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COMPARATIVE EVALUATION OF WATER COLLECTION METHODS USING MULTICRITERIA DECISION MAKING ANALYSIS

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Abstract

The necessity for the improvement and change of the way to collect water is of great need, especially nowadays that water tends to become a limited natural resource. The aim of this project is to study and evaluate an alternative water collection method, the artificial recharge, and compare it with the conventional established method of dam construction. The evaluation tool is a Multi-Criteria Decision Making Analysis. Multi-Criteria Analysis evaluates these two methods based on certain common criteria. More precisely, each method is examined multi-dimensionally, so that all aspects and possible problems of the application of these methods are studied.

Key words: *water collection method, artificial recharge, dam construction.*

Περίληψη

Η ανάγκη για βελτίωση των μεθόδων συλλογής ύδατος είναι ιδιαίτερης σημασίας, κυρίως σήμερα που αυτό τείνει να γίνει ένα στοιχείο με περιορισμένες φυσικές πηγές. Στόχο της παρούσας εργασίας αποτελεί η μελέτη και η αξιολόγηση της τεχνητής επαναπλήρωσης, μίας εναλλακτικής μεθόδου για τη συλλογή ύδατος και η σύγκρισή της με τη συμβατική καθιερωμένη μέθοδο κατασκευής φραγμάτων. Εργαλείο αξιολόγησης αποτελεί η ανάλυση ανάλυσης αποφάσεων πολλαπλών κριτηρίων, η οποία αξιολογεί τις δύο μεθόδους, με βάση ορισμένα κοινά κριτήρια. Η κάθε μέθοδος εξετάζεται πολυδιάστατα, έτσι ώστε να διερευνηθούν όλες οι πτυχές και τα πιθανά προβλήματα.

Λέξεις κλειδιά: *μέθοδος συλλογής ύδατος, τεχνητή επαναπλήρωση, κατασκευή φραγμάτων.*

1. Introduction – The Multi-Criteria Decision Making Analysis

It's worldwide known that the natural resources, that are available to the human being, have been diminishing rapidly and water is the most significant one. Besides, it is also knowu that the climate is changing periodically, therefore there are several periods of drought of either longer or shorter duration. The drought that takes place in this period is called the "Sahel drought". Based on these general conclusions, it is obviously quite easy to understand that it is imperative to constantly improve the water collection methods. During that process, one has to take into consideration all the

† Dimitris passed away on 10/11/2003 after a road accident (16/10/2003), when he was just 31 years old.

environmental parameters that might be linked with the application of the proposed method. The aim of this project is to evaluate and examine holistically these two water collection methods – the widely familiar method of constructing a dam and the method of artificial recharge. Unfortunately, the latter one has not been widely known, since the occasions of its application are just a few. For this evaluation the method of Multi-Criteria Decision Making Analysis has been used.

Generally, Multi-Criteria Analysis is a very important and powerful tool which has a wide application in environmental management problems and provides the optimal solution. In most cases the finding and the evaluation of the optimal solution is a complicated process. A one dimensional study of a problem does not lead to the best possible solution. Therefore, it is necessary to examine a problem based on certain common criteria. It is significant to choose the most appropriate criteria in order to draw the best possible conclusions. The type of criteria depends: (a) **directly** on the kind of problem which is going to be solved and on its special features and (b) **indirectly**, since the specific problem is being influenced or influences the attitude of several groups which are interested and, maybe, they have got something in common with the application of the method. The simultaneous examination of various alternative or suggested scenarios, based on certain properly chosen criteria, which aim at the best possible solution, is the Multi-Criteria Analysis.

2. Criteria Selection and Classification

The selection of these criteria should be:

- Complete multi dimensional in other words the criteria should examine the problem from all different aspects.
- Functional, meaning that all the criteria should be graded with specific for each alternative scenario grading and be classified in a specific scale of grades.
- Done in such a way to avoid contradiction between criteria.

The criteria which have been selected for the examination and the comparison of the final choice of the water collection method are classified into four groups and are the following:

1. **SOCIAL CRITERIA**

i) Social Approval

ii) Concordance with the existing Legislation

iii) New Jobs opportunities

iv) Application of possible Legislative Priorities

2. **ENVIRONMENTAL CRITERIA**

i) Environmental consequences

ii) Aesthetics

iii) Potential Dangers

3. **FINANCIAL CRITERIA**

i) The Initial Cost of the Project

ii) Operational Cost –Maintenance Cost

iii) Land/Property Requirements (Land acquisition cost)

4. **FUNCTIONAL AND TECHNICAL CRITERIA**

i) Functionality

ii) Life Span

iii) Existing Experience – Reliability

iv) Adjustability to Local Conditions

v) Flexibility

Further on, there is a detailed description of all the above mentioned criteria of each group.

2.1. A Detailed Description of Each Group's individual Criteria

2.1.1. Social Criteria

These criteria evaluate the relationship and the impact of each suggested method on the society of the region where it is applied.

i) Social Approval

It is a very important criterion for each method of making decisions. The social approval of each suggested method depends on several factors, such as the existing water collection method, the level of awareness of the inhabitants about the environmental problems and especially those problems that deal with the lack of water.

ii) Concordance with the Existing Legislation

By this criterion any existing legislation of the National Planning is taken into consideration as well as the one of the European Union concerning the application of water collection methods. More specifically, in our situation it is the 75/440 Directive of the E.U. concerning the required quality of the surface water which is going to be used for the abstraction of drinking water in the member-states, as well as the voting of the Council of the 25th February 1992 for the future policy concerning the underground water.

iii) Application of Possible Legislative Priorities

Based on this criterion we can examine how, through the application of suggested water collection methods, any Legislative Priorities take place which are dictated by not only the National Planning, but also by E.U legislation.

iv) New Jobs opportunities

The possibility of creating new jobs opportunities is a basic social criterion for the final choice of the suggested applications, moreover when we refer to semi-urbau and rural regions.

2.1.2. Environmental Criteria

These criteria deal with the question directly, which of the methods being examined has a minimum environmental impact. It should be mentioned that this question has got two parameters:

- One parameter has to do the direct impact of the project on the environment.
- The other parameter has to do with the possibility of operational malfunction.

i) Affecting the Environment

This criterion basically examines which of the two suggested methods has the minimum environmental impact.

ii) Aesthetics

The aesthetic alterations of the local scenery, caused by the development and function of the suggested methods make up a criterion of great significance which depends on the design of the method. This criterion is directly related to the 2i criterion (Affecting the Environment) as well as with the public opinion on the environmental efficiency of the method. The criterion of aesthetics usually becomes highly critical when auy construction takes place in heavily populated regions.

iii) Potential Dangers

This criterion examines the accident possibility factor and the danger factor concerning the exposure to danger of personnel and citizens of the region, while the method is operating, but it mainly refers to possible accidents or any possible malfunctions.

2.1.3. Economic Criteria

i) Initial (Capital) Cost of the Project

The criterion of the Initial Cost is one of the most critical in most environmental management problems. It becomes even more critical in those situations which part of the initial cost is shifted to the citizens, if the project is self financed.

ii) Operational Cost – Maintenance Cost

This criterion refers to all the expenses of operation and maintenance. This criterion is very significant for the final approval of the work because these expenses are substantially transferred to the inhabitants whom the work serves.

iii) Land/Property Requirements (Land acquisition cost)

This criterion is more significant to cases where there is either lack of land or the value of the land is very high (e.g. the islands).

2.1.4. Functional and Technical Criteria

The criteria of this group examine the functionality of the suggested scenarios as well as technical characteristics which are important for their normal and constant operation.

i) Functionality

Within this criterion the following are included and examined:

- Normal and constant operation.
- Demands of specialized personnel.
- Easy to maintain.
- Easy to operate.
- Durability of the suggested method.
- The expected time life of each method.

The "sum" of the above-mentioned factors defines the functionality of the method.

ii) The Existing Experience - Reliability

Any existing experience of the application of a corresponding method and system plays an important role to the evaluation of the suggested water collection methods. Especially when new methods are proposed (e.g. artificial recharge), it is important for their future adaptation and application.

iii) Adjustability to Local Conditions

The normal and successful function and application of each method depends directly on the suggested region's particular characteristics. All the physical-geological characteristics of the region should be included in the study.

iv) Flexibility

With this criterion every suggested method is being examined how it can adjust to possible changes of the quantities of water which it can accept. The criterion is very important wheu there are significant climatic changes influencing directly the annual water fluxes.

In a following chapter each criterion is analyzed according to each suggested scenario's special characteristics.

3. The System of Taking Decisions by using an Overall/ Holistic Function

Based on the above mentioned Multi-Criteria Decision Making System analysis, the comparative evaluation of the alternative scenario – choices takes place according to the following stages/steps:

- **1st Step**

In this first step, the groups of the criteria are set, where each group consists of a series of criteria which are described in the second step. Moreover, at this point the significance of each group of criteria is defined, which expresses the relevant meaning of each group for each examined scenario. Afterwards, based on the groups of the criteria and the corresponding significance of theirs, the final adding sequence is produced. The sum of the significance of each group of criteria is 100 %. It is quite understood that decision making using the multi-criteria analysis is quite subjective, since the significance of the criteria depends directly on the analyser. In the following table (Table 1) the factors of significance of each group of criteria are presented.

Table 1 - The Groups of Criteria and the Significance Factors

	Description	Significance Factor
OK_1	Social Criteria	0.25
OK_2	Environmental Criteria	0.30
OK_3	Economic Criteria	0.25
OK_4	Functional – Technical Criteria	0.20

Consequently, the overall/holistic function is the following:

$$f = 0.25OK_1 + 0.30OK_2 + 0.25OK_3 + 0.20OK_4$$

- **2nd Step**

In the second step the groups of criteria are "stripped down" to the special criteria they consist of, where by using the proper significance factors, the relevant significance of each criterion is defined. The sum of the significance of the criteria of each group is 100 %.

In Table 2, the special characteristics of each group are presented as well as the relevant significance of theirs, in the groups where they belong.

Table 2 - A Table of all the Special Criteria for the Evaluation of all the Alternative Scenarios

	Criteria
Criterion / Factor of Significance	SOCIAL – INSTITUTIONAL (0.25)
S_1 (0.25)	Concordance with the existing Legislation
S_2 (0.30)	Application of possible Legislative Priorities
S_3 (0.30)	Social Approval
S_4 (0.15)	New jobs Opportunities
	ENVIRONMENTAL (0.30)
EN_1 (0.40)	Environmental Impact
EN_2 (0.30)	Aesthetics
EN_3 (0.30)	Potential Dangers
	ECONOMIC (0.25)
E_1 (0.40)	Initial Cost of Investment

E_2 (0.40)	Operational Cost –Maintenance Cost
E_3 (0.20)	Land Acquisition/Property requirements
	TECHNICAL - FUNCTIONAL (0.20)
T_1 (0.30)	Functionality
T_2 (0.30)	Existing Experience – Reliability
T_3 (0.15)	Adjustability to the Existing Conditions
T_4 (0.15)	Flexibility
T_5 (0.10)	Life Span

- **3rd Step**

For each special criterion, initially an evaluation of its special characteristics takes place and afterwards it is marked on a scale from 1 to 10. The scenario which takes the highest marks is therefore the most desirable one.

3.1. Marking of All the Special Criteria

Further on, all the tables are presented according to which the marking of all the special criteria takes place.

SOCIAL – INSTITUTIONAL CRITERIA

S_1: Concordance with the existing Legislation

Complete Concordance	10
Partial Concordance	5
No Concordance due to lack of Legislation	5
No Concordance	1

S2: Application of possible Legislative Priorities

Complete Application	10
Partial Application	5
No Application	3
Opposite to the General Instructions	1

S_3: Social Approval

Complete Social Approval	10
Partial Social Approval	5
Social Approval due to lack of Environmental Awareness	3
No Social Approval due to lack of Environmental Awareness	3
(Unsocial) No Social Approval after the relevant Environmental Awareness	1

S_4: Opportunities for New Jobs

Opportunities for New Jobs at a high degree	10
Opportunities for New Jobs at a limited degree	5
No Opportunities for New Jobs at a high degree	1

ENVIRONMENTAL CRITERIA

EN_1: Environmental Impact

Maximum Environmental Impact	1
Moderate Environmental Impact	4
Minimum Environmental Impact	7

EN_2: Aesthetics

High Aesthetics	10
Relatively High Aesthetics	7
Moderate Aesthetics	4
Negative Aesthetics	1

EN_3: Potential Dangers

High Grade	1
Relatively High Grade	3
Low Grade	7
Negligible Grade	10

ECONOMIC CRITERIA

E_1: Initial Cost of Investment

High Initial Cost	1
Relatively High Initial Cost	3
Moderate Initial Cost	5
Low Initial Cost	8
Negligible Initial Cost	10

E_2: Functional Cost –Maintenance Cost

High Functional Cost	1
Relatively High Functional Cost	4
Moderate Functional Cost	7
Low Functional Cost	10

E_3: Land/ Property Acquisition

High Cost for Land acquisition	1
Relatively High Cost for Land Acquisition	3
Moderate Cost for Land Acquisition	7
Low Cost for Land Acquisition	10
Lack of Land	1

TECHNICAL – FUNCTIONAL CRITERIA

T_1: Functionality

High	10
Relatively High	7
Moderate	5
Low	3
Very Low	1

T_2: Existing Experience – Reliability

High	10
Relatively High	7
Moderate	5
Low	3
Very Low	1

T_3: Adjustability to Local Conditions

High	10
Relatively High	7
Moderate	5
Low	3
Very Low	1

T_4: Flexibility

High	10
Relatively High	7
Moderate	5
Low	3
Very Low	1

T_5: Life Span

Long Life Span >70 years	10
Average Life Span 30-70 years	5
Short Life Span <30 years	1

- **4th Step**

In the fourth step, initially all the characteristics of each special criterion are defined for every alternative scenario and afterwards each criterion is marked according to the tables which were formed in the previous step. This is described in the following tables. At this point we should make clear that the comparative evaluation of the two methods (artificial recharge and dam construction) takes place by taking into consideration those situations that the application of each method takes place under the most ideal conditions. That is, each method is examined either at several regions, or even at the same region, but in cases when the special characteristics of this region allow the successful application of both methods (e.g. the degree of karstification is so high that it allows the successful application of the artificial recharge).

Criteria of Comparative Analysis	ELEMENTS CONCERNING THE METHOD OF ARTIFICIAL RECHARGE	Grading
SOCIAL		
S_1: Concordance with the existing Legislation	There is complete concordance with the existing Legislation, as it is dictated by the voting of the Council of the 25th of February 1992 for the future policy concerning the underground water (95/C49/01).	10
S_2: Application of possible Legislative Priorities	Complete application of the Legislative Priorities of the voting (95/C49/01) of the European Council concerning the conservation and increase of quantity of the underground water.	10
S_3: Social Approval	The Social Approval is expected, provided that there will be constant cheek of the quality of the water for the recharge.	8
S_4: New Jobs Opportunities	While applying the method, new personnel of technical experts will be necessary, such as an operator, a supervisor, technicians for the change of the filters etc.	5
ENVIRONMENTAL		
EN_1: Environmental impact	Negligible environmental impact, therefore remediation of the natural environment is possible.	7
EN_2: Aesthetics	Affecting the environment, in general, is negligible and therefore the aesthetic intervention is also minimal.	8
EN_3: Potential Dangers	Due to the technique of the artificial recharge as well as the existence of immediate and constant technologically advauced supervision, the potential dangers are becoming less.	8

ECONOMIC		
E_1: Initial Cost of Investment	The initial cost for the application of the method of the artificial recharge is relatively low.	8
E_2: Functional Cost – Cost of Maintenance	The functional cost of the method consists of: the salaries of the personnel, energy costs as well as those concerning the maintenance of the whole construction, e.g. the change of a filter.	7
E_3: Land/ Property acquisition and Needs	Minimal land acquisition needs at a proper geologically sited region (e.g. regions of high karstification degree).	10
TECHNICAL – FUNCTIONAL		
T_1: Functionality	High / Efficient Functionality	9
T_2: Existing Experience – Reliability	The method of artificial recharge is worldwide known and reliable, as far as any of its applications is concerned. In Greece there are only research/ experimental applications.	7
T_3: Adjustability to Local Conditions	Total adjustability to local conditions, provided that the region where the method is applied has been chosen after a detailed geological and technical study.	9
T_4: Flexibility	The method is flexible to any periodic changes.	9
T_5: Life Span	Long life span.	10

Criteria of Comparative Evaluation	ELEMENTS CONCERNING THE CONCENTRATION OF WATER BY CONSTRUCTING A DAM	Grading
SOCIAL		
S_1: Concordance with the existing Legislation	There is no specific legislative framework which is dictated either by the E.U., or by the National Planning, therefore there is not direct concordance. Concordance is restricted in the wide subject of trying to increase the water resources	5
S_2: Application of possible Legislative Priorities	There is no specific Legislative Priority, but the general priority of maintenance and increase of the quantity of water resources is applied.	7
S_3: Social Approval/ Acceptance	So far dams are socially accepted. This result mainly from the inadequate awareness of the public on the environmental problems related to dam, as well as that the public is unaware of alternative water collection methods e.g. method of artificial recharge.	7
S_4: Possibility of New Posts of Work	Personnel for the function and the supervision of the dam will be necessary, such as operators, supervisors, technicians, electricians etc.	7
ENVIRONMENTAL		
EN_1: Environmental Impact	Huge Environmental Impacts. Remediation is impossible.	1
EN_2: Aesthetics	Affecting the environment in general is important and consequently the aesthetic intervention is also significant. Nevertheless, there are measures that should be taken in order not to be negative.	4
EN_3: Potential Dangers	Potential dangers are possible, due to the complexity of the method. Nevertheless, if proper measures are taken, like proper geological planning for site selection, constant and technologically advanced supervision, then potential dangers may be reduced.	5
ECONOMIC		
E_1: Initial Cost of Investment	The initial/capital cost for the investment for the construction of a dam is very high.	1
E_2: Functional Cost – Cost of Maintenance	The functional cost of a dam consists of: the salaries of the personnel, energy costs, as well as all those concerning the	5

	maintenance of the whole plant.	
E_3: Land Reclamation (Needs/Requirements of the Earth)	There are great land reclamation needs at a well chosen region, depending directly on the size of the dam.	3
TECHNICAL – FUNCTIONAL		
T_1: Functioning	High functionality.	9
T_2: Existing Experience – Reliability	Dams are used worldwide and are highly reliable.	9
T_3: Adjustability to Local Conditions	The adjustability of a dam to regional characteristics can be achieved, provided that the site selection study took into consideration the regions special characteristics	7
T_4: Flexibility	Provided that all the parameters concerning any periodic changes have been taken into consideration, such as flood fluxes, as far as these can be predicted, the method of water concentrating by constructing a dam may be flexible.	7
T_5: Life Span	Average life span, which depends directly on the solids flux of the river.	5

- **5th Step**

In this fifth step, all the grades that have been given in the previous step (4th step) for each criterion in particular, they are multiplied by the relevant factor of significance that each one has in the group of criteria they belong to. Further on, the results of the multiplications are added. Consequently, the final marking of each group is calculated as it is presented in the following table.

Criteria of Comparative Evaluation	Factor(s) of Significance	SCENARIO 1 Artificial Recharge	SCENARIO 2 Dam
SOCIAL (0.25)			
S_1: Concordance with the existing Legislation	0.25	10	5
S_2: Application of possible Legislative Priorities	0.30	10	7
S_3: Social Approval	0.30	8	7
S_4: New Jobs Opportunities	0.15	5	7
ENVIRONMENTAL (0.30)			
EN_1: Environmental Impact	0.40	7	1
EN_2: Aesthetics	0.30	8	4
EN_3: Potential Dangers	0.30	8	5
ECONOMIC (0.25)			
E_1: Initial Cost of Investment	0.40	8	1
E_2: Functional Cost – Cost of Maintenance	0.40	7	5
E_3: Land Reclamation (Needs/Requirements of the Earth)	0.20	10	3
TECHNICAL – FUNCTIONAL (0.20)			
T_1: Functioning	0.30	9	9
T_2: Existing Experience – Reliability	0.30	7	9
T_3: Adjustability to Local Conditions	0.15	9	7
T_4: Flexibility	0.15	9	7
T_5: Life Span	0.10	10	5

Criteria of Comparative Evalnation	Factor(s) of Significance	SCENARIO 1 Artificial Recharge	SCENARIO 2 Dam
SOCIAL (0.25)		**8.65**	**6.5**
S_1: Concordance with the existing Legislation	0.25	2.5	1.25
S_2: Application of possible Legislative Priorities	0.30	3	2.1
S_3: Social Approval	0.30	2.4	2.1
S_4: Possibility of New Posts of Work	0.15	0.75	1.05
ENVIRONMENTAL (0.30)		**7.6**	**3.1**
EN_1: Affecting the Environment	0.40	2.8	0.4
EN_2: Aesthetics	0.30	2.4	1.2
EN_3: Potential Dangers	0.30	2.4	1.5
ECONOMIC (0.25)		**8**	**3**
E_1: Initial Cost of Investment	0.40	3.2	0.4
E_2: Functional Cost – Cost of Maintenance	0.40	2.8	2
E_3: Land / Property acquisition	0.20	2	0.6
TECHNICAL – FUNCTIONAL (0.20)		**8.5**	**8**
T_1: Functionality	0.30	2.7	2.7
T_2: Existing Experience – Reliability	0.30	2.1	2.7
T_3: Adjustability to Local Conditions	0.15	1.35	1.05
T_4: Flexibility	0.15	1.35	1.05
T_5: Life Span	0.10	1	0.5

- **6th Step**

  The grading of each group of criteria which took place in the previous step (5th step) is multiplied by the relevant factor of significance according to the overall/holistic function (1st step) and finally the overall grade of each scenario is calculated, with which the final selection of a scenario will be made.

GROUP OF CRITERIA	SCENARIO 1 Artificial Recharge	SCENARIO 2 Dam
SOCIAL	2.1625	1.625
ENVIRONMENTAL	2.28	0.93
ECONOMIC	2	0.75
TECHNICAL – FUNCTIONAL	1.7	1.6
TOTAL	8.1425	5.2175

4. The Results of the Multi-Criteria Analysis

The evaluation of the suggested scenarios, according to the above Multi-Criteria analysis has the following results:

The method of artificial recharge has the highest grading (Artificial Recharge = 8.1425, Dam Construction = 5.2175), therefore the classification of the choices is the following: A1 = Artificial Recharge and A2 = Dam Constructing. Projects combining aquifers artificial recharge with flood preventing protection schemes are completely aligned with the principles of "Sustainable Development".

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