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Hamdy A., El Mahd A., Kheireldin K.

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TECHNIQUES FOR ENVIRONMENTAL PLANNING AND MANAGEMENT

INTEGRATION OF GIS AND MULTICRITERIA TECHNIQUES FOR WATER RESOURCES MANAGEMENT IN EGYPT

A. ElMahdi*, K. Kheireldin, A. Hamdy*****
*SRU, National Water Research Center, El-Qanatir, Qalybia, Egypt.
**National Water Research Center, El-Qanatir, Qalybia, Egypt.
***Istituto Agronomico Mediterraneo, Bari, Italy.

ABSTRACT

Integrated Water Resources planning and Management is considered a very complex issue. It is usually solved through the multisectoral, interdisciplinary and hierarchical decomposition approaches. In general, integrated management indicates the consideration of water, social, socio-economic, economic and environmental issues. The current study aims at merging the GIS and MultiCriteria evaluation (MCE) approaches and at solving the integrated management of a cultivation area. Thus, an area of about 120.000 thousand acres (250.000 Feddan) has been selected to be simulated through the merging of GIS and MCE for the sake of integrated management. The selected area is located in the Northern Nile River Delta area with a coastal zone on the Mediterranean. The GIS has been applied to picture the area with its different sectors that are: social, economic, environment and water. Different randomization cropping pattern distribution scenarios have been proposed. Through the merging of GIS and MCE three scenarios have been run and evaluated on three different levels: farmer, canal catchement area and integrated area. It has been found that this merging is a very powerful and robust tool for evaluation of different proposed plans on the integrated levels. The merging of GIS and MCE has really facilitated the decision making process for such type of problems. It is recommended to use such methodology in the integrated management of similar problems.

1. INTRODUCTION AND PROBLEM DEFINITION

Water is considered nowadays an important issue due its scarcity specially in the Middle East zone. Moreover, water now is considered a limiting factor for development in many countries. Usually water is controlled by water resources authorities that are responsible for managing water resources. These authorities usually have the power to control the infrastructures that deal with water discharge in rivers, canals and drains. In many places all over the world the water authorities are also responsible for assessing penalties in the case of violating the water distribution laws and irrigation rotations. However, from the interdisciplinary point of view, a number of other authorities are also involved in water use. There are Agriculture and Land Reclamation, Health, Tourism, Power generation, Transportation, Industry, Housing and New Communities. Each of these authorities has a different role in dealing with water. For example, the Agriculture and Land Reclamation Authority has special responsibilities in the countries that depend on irrigation rather than on rain because agriculture consumes the highest amount of water. For example, in Egypt the agricultural sector is responsible for the use ofabout 85% of surface water. On the other hand, and due to globalization several countries have started to change the cropping pattern to the liberal system where the farmer has the right to cultivate what he wants. Prior to this liberalization, the cultivation authorities used to decide, depending on the international market prices and national food safety, which crops were to be grown and where. Such planning was undertaken a year in advance. From this exercise, the requested specific volumes of water to be delivered to each canal could be estimated by the water distribution sector at the water resources authority. Then the water resources were allocated for each spatial zone through the irrigation canal network system.

Accordingly, the main problem that faces water distribution and water resources decision makers nowadays in a country that has a canal network and totally depends on irrigation is how to estimate water volume along the canal network under the condition that there is randomizing in the cropping allocation. This will lead to great difficulties in assigning water volumes along canals since the water distribution engineer has to know what the current cropping pattern is in each spatial unit which may be either governance level or agricultural directorate or farm...etc. Thus, the water distribution engineer uses some previous data, may be the previous year's cropping pattern to assign water for the new year. Moreover, the issue of integrated water resources management is also raised everywhere, since water now is considered one of the major issues in the sustainable development of any country. Thus, any water resources plan for a certain area must consider economic, environmental and social issues.

2. INTEGRATED MANAGEMENT

Water is the vital resource for human survival and economic development . Its demand increases with population and economic growth, while the availability of the resource remains constant. Shortage engenders water use conflicts, both in terms of quantity and quality. Efforts should be directed toward supporting water resources planning, policy making and management through development of a strategy that considers several issues associated with the core problem of developing multiple sources and managing multiple uses (municipal, industrial, irrigation) of water. Thus, over time more efficient water resources supply systems and use patterns should emerge, while maintaining or improving water quality (IADB, 2000).

There is consensus among the international community that water is a renewable but limited resource that requires an integrated participatory approach management. Because of the different competitive uses of this resource, water is recognized not only as a social commodity but as an economic one as well (Naiman, 1999).

The development of a macro planning tool relating the different economic sectors to water, requires an extensive complex knowledge domain. This complexity necessitates compiling and reducing data from their microscale to a simple macroscale level and applying a hierarchical decomposition principal in the model development (Simonovic et all, 1996). Previous studies show that the hierarchical decomposition principal is applied by modeling the economic development in water use sectors: agricultural, industrial, domestic, navigation and river regulation. These sectors are discretely modeled by the means of small basic components that describe the inter-sectoral structure (NWSU, 1996) Kheireldin et al (1996a,b).

3. CASE STUDY FOR MERGING GIS AND MCE

3.1. Study Area

In the current study, an area in Northern Egypt is selected to be a case study of merging GIS and MCE under the shed of integrated water resources management. The study area is located in the NorthEast of the Dakahlia governorate, named El-Khalalah, which has the longitude and latitude between (31° 15' - 31° 30') N and (31° 15' - 31° 30') E. It spreads over 34 km in length and 24 km in width. The population in this area is about 1.5 million capita and it contains 350 villages and different land use types. Figure 1 shows the general layout of this area.

3.2. Irrigation System in the Area

The irrigation network is considered relatively dense along the area It contains different trapezoidal canals of different bed widths ranging from main canals of more than 25 m in width, bifurcated into smaller canals ranging from 10 to 25m width and these canals are branched into small canals ranging from 5 to 10m in width. On the other hand, the drains in this area range from 5 to 25 m in width. The remaining area is classified as perennial lakes or ponds and marshes or under being reclaimed. Figure 2 presents the canal network and drainage network of the area.

3.3. Cropping Pattern

The main feature responding to the cropping system in this area is agricultural plants. However, this area is divided into old cultivated land, reclaimed land and non-cultivated land. The main crops in this area in summer are rice, maize, cotton and vegetables as presented in Figure 3. On the other hand winter crops are wheat, barley, berseem as presented in Figure 4. This information was obtained based on the 1999 cropping pattern system (CAPMAS, 1998) for each piece of land based on the land tenity.

3.4. Social System in the Area

The area under investigation is mainly inhabited by farmers. The farmer either has his own land where he works or he works on different farms with a daily or monthly salary. Men and women are usually employed in cultivating lands. There are different statistics that relate labour requirements for each crop at different stages (CAPMAS, 1998; EAYB, 1986,1992,1995).

3.5. Health Hazard Issues

Water borne diseases are very common in the farmers' communities. Shcitomaizes is very common in Egypt due to the infected waterways. The use of pesticides and fertilizers is also highly suspected as a health hazard issue. Accordingly, data regarding crop requirements from the Nitrogen- Phosphorus and Potassium Fertilizers has been collected (EAYB, 1986,1992,1995) and (CAPMAS, 1998). Also, pesticides such as fungicide, herbicide-and insecticide have also been collected (EAYB, 1986,1992,1995) and (CAPMAS, 1998). These types of data are collected for type of crop that is cultivated in the area under study.

3.6. Economic Issues

Information regarding farm gate price, crop cultivation cost, net return, return,...etc have been collected for the different crops in the area and their related economic issues (EAYB, 1986,1992,1995).

3.7. Soil Salinity Issue

The selected area is very close to the Mediterranean coast so that the problem of salt intrusion is very common. A map of soil salinity is shown in Figure 5 and it is clear that salinity is considered high in the area close to the seacoast.

3.8. Basic GIS Information

Information obtained for this study was taken from topographical maps of 1: 50,000 scale that cover the study area. Moreover, two field trips were undertaken in order to have a better idea of the region under study.

Fig. 1. General Layout of the study Area.

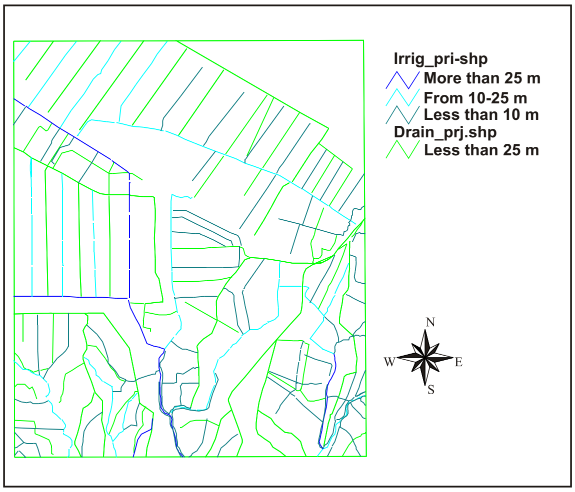

Fig. 2. Canal and Drainage Networks.

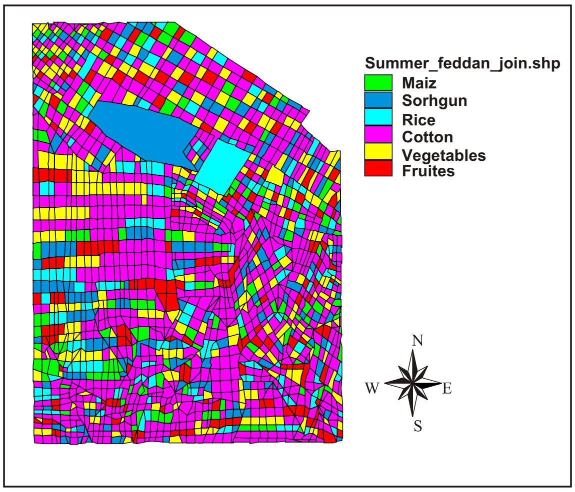

Fig. 3. Main Summer Crops.

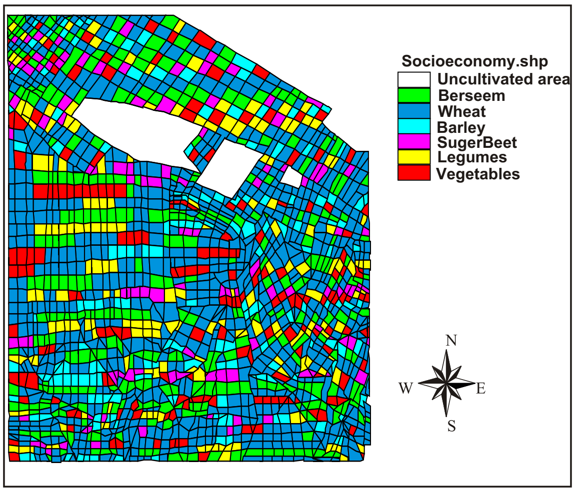

Fig. 4. Main Winter Crops.

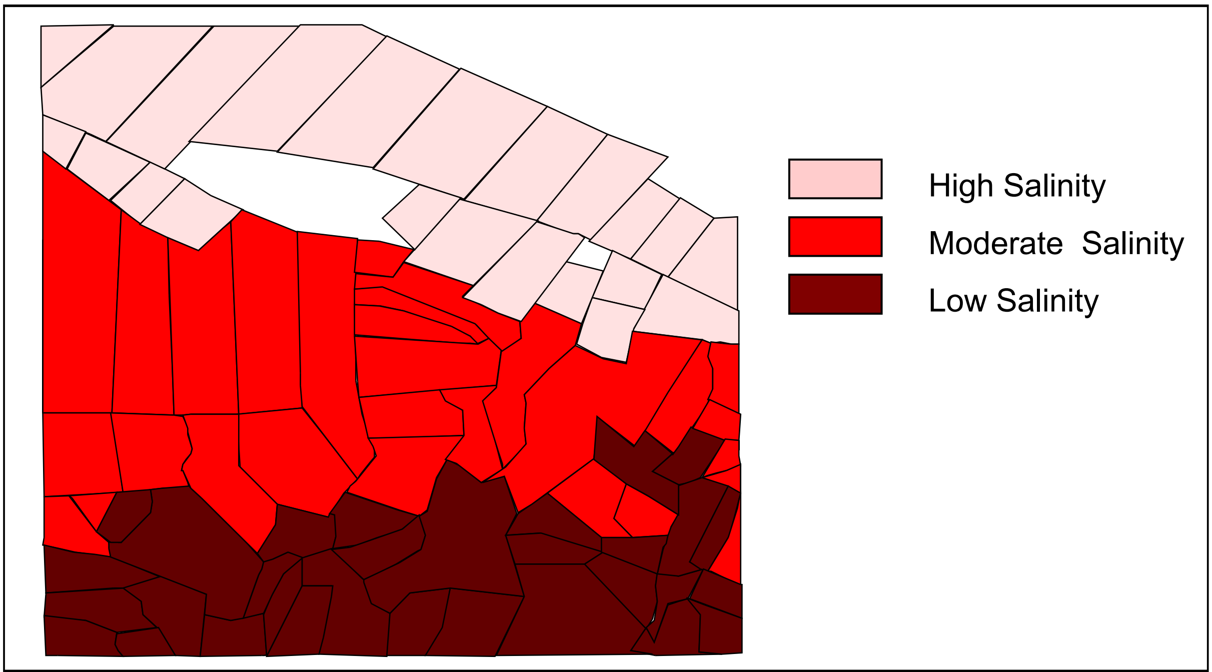

Figure 5 Soil Salinity Map.

4. PROBLEM SIMULATION

The following steps are followed to Simulate the Problem:

- The area has been classified into parcels, which range from 3 to 305 feddan according to the farmer families who own these areas. The cropping pattern is following the agricultural administration as a basic scenario for the whole area.
- The area served by each irrigation canal has been determined from the area served by irrigation maps and defined through GIS.
- To create more scenarios that simulate the free cropping pattern system a random distribution approach is assigned for each parcel. Accordingly, during each run a new random cropping pattern allocation for each parcel is proposed. The crops are limited to those described in Table 1.
- The databases, for different attributes, related to crops with the spatial data along the area of the study using GIS are merged and the different required calculations are done at this stage.

Table 1. The main crops existing in the area under investigating during different seasons.

CropID	Winter season	CropID	Summer season
C1	Berseem	C7	Maize
C2	Wheat	C8	Sorghum
C3	Barley	C9	Rice
C4	Suger beet	C10	Cotton
C5	Legumes	C11	Vegetables
C6	Vegetables	C12	Fruits

5. PROPOSED SCENARIOS

Different scenarios using the random distribution approach for the different parcels in the area to allocate crops has been proposed and presented in Table 2. Table 3 summarizes the percentage of each crop for the winter season while Table 4 summarizes the crop percentage for each crop in the summer season.

Table 2. Proposed cropping pattern in each scenario.

Scenarios ID	Winter	Summer
Sc1	C1+C4	C2+C5
Sc2	C2+C3+C5	C3+C6+C2
Sc3	C6+C4+C1	C4+C5+C3

Table 3. The percentage of each crop in Winter Scenarios.

Crops	Status Quo	Scenario1	Scenario 2	Scenario 3
Berseem	17%	30%	4%	20%
Wheat	33%	4%	30%	5%
Barley	12%	5%	25%	3%
Sugerbeet	4%	30%	3%	32%
Legumes	2%	10%	28%	8%
Vegetables	5%	5%	3%	30%

Table 4. The percentage of each crop in Summer Scenarios.

Crops	Status Quo	Scenario1	Scenario2	Scenario3
Maize	7%	30%	7%	4%
Sorghum	2%	10%	31%	5%
Rice	1%	8%	27%	18%
Cotton	30%	6%	4%	25%
Vegetables	7%	30%	5%	30%
Fruits	4%	5%	25%	7%

6. ANALYSIS OF RESULTS FROM GIS APPLICATION

6.1. Water Related Output Results

6.1.1. Canal Water Discharge

Water requirement for each canal in the distributed system is determined through the GIS technique. The monthly-required inflow of each major and minor canal is determined. The required discharge for major and minor canals in winter and summer has been directly calculated through the GIS technique. It can be presented in map format, table or graph. This is considered one of the major advantages for using GIS in the water distribution system. Discharge can also be calculated along the whole length of the canal following the water distribution at different frames. Discharge is calculated by the mass balance approach.

Figures 6-a, 6-b and 6-c present water quantity requirement during April, May, and June, when the high quantity of water is concentrated near the coast or in the north. This indicates that the crops in this area need a great quantity of water. This case is also very clear during July and August, when the high quantity is located in the northern area close to the coast only, as shown in Figures 7-a, 7-b and 7-c.

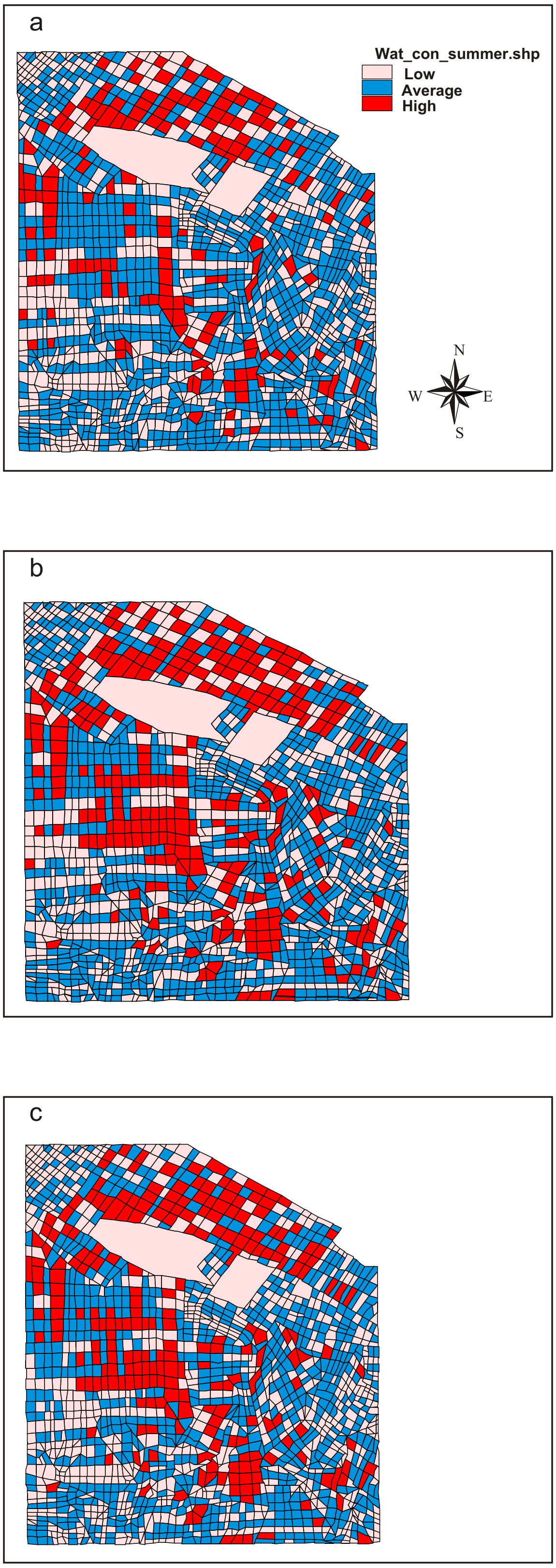

Fig. 6-a, 6-b, 6-c. Summer Water requirement during April, May and June.

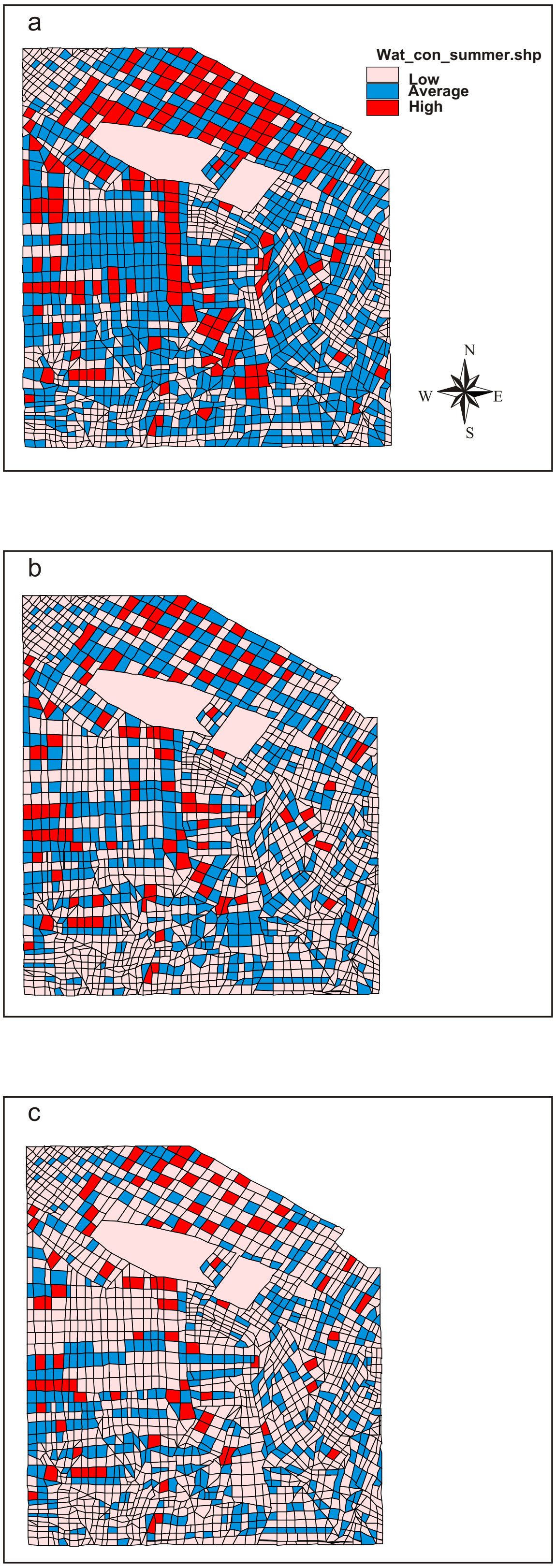

Fig. 7-a, 7-b, 7-c. Summer Water requirement during July, August and September.

6.1.2. *Water Sufficiency*

The water shortage has been determined through the GIS technique by calculating the demand of each parcel. The accumulation of water from each parcel inside the catchment area of each canal will result in the volume of water needed to be delivered through each canal. Accordingly, the input information of delivered water in each canal in the system is gained from the proper authorities. A comparison is done between the calculated water by the previous described method and that of the volume of water delivered by the governmental authorities. A map that describe the shortage, balance, or excess water at each catchement is resulted from the GIS technique. It can be easily shown the area where water shortage occurs and excess water occurs. Thus, this system is very applicable in determining the water balance of any cultivated area so that volume of water distributed in the channels can be modified until there is balance in the area.

6.2. Socio-Economic Output Results

It can be noticed that there are differences in labour requirements in each season because of the needs of different crops at different times. Moreover, more studies could be done by studying the labour travelling, immigration from different villages, etc. Economic results are also presented by GIS such as crop net income, crop production cost, return per Feddan and farm gate price of the different areas. As an analysis of some results, one can show the spatial variation of these items along the different zones. The high cost area is located in the northern area, while the net income has the highest value in the southern and western zones. The crop yield has also been considered in the current study. Moreover, the varieties due to change in salinity can be shown, since the crop yield is related to the soil salinity map.

6.3. Environmental Output Results

From the environmental point of view, the agro-chemicals used in the area under investigation have been determined in a qualitative scale. These are fungicide, herbicide and insecticide. It is obvious that the high quantity from pesticides is located in the northern zone and more related to crops, while the winter vegetables used the largest amount of pesticide. Related to fertilizer use, it has been indicated that high quantity is concentrated in the northern zone where there is the reclaimed land . Three different types of pesticides are commonly used in this area which are nitrogen, phosphorus, and potassium.

7. MULTICRITERIA EVALUATION

7.1. Multicriteria Evaluation: Basics and Methods

The basic mathematical approach for MultiCriteria evaluation depends on filling an evaluation matrix for all possible alternatives and evaluation criteria as presented in Table 5-a. Next to this matrix there are the different proposed preferences or weights for each criterion as presented in the first column of Table 5-b. Through the different methods of solving such matrix, results are shown in what is defined as appraisal scores. The conclusion may therefore be the selection of the alternatives with a better score.

There are several arithmetic techniques for MultiCriteria evaluation and many researchers have classified MultiCriteria methods in different ways. The most common is the Quantitative-Qualitative classification given by (Nachtnebel, 1991). Hobbs et. al., 1992 designed an experiment to evaluate different multicriteria methods such as Goal Programming, ELECTRE I, Additive Value Functions, Multiplicative Utility Functions, and three techniques for choosing criteria weights. The authors concluded that experienced planners generally prefer simpler, more transparent methods. However, none of the methods are endorsed by a majority of the participants. Many users preferred to use no formal method at all. Finally, it has been stated that decisions can be as sensitive or more to the method used according to the person who applies it. Another research has been conducted (Nachtnebel, 1991) to compare the different methods. In the current paper the compromise programming is used and this is described in what follows.

Table 5-a. Major and sub-evaluation criteria.

Major Criteria	Sub-Criteria
Water	Water Requirenments Water Shoratge
Environment	Amount of Fertilizers used (Nitrogen, Phosphurs, and Potassium) Amount of Pesticides Used (Fungicide, Herbicide, and Insecticide)
Social	Labour Net Income of the farmer Return
Economic	Whole area Return Cost Crop Yield

Table 5-b. MultiCriteria evaluation matrix.

Weight	**Criteria**	**Alternative A**	**Alternative B**	**Alternative C**	**Alternative D**
W1	C1	A1	B1	C1	D1
W2	C2	A2	B2	C2	D2
W3	C3	A3	B3	C3	D3

7.2. Compromise Programming method

This method is a distance-based technique. Distance based techniques are designed to identify non-dominated solutions that are closest to an ideal solution by some distance measure. An ideal solution, in general, can be defined as the vector $f^* = (f_1^*, f_2^*, \ldots\ldots, f_N^*)$ where f_i^* are the solutions to the problem stated as Optimum $f_i(x)$, i = 1, 2,......, N. In a discrete setting such as the case problem under consideration, the ideal solution is defined as the vector of best values selected from the payoff matrix. The vector of worst values represents the minimum objective function values denoted as f_i^{**}. These values are valuable for determining the degree of closeness of an alternative to the ideal solution. One of the most commonly used measure of closeness is a family of L_p metrics that could be expressed as:

$$L_p = \left[\sum_{i=1}^{N} W_i^p \left[\left| \frac{f_i^* - f_i(x)}{f_i^* - f_i^{**}} \right| \right]^p \right]^{\frac{1}{p}}$$

Where $f_i^{**} = \min f_i(x)$; i= 1, 2,......,N is the minimum objective function in terms of criterion i, W_i's is the criterion weight, and p is the balancing factor and is usually taken equal to 2.
As a last step in this technique, upon determination of the distance of each alternative from the ideal solution in the preceding procedure, the alternative with the minimum distance is selected as the compromise solution.

8. EVALUATION CRITERIA

In this study selected criteria have been chosen to satisfy the MultiCriteria basis. Evaluation has been decided to be done on three major levels that vary from the farm level, canal catchement level and whole area level. This is in order to simulate the real needs of different decision maker levels. A farmer will evaluate his decision based on social and economic aspects. However, the mid level decision maker usually evaluates his decisions based on water issues, some minor environmental issues, and social issues. At the higher decision levels the decision-maker will evaluate based on environmental, water, economic and social levels. Thus, the current study aims at introducing the evaluation of the different scenarios from different perspectives. Table 6 shows basic evaluations criteria that were selected in the current study.

Table 6. MultiCriteria Evaluation analysis Field Level - Summer Scenario.

Scenario	A	B	C
Status Quo	1	1	2
Scenario 1	3	2	1
Scenario 2	4	3	3
Scenario 3	2	4	4

9. SCENARIOS EVALUATION

9.1. Field Level

At this level, MCE analyses were applied to three different fields in the area that were selected at three different soil salinity levels. Field A with high salinity, field B in average salinity area and field C in low soil salinity area. A sample of the output is presented in Table 7 for the different fields. It must be concluded that this evaluation was done giving equal weight for the different criteria.

9.2. Canal Catchement Level

In this stage the MCE was applied assuming that decision-maker preference has different orientations. First, all of the criteria give the same weight, then the evaluation is done giving the environmental issue the highest weight. The evaluation was also done two times more by giving the highest weight to the social aspects and water aspects respectively. The results are shown in Table 8.
It can be shown that the scenario ranking changes by changing the weight to different criteria. For example, the Status Quo scenario was ranked third when giving equal weight to all criteria. However, changing the weight to the environmental, water and socio-economic criteria, the same scenario gained first rank. This can be considered a very important issue when evaluating the scenarios, since giving weight to any criteria highly affects the rank results. Different results are obtained from different catchement areas.

9.3. Whole Area level

Table 9 shows that scenario 1 was recorded as the best one along the area when equal weight is assigned to all criteria, but the best scenario was the scenarios 3 when weights are changed for environmental, socioeconomic and water aspects,.This means that it is the best one using fertilizers and pesticides. Moreover, it has a good income and return with low percentage of shortage and low water quantity requirement.

Table 7. Example of MultiCriteria Analysis results for Catchemant Area Summer Scenario (The table shows the ranks of different scenarios: 1= the highest score , 4= the lowest score)

Scenario	Evaluation Criteria			
	Equal Weight	Environmental	Socio-Economic	Water
StatusQuo	3	1	1	1
Scenario 1	1	3	3	3
Scenario 2	2	2	2	2
Scenario 3	4	4	4	4

Table 8. Example of MultiCriteria Analysis results for Whole Area -Summer Scenario (1= the highest score, 4= the lowest score).

Scenario	Evaluation Criteria			
	Equal Weight	**Environmental**	**Socio-Economic**	**Water**
StatusQuo	3	3	3	3
Scenario 1	1	4	4	4
Scenario 2	4	2	2	2
Scenario 3	2	1	1	1

10. CONCLUSIONS

From the current study the following can be concluded:

1. A methodology for integrating environmental, social and economic aspects in order to help the decision maker to evaluate water resources plans under the condition of free cropping pattern has been developed.
2. The amalgamation of GIS and environmental, social and economic aspects is a powerful tool for studying and analyzing several issues in water resources management.
3. The MultiCriteria evaluation technique shows a significant powerfulness in evaluating complex and diverted scenarios based on randomized distribution of crops in a certain area.
4. Mutlicriteria evaluation provides the decision maker with very powerful information for ranking the different scenarios which lead to facilitate decision procedures.

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