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Multi-Criteria Analysis for Irrigation Management in Magnesia Region, Greece

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Abstract: *The purpose of this study was to find the optimal economic management of agricultural production, by minimizing the use of available water resources. The plain of the Magnesia prefecture was chosen for this study, as it constitutes the most representative part of the plains of Greece. The method of Multi-criteria Analysis and more specifically the Compromise Programming was used for the optimization of the agricultural production. The aim was to find the relatively optimal solution by evaluating alternative crop restructuring scenarios for the irrigation network. The result of this research is the final optimal restructuring of crops in irrigation network that brings all the benefits of using it, in both economic and environmental terms.*

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I. Introduction

The exploitation of the water resources of the planet, usually without planning, is a phenomenon that deeply concerns the scientists and the state. Therefore, the analysis of both the existing and future situation that forms the level of demand and the investigation of the possibilities of water saving through appropriate actions and interventions are of particular importance [1].

The largest amount of water in Greece and internationally is used for irrigation and ranges from 70% to 80%. Despite the fact that the irrigated areas of the planet, occupy the 17% of the arable area, they consume about 70% of the global water supplies [2,3]. This percentage is reduced to approximately 40% in countries that import food and have well-developed economies but exceeds 95% in countries whose main economic activity is agriculture [3].

The water demand management (WDM) is increasingly considered as a strategy to alleviate water scarcity problems, through a variety of participatory measures, including technical, political, institutional, financial and educational tools, in order to inform farmers about the better use of existing resources before demand increases. With the improved management of water needs, it is estimated that up to 25% of water can be saved[4]. Advances in science and technology are also efficient tools in order to control every drop of water in the hydrological cycle.

Nowadays, decisions on the management of water needs and on irrigations generally, are based not only on experience and economic analysis, but mainly on the construction and adaptation of appropriate mathematical models. These models permit the complete description of these units, the detailed analysis, the systematic organization, predictions about the process of their main parameters and generally making more rational decisions [5]. These models usually consist of a system of real variable equations (which constitute a special mathematical method), depending on their form, their type of variables, their way of solving, the degree and the nature of interdependence between the variables as well as the equations, the objective purpose, etc.[6].

For the optimization of agricultural production the multi-criteria analysis model was used, particularly the method of compromise programming. This study is a follow-up of a published study entitled: Irrigated crops water needs in Magnesia region, Greece [7]in which the configuration of the study area and the existing economy-environment situation (for five years reference 2012-2016), are presented analytically.

In this study compromise programming is applied in order to find the relatively optimal solution by evaluating ten (10) alternative crop restructuring scenarios for the study area. In order to be considered reasonable, these scenarios are based on the judgment of the research team, that plays the role of the responsible authorities, and are derived from the results of a previous research study[8].

The criteria with which the alternative scenarios are examined were determined and the weighting coefficients of these criteria were also settled on. A compromise algorithm that works in a Visual Fortran Environment and was designed by Tzimopoulos[9], was used in this research [10]. The result of this research is the final optimal restructuring of crops in terms of the irrigation network, which brings all the benefits of its use, both economically and environmentally (optimal management of available irrigation water).

II. Material And Methods

Multi-criteria analysis:

The main objectives of the multi-criteria analysis can be summarized in the following four stages: 1) Analyzing the competitive nature of the criteria, 2) Modeling of the decision maker's preferences and 3) Identifying satisfactory solutions [11].

1st Stage: Determining the objective of the decision, defining and constructing the problem of developing alternative scenarios.

2nd Stage: Determining a consistent set of criteria and defining all the evaluation criteria.

3rd Stage: Developing the criteria synthesis model, selecting the evaluation method (choosing between discrete and continuous methods, determining the system of preferences of the decision maker) and implementing the method.

4th Stage: Support of the decision and final conclusions.

The multi-criteria analysis is a quantitative and qualitative method of evaluating multiple and invariably conflicting criteria when making a decision. It has been widely applied in management problems of water systems that serve more than one use of the water. Even in recent years, with the consideration of the environmental-ecological component, the need to choose, the best possible political decision has made multi-criteria analysis an essential decision support tool.

The most well-known criteria analysis methods reported in literature are: ELECTRE I, ELECTRE II, PROMETHEE, Compromise Programming, Goal Programming, Weighting Method and A.H.P. [7].

Compromise programming:

The Compromise Programming [12] is one method of multi-criteria analysis. It aims to determine feasible solutions that are so close to the ideal but practically impossible solution. The deviation from the ideal solution represents the magnitude of the decision-making center's preference:

$$L_p(x) = \left\| \frac{f(x) - f^*}{M - m} \right\| = \left[\sum_{i=1}^{n} w_i^p \left(\frac{\| f_i^* - f_i(x) \|}{\| M_i - m_i \|} \right)^p \right]^{\frac{1}{p}} \quad (1)$$

where:

$L_p(x)$: is the divergence.

w_i: are the weights or the importance of the criteria.

f_i*: is the optimal value of the criterion i.

$f_i(x)$: is the result of the implementation of the x decision with regard to the criterion i.

M_i και m_i: is respectively the maximum and the minimum value of $f_i(x)$.

p: is the parameter, $1 \leq p \leq \infty$.

The intentions of the decisions makers are indicated by setting a set of weights w_i. If the values of the weights and of the parameter p are given from the beginning, then the minimizing of the above equation gives the optimal solution according to the given data.

For the center of decisions, the analyst's presentation of various compromises that are obtained from various values of the parameter p, is useful. For p=1 and w_i=1 where i=1,…..,n the compromise programming is converted to the goal programming method. For p=2 and Σw_i=1 it is converted to the Euclidean norm, whereas for p=∞ and w_i=1 where i=1,…..n the compromise programming is degenerated in the Min-Max method [13].

The compromise programming has two parameters,the parameter p, which reflects the importance of the maximum deviation from the ideal solution and the relation between the criteria, andthe w_i weight, which reflects the relative importance of the i criterion.

The designer of the method creates a number of different weight groups, in case the decision centers are not ready to state their preferences. These groups are selected to cover a wide range of preferences. Once the corresponding solutions are created for each group of weights with the help of compromise programming, then they are rated. Thus, the normal procedure for finding the alternative solution that has the highest degree of ranking (that is the lowest $L_p(x)$ value) is replaced by the search for a more stable alternative. If the best solution is not accepted, then more information is gathered and the process is repeated.

The alternative solution, which is less sensitive to changes in weight, is considered to be more stable (sensitivity analysis). The resulting solutions for each weight group are rated. The most stable alternative is the one that gets the highest grade (that is the lowest $L_p(x)$ value, most of the times).

The sensitivity analysis of the compromise programming is done in relation to the change of weights w_i, and the change of the parameter p.

The choice of solutions within acceptable limits, gives to the user the ability to select and apply a different solution that has been found as optimal in the absolute ranking. In the context of environmental and economic feasibility, the responsible bodies are invited to evaluate the proposed solutions and to identify and then adopt the optimal one [14].

The compromise programming algorithm [15], consists of two parts:

Part A: A trial compromise solution is defined.

1st Step: The table of the system in relation to the criteria is given as input:

$$\left| f_{ij} \right|_{Nxj}$$

2nd Step:The best b_i and the worst wor_i value are defined for the criteria functions from the table:

$$\left| f_{ij} \right|_{Nxj}$$

$$\mathbf{b_i} = \mathbf{best}(\mathbf{f_{ij}}), \quad \mathbf{j} \in \mathbf{J}, \; \mathbf{wor_i} = \mathbf{worst}(\mathbf{f_{ij}}), \quad \mathbf{j} \in \mathbf{J}, \; i = 1,\ldots\ldots\ldots N$$

3rd Step:The relative distances d_{ij} of the alternative solutions from the ideal point and the relation for the $L_p(x)$, are calculated.

$$d_{ij} = \left(\frac{b_i - f_{ij}}{b_i - wor_i} \right)^p \quad ,j = 1,\ldots\ldots.J, \text{ and } i = 1,\ldots\ldots\ldots N$$

$$L_p^j = \left(\sum_{i=1}^{N} d_{ij} \right)^{\frac{1}{p}} \quad , j = 1,\ldots\ldots..J \qquad (2)$$

where p ∈ Q, Q is asset of integers, usually (1,2,∞).

4th Step: The relation is defined

$$\min_{j \in J} L_P^j, \; \mathrm{p} \in \mathrm{Q} \qquad (3)$$

and the corresponding solution of the compromise programming x(p).

5th Step:The different compromising solutions are compared and especially the solutions $x_{(1)}$, $x_{(2)}$, $x_{(\infty)}$.

6th Step: The solutions are presented at the decision center.

Part B: A second repetition of the algorithm is executed only when the decision center will give weight coefficients for the criteria.

1st Step:

The data, the table $|f_{ij}|_{Nxj}$ and the weights w_i are imported. The process is repeated as in Part A (Steps 2 to 7), using in Step 3 the relation,

$$L_P^j = \left(\sum_{i=1}^{N} w_i^P d_{ij} \right)^{\frac{1}{P}} \; (4)$$

Application in the plain of Magnesia Prefecture: Criteria and alternative scenarios.

The criteria of the model mostly derive from sustainability indicators (economy-environment). The model includes in total seven criteria which all defined in relation to the irrigation network of the study area and are:

1. Profit (Net economic benefit).
2. Cost of Production of Agricultural Products.
3. Water (Crop water needs).
4. Working Hours (Human labor expressed in hours).
5. Subsidies (Common Agricultural Policy).
6. Distribution of the Products (Supply-Demand, Marketing).
7. Environment (Use of Agrochemicals: pesticides, fertilizers, etc.).

The way all the above criteria are combined in the formulation of the multi-criteria analysis model is determined by the general policy in the field of irrigated agriculture. Considering the political aspirations of the responsible body and the basic guidelines that society defines, both the objectives and weight coefficients of the analysis model are defined. At this point, it should be noted that the decision maker is not the farmer, but the enforcer who carries out the policy.

The scenarios that were created for the implementation of the multi-criteria analysis (Table 1) consist of a set of potential alternative scenarios, the boundaries of which are defined by the tolerances of the system, so that it can be characterized as sustainable as it has emerged from the previous study mentioned before.

Table no 1 : Scenarios of the use of Multi-criteria Analysis

	LAND USES (hectares)					
SCENARIOS	Cotton	Maize	Alfalfa	Industrial Tomato	Beets	TOTAL AREA
1	3050	3050	650	2500	300	9800
2	3650	2450	650	2750	300	9800
3	3650	2450	550	2750	450	9800
4	3650	2450	800	2750	200	9800
5	2450	3650	650	2600	450	9800
6	3650	2450	550	2850	300	9800
7	2450	3650	800	2650	300	9800
8	2550	3650	550	2750	400	9800
9	3650	2450	800	2600	300	9800
10	3650	2500	650	2850	200	9800

These scenarios will be evaluated and classified in the order of preference by applying the Compromise Scheduling of Multi-criteria Analysis, based on the criteria that were defined above and the weights that were defined by the research team.

These ten (10) scenarios are essentially ten (10) different crop restructures for that area. The whole area of all the scenarios was set to be the average of the total cultivated irrigated area of the last five (5) reference years.

Each scenario differs from the other in the percentage of participation of each crop in that irrigation network. This difference was chosen to be about 10% to 30% for each crop, in order to be considered sustainable and reasonable, based on the results of the previous study. Therefore, the resulting scenarios differ in the percentage of participation of each crop and this creates a different result (application) of each criterion, for each scenario that should be calculated.

Criteria calibration and weight factor calculation: The evaluation of each criterion was made with the use of calibration which was introduced by Saaty (1980) and according to which the criteria are calibrated on a scale (1~9). The worst grade is one (1) and the maximum is nine (9). Table 2 shows this calibration.

Table no 2 : Fundamental scale by Saaty (1980)

Numerical calibration	Reasonable calibration
9	Excellent preference
8	Vigorously excellent preference
7	Very strong preference
6	Strongly highly preferred
5	Strong preference
4	Moderately strong preference
3	Moderate preference
2	Almost moderate preference
1	Almost preferred

Saaty[16] developed a procedure that determines the scale of the ratio of interest for a set of p values, based on pairwise comparisons. Assuming that there are p criteria (objectives and constraints) and there is a desire to construct a scale, which rates these criteria in terms of their importance (interest) in relation to the decision, then the decision maker will compare these criteria in pairs.

In the compromise programming algorithm, which works in a Visual Fortran environment, the following terms are used [9]:
withw_i the weights are symbolized.
withλ_i the weights are symbolized by the method of Shannon.
with AMAX the best value for each criterion is symbolized.
with AMIN the worst value for each criterion is symbolized.
with p the damage-compensation factor is symbolized.

Table D(I,J) describes the normalized distance between the best and the current value and is calculated by the following equation:

$$D(I,J)=\left(\frac{AMAX-F(I,J)}{AMAX-AMIN}\right) \quad (5)$$

The normalized distance is so defined as to bypass unit problems (compatibility). With L_p the norm of the deviation of different solutions from the best one is symbolized. In the compromise programming the calculation of distance in a one-dimensional table is given by the following equation:

$$L_P=\left[SUM\left(w_i^P * D(I,J)^P\right)\right]^{\frac{1}{P}} \quad (6)$$

or

$$L_P=\left\{\sum_{i=1}^{m}\left(w_i^P * d_i^P\right)\right\}^{\frac{1}{P}} \quad (7)$$

When data is in the registry format of w = w_{ij} and d = d_{ij} then the equation is converted to the following form:

$$L_p(s_j)=\left\{\sum_{i=1}^{m} w_i^p d_{ij}^p\right\}^{\frac{1}{p}}, \quad j = 1,2,\ldots\ldots n \quad (8)$$

where j are the scenarios and i are the criteria.

As it can be seen from the above equation, the L_p deviation is only an extension of the Pythagorean theorem (p is not limited only in the 2 value), using additionalweights.Then, in the program the tables of the weights are defined. Saaty, entropy methods and the rest of the data were used, the data was read and$L_{p(J)}$ deviation was calculated for p=1,2 and ∞ values, which are also the most important values for p. The alternative solution, whose sum of distances from the optimal solution, for the various w_i and p, is the smallest, is considered to be the best. Namely, the scenario with the smallest L_p is the proposed one.The w_i are the weights that were generated by Saaty's method [17] (Table 3). According to Yager[18], the determination of the intensity of interest is based on Saaty's theory [17].

Table no 3 : Final weights w_i by Saaty (1980).

W =

PROFIT	0,224
COST	0,029
WATER	0,265
WORKING HOURS	0,020
SUBSIDIES	0,081
DISPOSAL	0,111
ENVIRONMENT	0,270
SUM.	1,000

III. Results

The implementation of compromise programming in this specific research was conducted with the "Compromi" program, which operates in Visual Fortran environment. As a final result, the compromise programming allows finding the optimal solution and the scenario prioritization (alternative crop restructuring proposals) in the study area. This allows the decision maker to carry out a rational planning for the area.

The aim was to find the "optimal scenario" in a set of criteria among ten (10) alternatives. In Table 4 the optimal scenarios are presented among the ten (10) alternatives, according to the results of compromise programming for the calculation method of the preference weights of the Saaty criteria for Lp_1[19]. The classification order starts from the most preferred and the next two least preferred ones follow (01-03). Also in Table 4 the three last preferred scenarios (08-10) are presented in a rank order of the whole ten (10) for all of the criteria.

Table no 4: Classification of scenarios with subjective criteria [17].

CLASSIFICATION	SCENARIO	COTTON(ha)	MAIZE(ha)	ALFALFA(ha)	INDUSTRIAL TOMATO(ha)	BEETS(ha)	Lp_1
01	10	3650	2500	650	2850	200	0,084
02	4	3650	2450	800	2750	200	0,156
03	6	3650	2450	550	2850	300	0,172

10	8	2550	3650	550	2750	400	0,839
09	5	2450	3650	650	2600	450	0,778
08	7	2450	3650	800	2650	300	0,738

IV. Conclusions

The results showed that the optimal scenario of crop restructuring in the plain of Magnesia prefecture for all of the criteria, is the scenario that refers to the superiority of cotton crop and is proposed to cover 3650 ha (scenario 10). Then, industrial tomato and maize crops that cover 2850 ha and 2500 ha respectively, as well as alfalfa crops with 650 ha and beet crops with 200 ha follow. The least preferred scenario of the 10 available is: cotton 2550 ha, industrial tomato 2750 ha, maize 3650 ha, alfalfa 550 ha and beets 400 ha (scenario 8).

Comparing the final optimal scenario of the multi-criteria analysis, namely the values of the crop areas that have been proposed, with the average crop prices of the five year reference period of the study area, a big difference between the proposed and the existing situation can be seen. The crop restructuring that is proposed by the present study in relation to five-years average reference period is shown in Table 5.

Table no 5: Optimal scenario and current situation of Local Land Improvement Organization ofPinios.

CULTIVATIONS	OPTIMAL SCENARIO (ha)	EXISTING SITUATION (ha)
COTTON	3650	5890
MAIZE	2500	1750
ALFALFA	650	1622
INDUSTRIAL TOMATO	2850	341
BEETS	200	145

The wrong choice of most producers, in this study area, who cultivated cotton more in than the half area (60%) driven by the subsidies mainly, is being identified. Even with this option, they were damaged both financially and environmentally by exhausting the precious natural resource that is called water.

Compared to the current situation, it is proposed to reduce the area of cotton cultivation by almost half. Respectively, it is proposed to increase the cultivation area of the corn by 750 ha, almost eightfold of the cultivation area of the industrial tomato, and increase the cultivation area of sugar beets per 25%. The cultivation area of alfalfa should be decreased by 100 ha.

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