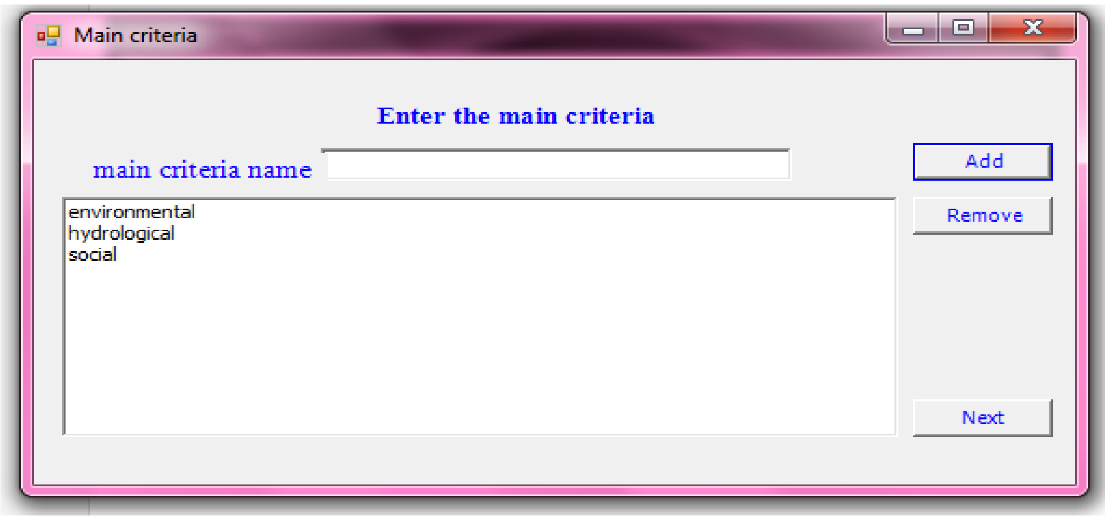

Fig.11. main criteria of water harvest structure.

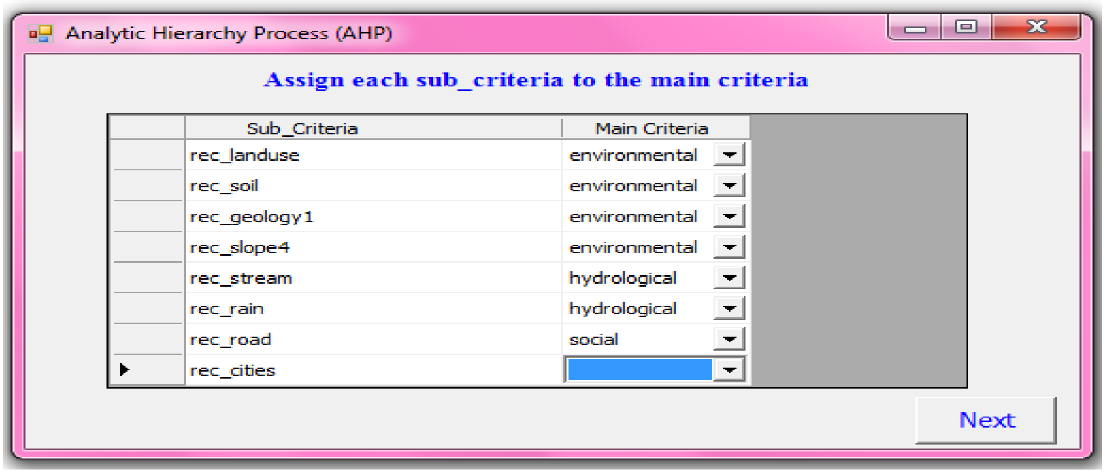

Fig .12.main criteria and corresponding sub criteria

After building the AHP model, the relative weights for all objective clusters and their related attributes are calculated using the pairwise comparisons Saaty 1980. Pairwise comparison method required an expert in dams planning to provide his/her best judgments regarding the relative importance of objectives and attributes. Figure from (13) to (16) show the Pairwise comparison matrix between each main criteria and sub-criteria.

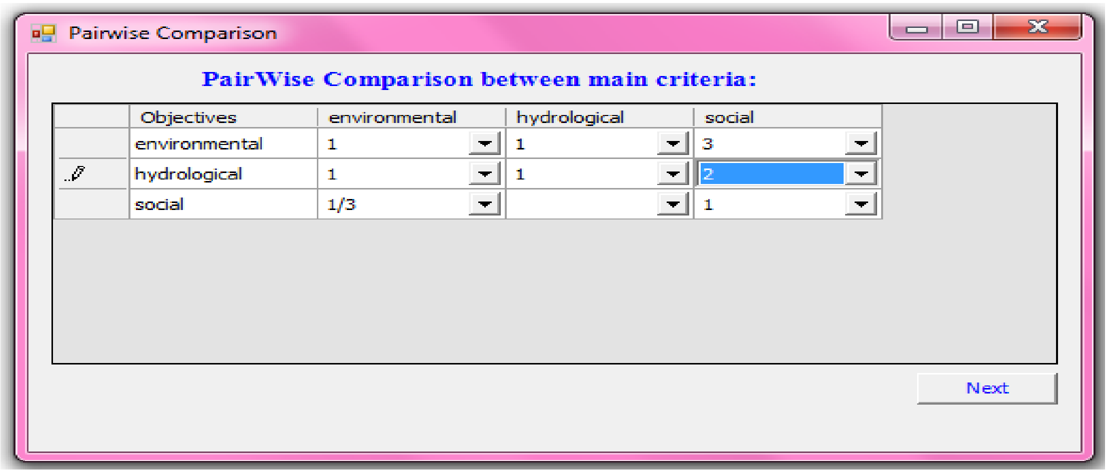

Fig.13. Pairwise comparison matrix between main criteria

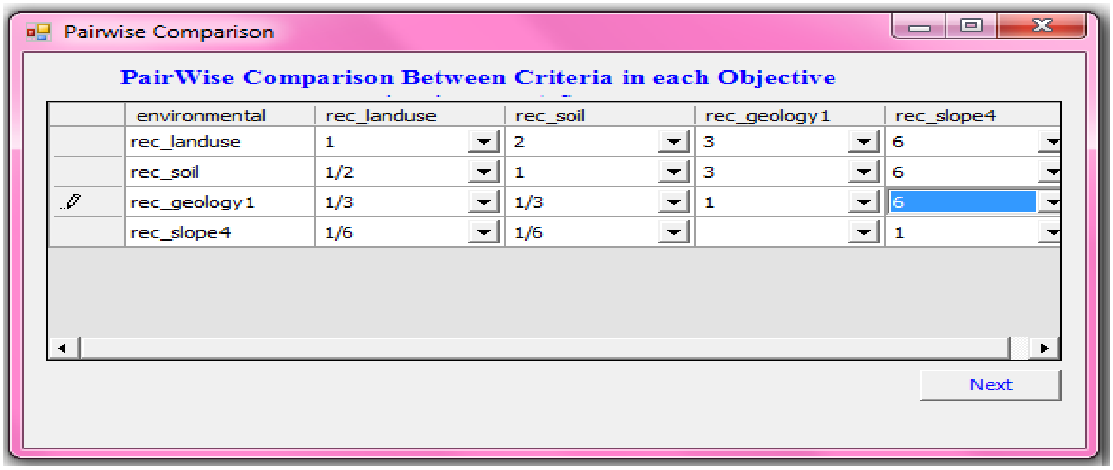

Fig.14. **Pairwise comparison matrix between sub Criteria according to Environmental**

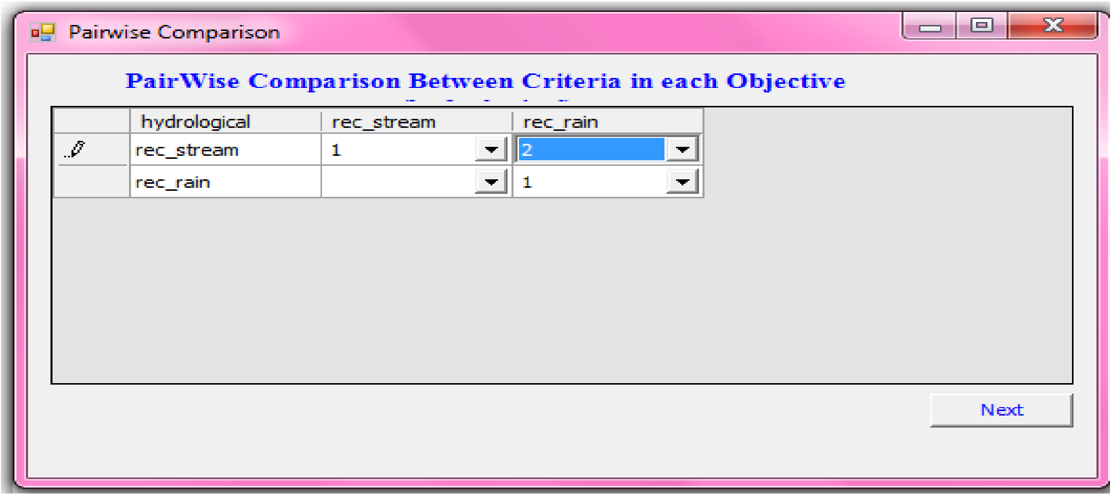

Fig.15 **Pairwise comparison matrix between sub_Criteria according to hydrological**

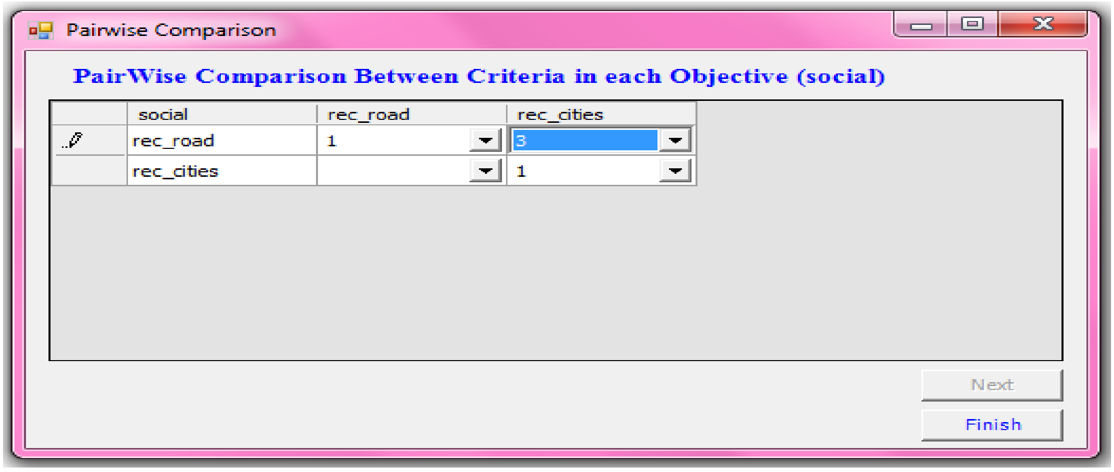

Fig.16. **Pairwise comparison matrix between sub_ Criteria according to social-economic**

The final suitability map of Analytic Hierarchy Process (AHP) is shown in figure (17)

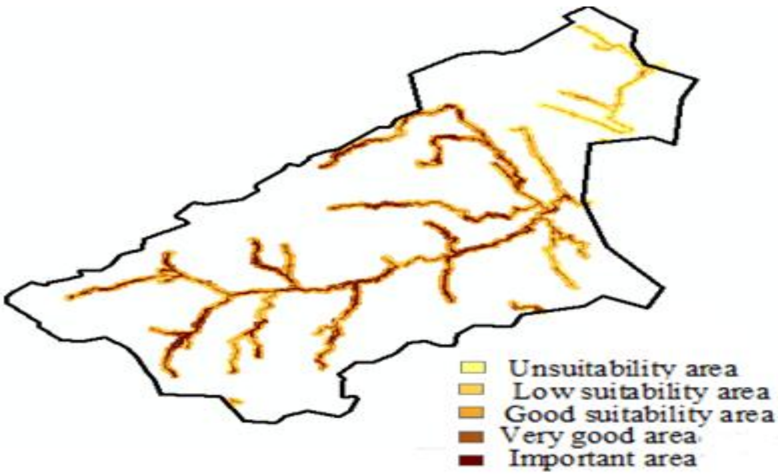

Fig.17. **Site suitability for dam site using AHP**

Model validation was done:

a) By comparing the resulting suitability sites of AHP, OWA approach with previous study [3] of Qassim region as in Figure (18).

b) by visual comparisons were performed between the resulting suitability index values and the google images of region the comparison shows similarity with the present dams in the study area figure (19).

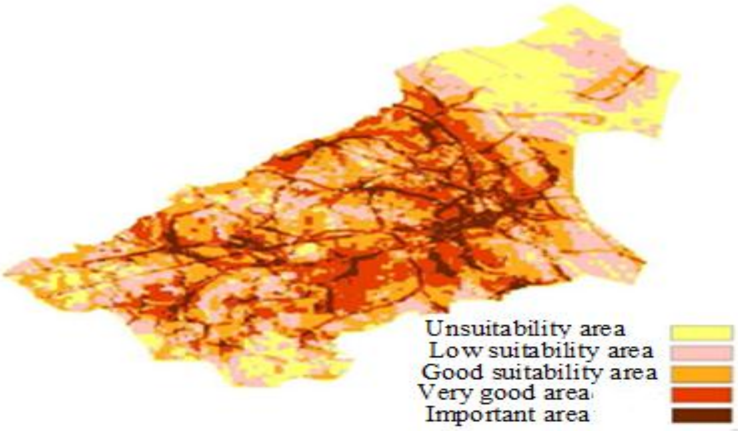

Fig.18Site suitability for dam site using raster calculation

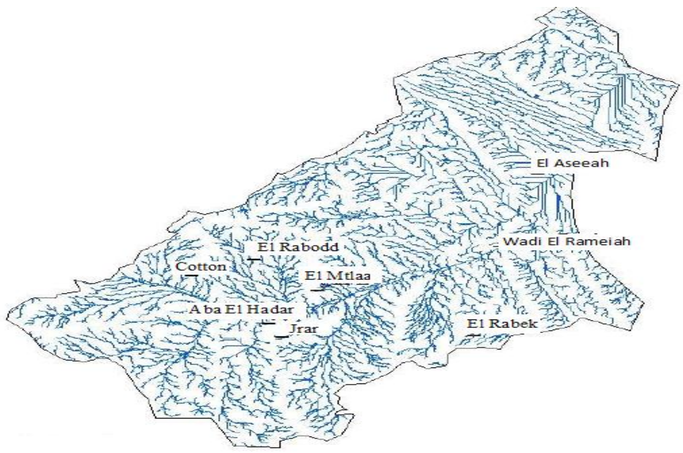

Fig.19present dams in the study area

5. CONCLUSION

One of the most important and complex problems in arid and semi-arid regions is locating the water harvest site. A large mass of information must be gathered, combined and analyzed to make correct criteria that may effect on making the final decision. This paper has presented the theoretical basis for a novel GIS-based MCM procedure. The paper has suggested two multicriteria decision methods (Analytical Hierarchy Process and Ordered Weighted Averaging) in GIS environment. GIS-based MCE Dam Site Selection Tool has been developed as a toolbar in ArcGIS9.3

Site selection for rain water harvest is carried out by considering the slope, soil, land use/land cover, geology, buffered stream order, distance from roads, distance from cities criteria for decision machining in Qassim region.

6. We noticed that

1. **Geographical information systems are very useful tools to determine the best locations for water harvesting projects. The application of multi-criteria increases the accuracy of the results and limits the appropriate areas of the sites selected carefully to ensure the success of the project.**
   2- **Using AHP method is inability to address the uncertainty in the decision maker's judgments, although it calculated the weight using the Pairwise comparison and priority vectors of each level and used the WLC as decision rules in aggregation**
   3- **By changing the linguistic quantifiers, the GIS-based OWA can generate a wide range of decision strategies but it lack in calculating the criteria weight.**
   4- **Several alternative scenarios of site suitability for water harvesting have been developed in this study. They show how the decision-maker's attitude involved in suitability dam site decision-making process can influence the outcomes.**

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استخدام نظم المعلومات الجغرافية وطرق المعايير المتعددة لإتخاذ القرار لإيجاد مواقع سدود حصاد المياه

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الملخص :

إيجاد مواقع سدود حصاد المياه مسالة اتخاذ قرار معقدة نتيجة تداخل المعايير المـأخوذه بالاعتبار. إيجاد الموقـع الأفضل يتطلب الدمج بين نظم المعلومات الجغرافيـة والمعايير المتعددة لاتخاذ القرار لهذا كان لابد من الاستفادة من مميزات هاتين الطريقتين لحل هذه المشكلة. .تتضمن هذه الطريقة استخدام تقنية التحليل الهيكلي ومتوسط الأوزان المرتبة (AHP-OWA) في بيئة نظم المعلومات الجغرافية. استخدم هذا التكنيك من أجل إيجاد مواقع سدود حصاد المياه في منطقة القصيم بالسعودية. أخذ بعين الاعتبار المعايير التالية: ميل الحوض، نوع التربة، صلابة الجيولوجية السطحية، استخدامات الأراضي، توزع الأمطار، شبكة التصريف النهري، المسافة إلى الطرق، والمسافة للمناطق المخدمة كمعايير لاتخاذ قرار تحديد المواقع الممكنة للسدود. حيث أظهرت النتائج إمكانية الحصول على تقنية مفيدة تسمح بالحصول على مجال واسع من استراتيجيات القرار بين السيناريوهات المتفائلة والسيناريوهات المتشائمة.