The 7th Balkan Conference on Operational Research
"BACOR 05"
Constanta, May 2005, Romania

WATER RESOURCES PLANNING USING THE AHP AND PROMETHEE MULTICRITERIA METHODS: THE CASE OF NESTOS RIVER - GREECE

K. P. ANAGNOSTOPOULOS
Dept. of Production and Management Engineering, Democritus University of Thrace, Xanthi, Greece

C. PETALAS
V. PISINARAS
Dept. of Environmental Engineering, Democritus University of Thrace, Xanthi, Greece

Abstract
In this paper four alternative irrigation projects for the East Macedonia-Thrace District are evaluated. The projects goal is the rational water resources management of Nestos River in relation to the operation of two recently constructed dams. The management of the water supply system should balanced the needs for irrigation, the needs of the Public Electrical Corporation for hydropower generation, as well as environmental requirements given the presence of valuable natural ecosystems in the area. In order to evaluate the projects, the Analytic Hierarchy Process (AHP) and PROMETHEE multicriteria methods are used. The projects evaluation is based on economic, social, environmental and cost criteria. Alternative scenarios on the availability of water resources are also incorporated in the model.

Keywords: AHP, multicriteria evaluation, PROMETHEE, water resources planning

1. INTRODUCTION

This work is referred to evaluation of alternative irrigation projects in the greek part of the Nestos River catchment aiming to the satisfaction of the water demands within the Prefectures of Kavala, Drama and Xanthi of the East Macedonia-Thrace District. The issue of sustainable management of waters of Nestos River arises from the operation of

two recently constructed hydroelectric dams in the region, namely Thesauros and Platanovrisi dams. The management of the water supply system should balanced the needs for irrigation, the needs of the Public Electrical Corporation for hydropower generation, as well as environmental requirements given the presence of valuable natural ecosystems in the area.

Water management covers a wide range of activities, in which technical, economic, environmental and social issues are involved. Since several groups with divergent interests are also concerned in determining the public resources management, human value and judgment systems are parts of the decision problem. Therefore, the elements to be considered in designing an efficient strategy are numerous, and their relationships are extremely complicated and highly nonlinear. Given the complexity of the decision process, much attention has been paid to multiple criteria decision-making (MCDM) approaches in order to enhance the ability to make sound decisions in water resources management: river basin planning problem [10, 19], hydropower operation [5], groundwater planning problems [6], irrigation planning [14], the choice of alternative investment options that best satisfy the national objectives relevant to the water sector in Jordan [1], and the evaluation of water management strategies with respect to their ecological effects on the surface water system [18].

Many MCDM methods have been proposed in the literature. Unfortunately, there is no method for choosing among them the most appropriate for a given decision problem, the choice remaining a subjective task. Furthermore, each method may product different rankings [11]. Given these drawbacks, it is suggested the use of more than one MCDM method in order to enhance the selection process [6].

The evaluation of the irrigation projects in this study was based on a multicriteria analysis carried out via two multicriteria methods: the *Analytic Hierarchy Process* (AHP) [15, 16, 17] and the PROMETHEE method [2, 3, 4]. The application of the methods was supplied by data deriving from a Ministry of Agriculture study [12] as well as from a recent study realized by Democritus University of Thrace [7], in which the economic, social, and environmental characteristics of the region are fully analyzed. The necessary computations were realized with *Expert Choice* 9.0 and *Decision Lab*, two software packages developed for AHP and PROMETHEE methods respectively.

The rest of this paper is organized as follows. In section 2 the Nestos river and the irrigation area are described. In the next section the two methods are presented. In section 3.1 after a brief presentation of the AHP, the decision hierarchy is presented and the hierarchies evaluation is analyzed. In section 3.2 we describe briefly the PROMETHEE method and the evaluation and ranking are presented. The last section contains the conclusions.

2. THE NESTOS RIVER AND THE IRRIGATION AREA

The population of the three prefectures of Kavala, Drama and Xanthi comes up to 323,554 people (fig. 2.1). The catchment's area which is 5,184 km^2, belongs partially to Bulgaria (2,872 km^2 or 55% of the catchment) and partially to Greece (2,312 km^2 or 45% of the catchment). The topography of the main part of the Nestos catchment is an alternating sequence of valleys and ridges, except the Nestos Delta plain. As far as the geology of the catchment area is concerned, the mountainous part of the Nestos

catchment consists of metamorphic rocks (marbles, gneisses, schists), igneous rocks and deposits of quaternary to recent age. According to the Thornthwaite climatic classification, the climate type of the topographically low areas is C2sB2b3 (Mediterranean climate) and that of the topographically high areas is C1dB'2b'4 (middle European climate).

The average annual precipitation of the study area is 760 mm and ranges from 521 to 1019 mm during the period 1964-1998. A severe drought period with annual precipitation well below-normal precipitation was observed during the period 1986-1996. According to the available data another severe drought period is possibly in progress.

The water of the Nestos River is generally of good quality. The average annual discharge of the river downstream of the Dams, for a long period (1965-66/1995-96) is 1039.4×10^6 m^3 and that for the drought period (1986-1996) is 757.9×10^6 m^3. Watershed and riverine system of the Nestos River, including wetlands, streams, riparian zones, and aquifers, provide critical support for ecosystems as well as producing and delivering water supplies for human use. Preserving this natural water system is the key to sustainable development. Riverine systems need a comprehensive approach–sort of a "total river management program". Every management action should strive for ecological integrity in the Nestos watershed and riverine system management.

The greek part of the Nestos River basin downstream of the Dams constitute a very complex water system and follows a course through a karstic region. The reach of the river from Paschalia to Toxotes lies almost exclusively on karstified rocks. Along this reach a complex and potential karstic aquifer system is developed. This groundwater system is interconnected in part with the surface system of the river. A great number of karstic springs are discharged into the stream along the Rivers' course. The relationship between the surface system and the groundwater system has not been adequately studied since most of the karstic springs developed along the course of the river are not visible. In any case, it is evident that considerable quantities of the flow of the river recharge the karstic groundwater system. Also, this vast reservoir sustains stream flows during precipitation free periods and is the principal source of freshwater during the drought periods.
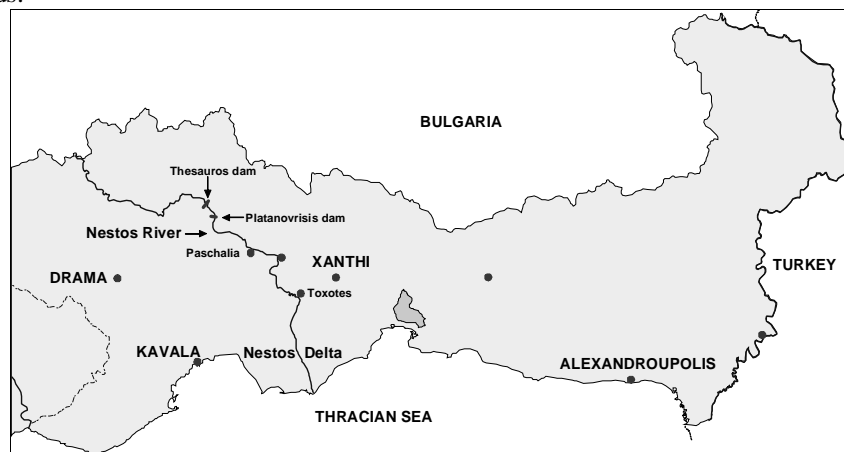

Figure 2.1 The Nestos River and the study area

After Toxotes, the River flows, down to the sea, through a plain area, namely the Nestos River Delta plain, consisting mainly of deltaic deposits of considerable thickness. The river even in this reach losses a significant part of its flow, namely 84.4 millions cubic meters of water per year, to recharge the porous aquifer system developed in this area. This aquifer system partially is recharged from the downward percolation of precipitation. Up to now the great part of the delta groundwater system is normally exploited. Problems such as seawater intrusion into coastal aquifers are arised near the coast, especially in the east part of the Nestos Delta, due to overexploitation. Up to now, the Nestos River serves the irrigation of a significant part of the Delta area by using a surface water supply system. The system obtains water directly from the River through a diversion system near Toxotes.

The annual distribution of irrigated water supplied by this system is about 200 millions cubic meters. The operation of the Dams will certainly affect at least partially the recharge regime of both aquifer systems in the area downstream of the dams. So becomes evident that it is necessary the application of whatever water management program in this area to take into account the possible adverse impacts on the natural environment. An instream flow or environmental flow of 6 m^3 per second was designed to enhance or maintain the habitat for riparian and aquatic life.

Two recently constructed dams have dramatically modified the hydrologic regime of the river through storage of water during high-runoff periods for later release when demands are higher. "Peaking power" hydroelectricity production imposes also an "on-off" pattern on the natural flow regime as turbines are quickly brought on-line to supplement daily electricity requirements during peak-demand periods. The annual working or sometimes called useful storage capacity of the two dams are 565×10^6 m^3 (Thesauros dam) and 63×10^6 m^3 (Platanovrisi dam) respectively, meanwhile the power electric generation capacity for the two dams is 692 Gwh/annum. The minimum water-level of operation for Thesauros dam is +320 m or a working storage capacity of about 137×10^6 m^3. Approximately 40,000 hectares of the study area are irrigated from the Nestos River water. The average annual inflow from the Bulgarian part of the catchment will be according to a Greek-Bulgarian agreement 435×10^6 m^3, on the basis of the runoff of the period 1935-1970. This amount constitutes only 42% of the total average annual inflows into the Dams of the period 1980-1995, but in fact the inflows from the Bulgarian part of the same period exceed 59 % of the total average annual inflows (605×10^6 m^3). Dams typically affect both the hydrology and channel morphology of the regulated stream. Regulation results in a reduction of peak flows, which reduces the ability of the stream to carry sediment. Flow regimes can also be altered through regulation, in terms of the duration of flows of a given magnitude, the total annual discharge, flow variability, or the frequency of flood peaks [8]. The altered flow regimes can influence oxygen levels, temperature, suspended soils, as well as having direct impacts on biota.

3. EVALUATION OF PROJECTS
3.1 CRITERIA AND ALTERNATIVES

The evaluation model consists of three alternative scenarios on the future availability of water resources and four criteria broken down into subcriteria. Four projects are to be evaluated.

Precipitation scenarios. Three alternative scenarios on the future availability of water resources are incorporated in the model. The scenarios are based on the rainfalls of the period 1964-1998 for which data are available. In scenario 1 (normal prospect) it is considered that the future availability of water resources will essentially remain the same with that of the period 1964-1998. In scenario 2 (optimistic prospect) it is considered that the average annual precipitation will be similar to that of the period 1964-1998 excluding the years of the drought period. This average exceeds too much the average of the period 1964-1998. In scenario 3 (pessimistic prospect) it is considered that the average annual precipitation will be similar to that of the period 1964-1998 excluding the years of the wet period. It must be noted that in the evaluation process the probability the scenario 2 to be realized is considered to be very small.

Economic. In the economic criteria, the increase in rural income and in employment are included, as well as the positive side effects that will result from the increase in rural production and incomes. The water supply is expected to have important direct economic repercussions in the primary sector and indirect in the rest of the economy of region. However, we consider excessive the estimates for the anticipated increase in rural income and in employment that are given in [12]. The possibility for dynamic crop production, the increase in livestock capital and the build up of processing industries are encouraged also from the improvement of infrastructures.

Social. The more the increase in incomes and in possibilities for employment the more the improvement in the quality of life of inhabitants and the less the urbanization in the region.

Environmental. The construction of new reservoirs is often registered by members of the public because of side effects that are considered to be negative. Some of these side effects are [9]. If water is diverted directly from the stream, the reduction in downstream flow will have the same ecological consequences as a diversion for any other purpose that results in a reduction in streamflow with the same timing and quantity [13]. Ecosystems (especially the riparian ones) can be changed because the schedule of water release and the quality of the water can be altered. The flow of the karstic springs of the study area supported by the river flow recharge will be considerably altered (mainly reduced). In the coastal area the decreased flows of the stream might help maintained more variable salinity conditions and to counter sharp seasonal migration of the freshwater-saltwater interface in the stream channel and of the coastal aquifers (reduced recharge). Consequently, the reduced streamflow could result in undesirable changes to wetland environments and to salinity conditions of the Nestos' estuary. The serious decline of ground water levels will increase subsidence especially in the areas were the artesian aquifers are present.

Cost. The financial cost includes the cost of the initial investment, the maintenance and administrative costs after the realization of the project and the financial consequences by abandoning or downgrading current activities.

The alternatives. Four projects are evaluated. Project A: It includes the Drama plain up to the contour line of +100, the Nestos Delta-Xanthi plain, and the rest of Kavala's agricultural land. Project B: It includes the Drama plain up to the contour line of +160, and the Nestos Delta-Xanthi plain. Project C: It includes the Drama plain up to the contour line of +160, the Nestos Delta-Xanthi plain, and the rest of Kavala's agricultural land. Project D: It includes the Drama plain up to the contour line of +100, and the Nestos Delta-Xanthi plain. The net irrigated areas, after the completion of the projects, will be equal respectively to 107,400, 113,400, 119,300 and 101,500 hectares.

3.2 THE ANALYTIC HIERARCHY PROCESS

AHP is a systematic procedure for dealing with complex decision-making problems in which many competing alternatives (projects, actions, scenarios) exist [15, 16, 17]. AHP is based on a hierarchical structuring of the elements that are involved in a decision problem. The hierarchy incorporates the knowledge, the experience and the intuition of the decision-maker for the specific problem.

The hierarchy evaluation is based on pairwise comparisons. The decision-maker compares two alternatives A_i and A_j using a criterion and assigns a numerical value to their relative weight. The result of the comparison is expressed in a fundamental scale of values ranging from 1 (A_i, A_j contribute equally to the objective) to 9 (the evidence favoring A_i over A_j is of the highest possible order of affirmation). Given that the n elements of a level are evaluated in pairs using an element of the immediately higher level, an $n \times n$ *comparison matrix* is obtained.

A comparison matrix is consistent if and only if $a_{ij} \times a_{jk} = a_{ik}$ for all i, j, k. AHP measures the inconsistency of judgments by calculating the *consistency index* CI of the matrix $CI = \dfrac{\lambda_{\max} - n}{n-1}$, where λ_{max} is the principal eigenvalue of the matrix.

The consistency index CI is in turn divided by the *average random consistency index* RI to obtain the *consistency ratio* CR = CI / RI. The RI index is a constant value for an $n \times n$ matrix, which has resulted from a computer simulation of $n \times n$ matrices with random values from the 1-9 scale and for which $a_{ij} = 1/a_{ji}$. If CR is less than 5% for a 3×3 matrix, 9% for a 4×4 matrix, and 10% for larger matrices, then the matrix is consistent.

Once its values are defined, a comparison matrix is normalized and the local priority (the relative dominance) of the matrix elements with respect to the higher level criterion is calculated. The overall priority of the current level elements is calculated by adding the products of their local priorities by the priority of the corresponding criterion of the immediately higher level. Next, the overall priority of a current level element is used to calculate the local priorities of the immediately lower level which use it as a criterion, and so on, till the lowest level of the hierarchy is reached. The priorities of the lowest level elements (alternatives) provide the relative contribution of the elements in achieving the overall goal.
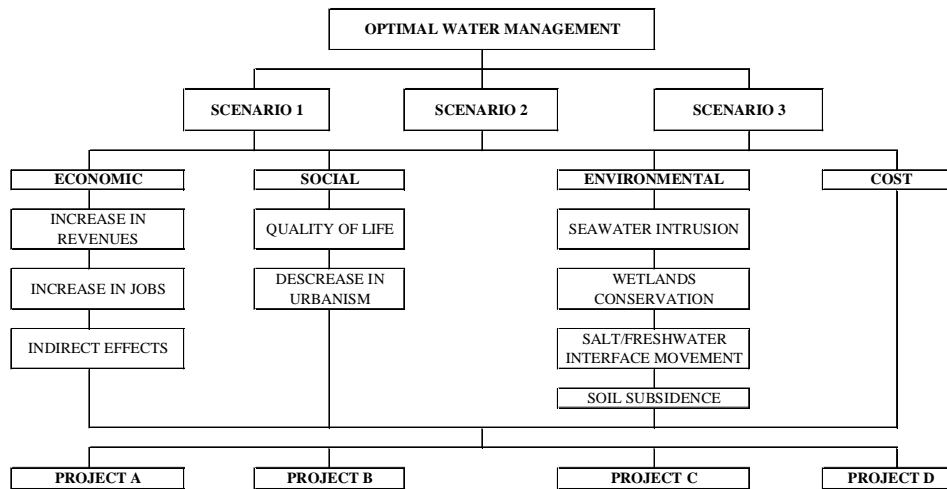
Figure 3.1 The hierarchy of the evaluation problem

3.2.1 THE DECISION HIERARCHY

A hierarchy including the parameters involved in the problem is formed. For every project a priority will occur from this hierarchy, based on their contribution to the overall goal. The hierarchy is articulated into five levels (figure 3.1): On the first level lies the overall benefit from the realization of the projects, as the main goal of the hierarchy. On the second level lie the scenarios on the future availability of water resources. On the third level the economic, social, environmental and cost components are included. On the fourth level lie the subcriteria of the third level components in order to give a more detailed description of the problem, so that the study will acquire a more overall view of its comprising parameters. On the fifth level the four projects to be evaluated are included.

3.2.2 HIERARCHIES EVALUATION

Afterwards the evaluation of parameters of hierarchy, the inconsistencies in the judgements were checked and only insignificant changes were required for the re-establishment of consistency in judgements. In table 3.1 some local and composite priorities resulted from the treatment of judgements in the Expert Choice are given. The contribution of scenario 1 in the achievement of the overall goal is 64.8%, while of the scenarios 2 and 3 are respectively 12.2% and 23%.

The economic subcriteria for the hierarchy acquire the priorities of 0.101, 0.674 and 0.226, with respect to the economic criterion, and 0.065, 0.437, 0.146 with respect to their contribution to the overall goal of the hierarchy. Similarly, the social subcriteria for the hierarchy are evaluated with priorities of 0.181, 0.729 and 0.09 with respect to their contribution to the social cost and with 0.037, 0.151 and 0.019 with respect to their contribution to the overall goal.

The final priorities for projects A, B, C and D in the achievement of the overall goal are respectively 19.2%, 22%, 28.4% and 30.4%. It must also note that the sensitivity analysis has proved the stability of the priorities for small changes in judgments.

3.3 THE PROMETHEE METHOD

In our study the PROMETHEE and GAIA methods are also applied in order to evaluate the four irrigation projects for the Nestos region. The family of PROMETHEE methods belongs to the outranking multicriteria methods. GAIA is a visual modeling method associated to the PROMETHEE methods [1, 2, 3, 4]. The basic principles of the PROMETHEE methods are the extension of the notion of criterion, i.e. the valued outranking relation, and the exploitation of the outranking relation. Let A be the set of the n projects that are evaluated through k criteria $f_1 \cdots f_k$. The PROMETHEE methods include the three following steps:

	LOCAL PRIORITIES			COMPOSITE RELATIVE PRIORITIES		
SCENARIOS	SCEN 1	SCEN 2	SCEN 3	SCEN 1	SCEN 2	SCEN3
	0.648	0.122	0.230	0.648	0.122	0.230
CRITERIA						
ECONOMIC	0.435	0.374	0.549	0.282	0.045	0.125
SOCIAL	0.071	0.066	0.065	0.046	0.008	0.015
ENVIRONMENTAL	0.227	0.113	0.279	0.147	0.014	0.064
COST	0.267	0.448	0.107	0.173	0.055	0.024
SUBCRITERIA						
INCREASE IN REVENUES			0.630	0.178	0.029	0.080
INCREASE IN JOBS			0.218	0.061	0.010	0.028
INDIRECT EFFECTS			0.151	0.043	0.007	0.019
QUALITY OF LIFE			0.750	0.035	0.007	0.011
DESCREASE IN URBANISM			0.250	0.012	0.006	0.004
SEAWATER INTRUSION			0.566	0.098	0.031	0.014
WETLANDS CONSERVATION			0.112	0.019	0.006	0.003
SALT/FRESHWATER INTERFACE MOVEMENT			0.266	0.046	0.015	0.007
SOIL SUBSIDENCE			0.055	0.001	0.003	0.001

Table 3.1 Results of the hierarchy

1. The generalized criteria. A generalized criterion is associated to each criterion in order to take into account the deviations and the scales of the criteria. For this purpose the (normalized) preference function *P(a,b)* giving the degree of preference of project *a* over

project b for criterion f is defined as a function of the deviation $d = f(a) - f(b)$. Figure 3.2 illustrates the typical non-decreasing function $H(d) = P(a,b)$, $d \geq 0$ for a criterion f to maximize. In order to facilitate the choice of a generalized criterion, six types of functions that cover most of the cases occurring in practical applications are proposed in the literature [3,4]. For each generalized criterion, at most two parameters have to be identified by the decision-maker.

2. Outranking relation. A multicriterion preference index $\pi(a,b)$ of project a over project b taking into account all the criteria is defined as follows:

$$\pi(a,b) = \sum_{j=1}^{k} w_j P_j(a,b), \quad \sum_{j=1}^{k} w_j = 1 \ and \ w_j > 0$$

The preference index $\pi(a,b)$, varying from 0 to 1, expresses how and to which degree project a is preferred to project b, and a preference index $\pi(a,b)$ how b is preferred to a, over all the criteria.
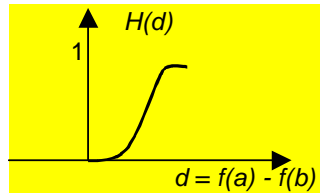

Figure 3.2 Preference function

3. Exploitation for decision aid. Regarding the exploitation of the outranking relations for the ranking of projects the following two preference flows are defined:

1. *The positive outranking (leaving) flow*, expressing how much the project a is outranking all other projects:

$$\phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x)$$

2. *The negative outranking (entering) flow*, expressing how much the project a is outranked by all other projects:

$$\phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x,a)$$

Based on the values of flows, the PROMETHEE I method provides a partial preorder on the set of possible actions (projects). The PROMETHEE II provides a total preorder on the set of possible actions (projects) based on the values of the net outranking flow:
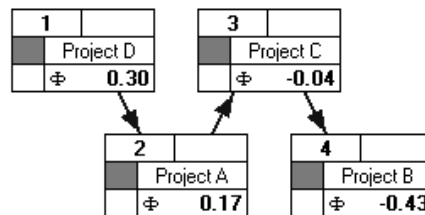
$$\phi(a) = \phi^+(a) - \phi^-(a).$$

Figure 3.3 The complete ranking under the all scenarios hypothesis

3.3.1 EVALUATION AND RANKING

For the evaluation of projects using the PROMETHEE method, larger values of weights are associated to economic criteria (especially to cost, increase in revenues criteria and increase in jobs) and to environmental criteria (especially to sea water intrusion criterion) and smaller values are associated to social criteria. The U-shape is used as the preference function for the economic and social criteria, and the level function for the environmental ones. In both cases, a five qualitative scale within the range one to five is used for each criterion.

The figure 3.3 illustrates the complete ranking under the all scenarios hypothesis. Based on the net preference flows, the projects D and A are clearly the best ones. It must be noted that the net preference flows are 0,29, 0,16, -0,01 and -0,43 for the projects D, A, C and B respectively under the normal scenario, and the same ranking is also obtained under the two others scenarios considered separately. Finally, the weight stability intervals −determining for each criterion the limits within which its weight can be modified without changing the PROMETHEE II complete ranking− are very large.
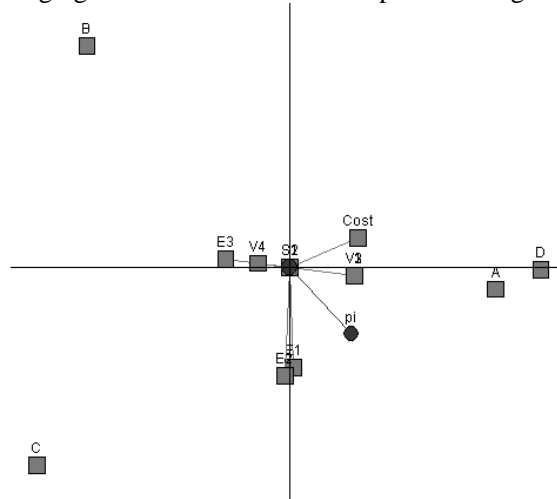

Figure 3.4 The GAIA plane

In figure 3.4 the GAIA plane is represented (see [2] for a description of the GAIA decision support system). The short names of the criteria are as follows: E1-Increase in Revenues, E2-Increase in Jobs, E3-Indirect Effects, S1-Quality of Life, S2-Descrease in Urbanism, V1-Seawater Intrusion, V2-Wetlands Conservation, V3-Salt/Freshwater Interface Movement, V4-Soil Subsidence. The *pi* decision axis representing the weighing of the criteria shows the compromise that corresponds to the current weights. The orientation of the *pi* decision axis is due mainly to the weights of cost, increase in revenues, increase in jobs and seawater intrusion criteria. The Δ value −a measure of the quality of the GAIA display − equal to 98.75, is very adequate.

4. CONCLUSION

The issue of sustainable management of waters of Nestos River arises from the operation of two recently constructed hydroelectric dams in the East Macedonia-Thrace region. The needs for irrigation and hydropower generation, and environmental requirements have taken into account in order to evaluate four alternative irrigation projects. The projects have evaluated using several criteria via the *Analytic Hierarchy Process* and the PROMETHEE methods. The application of the methods has been based on a Ministry of Agriculture study as well as on a recent study realized by Democritus University of Thrace in which the economic, social, and environmental characteristics of the region are fully analyzed. It must be noted, however, that qualitative judgements were inevitable given the lack of data for solid quantitative analyses.

The final ranking of the projects via the PROMETHEE method are similar to the ranking that has been obtained by the application of the AHP method. Moreover, the sensitivity analyses have been proved that both methods have provided very stable rankings. Given the subjectivity of decision makers judgements, these results are a satisfactory indication that the chosen project is the best one.

In any case, the realized analysis, the intermediate results and the final ranking of the projects constitute a solid contribution to the decision making. Although the authors of this paper have a slight preference for the AHP method, both methods have advantages and disadvantages. Therefore, the use of both methods has enhanced the selection process. As a final word, we think that the essential gain of the application of multicriteria methods is the rationalization of the decision making process, especially in administrative contexts in which the decision making, traditionally and exclusively, is based on the 'intuition' of decision makers.

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