RISK ANALYSIS OF WASTEWATER REUSE IN AGRICULTURE

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ABSTRACT

Two of the main concerns for wastewater reuse in agricultural irrigation are environmental and human security. Different research studies and practices have been developed recently in order to quantify the risk of possible environmental contamination of surface and groundwater resources as well as the risk to public health from enteric viruses. Other, far from negligible, related issues are largely of a socio-economic and technical character. For example, the social acceptance, especially by farmers, of wastewater reclamation and reuse in agriculture, is influenced by specific local cultural, religious and socio-economic conditions. Economic and technical factors should also be taken into consideration, such as the water and wastewater treatment costs, the cost of maintenance, the employment of rural labour, the structure of irrigation networks and crop patterns. In this paper, the concept of sustainability in wastewater reclamation and reuse is formulated by using a general risk analysis framework and by taking into account all the above factors. The paper suggests a methodology for sustainable wastewater reuse in agriculture by considering not only technical and economic, but also environmental and social risks. Alternative strategies based on different treatment and irrigation technologies are evaluated using the Multicriteria Decision Analysis (MCDA) technique. The methodology is illustrated in a case study of wastewater reclamation and agricultural reuse in the city of Thessaloniki, Macedonia, Greece.

KEYWORDS
wastewater reclamation, reuse, irrigation, risk analysis, multicriteria decision making

INTRODUCTION

In wastewater reclamation and reuse, the advanced treatment of municipal wastewater has been largely accepted as sufficient in order to satisfy public health and environmental concerns. However, even after tertiary wastewater treatment, there is still a risk from enteric virus, toxic contamination and pollution of the environment. The decision on

whether to replace the conventional or other non-conventional water sources for the purposes of agricultural irrigation with reclaimed wastewater depends primarily on risks to public health that must be reduced to an acceptable level, and secondarily on environmental risks. For an acceptable solution both these should be weighed against economic benefits. To evaluate criteria and standards for wastewater reclamation and reuse, risk analysis and MCDA are very useful tools (Ganoulis, 2003; 2009).

In the past, wastewater was processed to make it reusable for the purposes of:

- wastewater treatment
- protection of surface and groundwater resources
- agricultural irrigation.

Although advanced wastewater treatment was tested in some Mediterranean countries (Tremea and Soulie, 1991) and in the state of California, USA (Pettygrove and Asano (eds.), 1985), in most cases reclaimed wastewater is led to the sea and not used for irrigation. Also there is no systematic assessment of the risks involved in wastewater reuse. In the Mediterranean area there has been significant progress in this field and many applications have been tested, especially in countries such as Israel, Tunisia and Cyprus, where several methods for irrigation have been developed after tertiary treatment of wastewater coming from small units, like hotels and tourist residences (Papadopoulos, 1989).

There are well-known historical examples of wastewater reclamation and reuse in big industrial cities in northern Europe (Berlin, 1836; London, 1845; Paris, 1875). However, it is in regions with a semi-arid climate and long-lasting droughts (Mediterranean, California) where such practices have been and should be developed (Angelakis, 1993). Two literature reviews refer to technical developments and applications of wastewater reuse in the Mediterranean (Tremea and Soulie, 1991) and in the state of California, USA (Pettygrove and Asano (eds.), 1985).

A distinction should be made between

- *indirect reuse*, in which wastewater is first discharged to a receiving natural water system (aquifer, river) and then water is withdrawn downstream. Municipal wastewaters can be reclaimed and reused indirectly.

- *direct reuse*, were the effluent is treated and reused immediately after reclamation. This is mostly the case for industrial wastewaters captured and reused in closed loops in industrial processes, such as pulp and paper industries.

In this paper we are interested in recycling municipal wastewaters for agricultural reuse in the Mediterranean socio-economic context. Significant progress has been made in this area and many applications have been tested, especially in countries such as Israel, Tunisia and Cyprus. Different methods for municipal wastewater reuse have already been developed in these countries. In Israel, 98% of wastewater is treated, mostly by using ponds; the water is

then used for irrigation (Sne, 1990). In Tunisia, wastewater is treated by using active sludge and ponds (Saied and Koundi, 1990). In Cyprus, several methods for irrigation have been developed after tertiary treatment of wastewater coming mostly from small units, like hotels and tourist residences (Papadopoulos, 1989).

Although advanced wastewater treatment was tested in some Mediterranean countries, in most cases reclaimed wastewater is led to the sea and not used for irrigation. Also there is no systematic assessment of the risk involved in wastewater reuse. Taking the decision to reuse water for irrigation is complicated and problematic, as technological alternatives and local social and cultural conditions have to be taken into consideration. The water characteristics of importance in agricultural or landscape irrigation are specific chemical elements and bacteriological concentrations that affect plant growth and may threaten public health. These characteristics are not often measured or controlled by wastewater treatment agencies. Consequently, when obtaining data to evaluate or plan wastewater reuse and irrigation systems, it is necessary to assess the risk to public health. The problem will be formulated in terms of alternatives, economic benefits, environmental and other criteria in order to manage the different risks involved.

RISK QUANTIFICATION

Definition of Risk

Risk and reliability have different meanings and are applied differently in various disciplines such as engineering, statistics, economics, medicine and social sciences. The situation is sometimes confusing because terminology and notions are transferred from one discipline to another without modification or adjustment. This confusion is further amplified as scientists may have different perceptions about risks and use different tools to analyse them.

Environmental risk is different from economic, social or health risks. It may refer to a pollutant concentration exceeding given regulations. *Environmental risk analysis* is based on the quantification of various uncertainties that may occur in the evolution of physical processes. The use of modelling techniques to quantify such uncertainties is an essential part of environmental risk analysis. Furthermore, because engineering projects are based on predictions of how processes might develop under uncertainty in the future, probabilistic approaches are more appropriate than deterministic methods for this purpose. Probabilities, and more recently *the fuzzy set theory* (Ganoulis, 2009), are suitable tools for quantifying uncertainties, which may induce a risk of pollution and threats to human health.

The maximum concentration of a specific pollutant Cm may be chosen to indicate the adverse effects produced in the water environment. Depending on the specific use of water, e.g., irrigation, recreation, etc., a maximum allowable pollutant concentration, C_0, is specified by the environmental quality standards. This concentration should be considered

as the *resistance* r or the *capacity* of the environment to sustain pollution. A critical condition producing adverse effects and risk of pollution occurs when the maximum pollutant concentration Cm or the load l exceeds the receiving capacity of the system, i.e. when $Cm > C_0$. Otherwise the system is safe, as far as pollution is concerned. So we have:

pollution : $Cm > C_0$ (1)

safety : $Cm \leq C_0$ (2)

In a typical problem of failure under conditions of uncertainty, we usually face three main questions, which may be addressed in three successive steps (Ganoulis, 2009):

Step 1 When does pollution occur?

Step 2 How often is pollution expected?

Step 3 What are the likely consequences?

The two first steps form part of the uncertainty analysis of the system. The answer to question 1 is given by the formulation of the critical condition in Eq. (1), i.e. when the load l exceeds the resistance r. To provide a satisfactory answer to question 2 we may consider the variables of the problem such as the load l and resistance r, as non-deterministic.

Uncertainties in Wastewater Reuse

A distinction should be made between

(1) *aleatory* or *natural uncertainties* or *randomness* and,
(2) *epistemic* or *man-induced* or *technological uncertainties*.

Aleatory Uncertainties or Randomness

It is postulated that natural uncertainties are inherent to the specific process and they can not be reduced by use of an improved method or more sophisticated model. Uncertainties due to natural randomness or aleatory uncertainties may be taken into account by using the stochastic or fuzzy methodologies, which enable us to quantify uncertainties.

Epistemic or Man-Induced Uncertainties

Man-induced uncertainties are of different kinds: (a) data uncertainties, due to sampling methods (statistical characteristics), measurement errors and methods of analysing the data (b) modelling uncertainties, due to the inadequate mathematical models in use and to errors in parameter estimation, and (c) operational uncertainties, which are related generally to the construction, maintenance and operation of engineering works. Contrary to natural randomness, man-induced uncertainties may be reduced by collecting more information or by improving the mathematical model.

RISK MANAGEMENT

Management of water resources involves addressing not only technical issues but also many social factors, institutions and administrative procedures. The main objective of the effective management of water resources in urban environment is to satisfy the demand, given the possibilities and limitations of water supply (Fig. 1). This balance between supply and demand should take into consideration both water quantity and quality aspects and the protection of the environment.

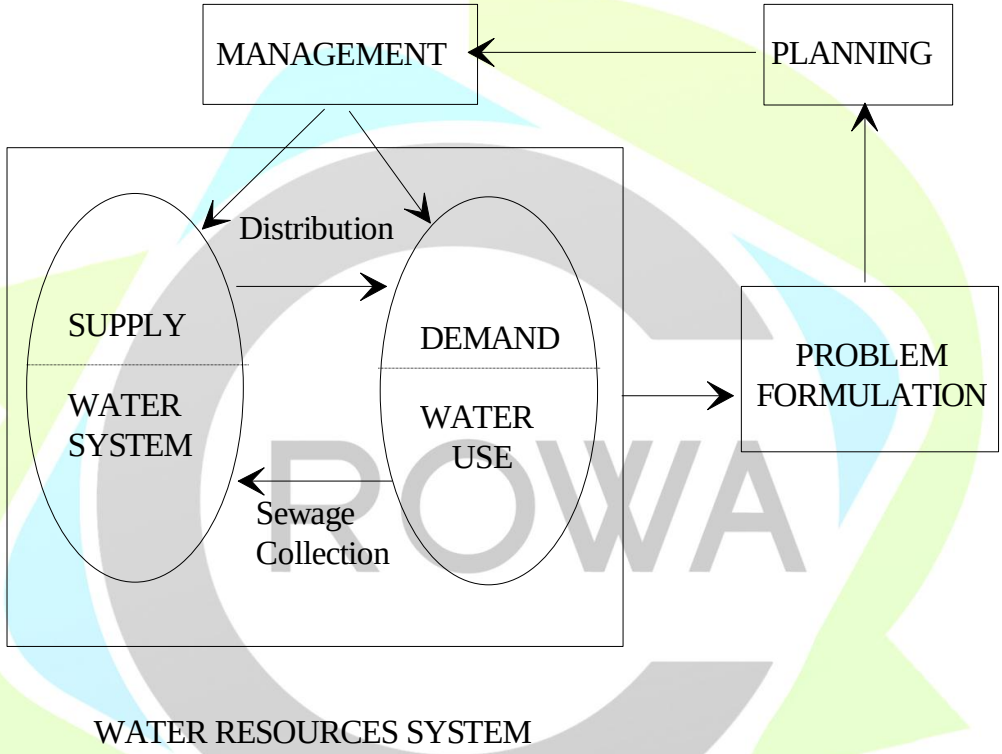

Fig. 1 Urban water resources management.

As seen in Fig. 2, the process leads to problem formulation, planning and management. The latter involves taking measures and regulating both water demand and supply.

The various steps involved in the management of wastewater reuse, from problem formulation to decision-making, are described schematically in Fig. 2. Various methodologies may be used (Ganoulis, 2009) to identify and quantify risks, including

* Statistical analysis of data
* Probabilistic modelling
* Fuzzy set approaches.

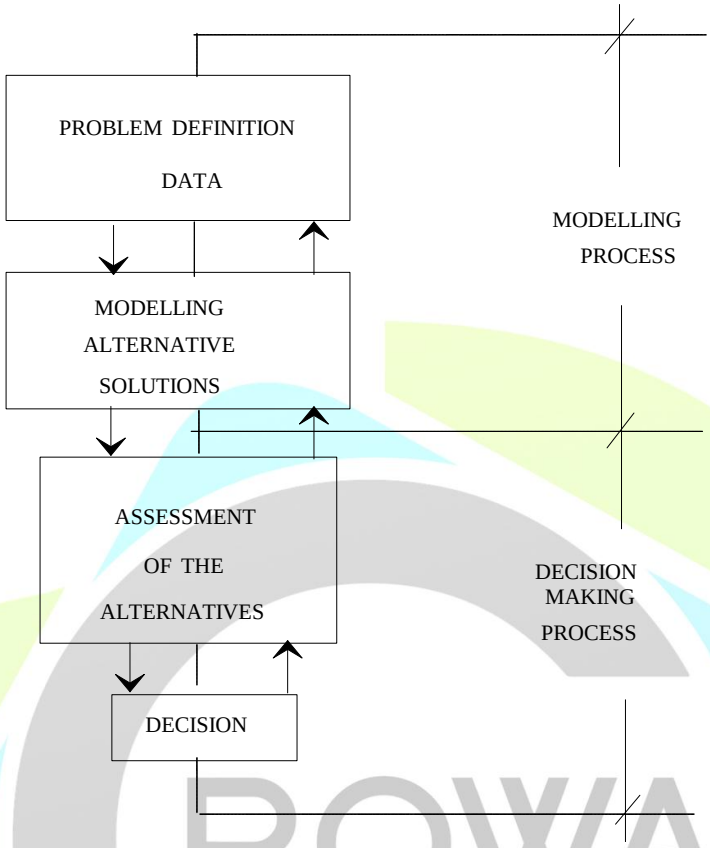

Fig. 2 Modelling and decision-making processes in wastewater reuse.

Quantification of risk as a function of technological methods, climatic factors, physical conditions and socio-economic parameters is essential for the management of risk. As shown in Fig. 3, application of engineering risk analysis consists of two main phases:

(1) assessment of risk, and
(2) risk management.

The assessment of risk is mainly based on modelling of the physical system, including forecasting of its evolution under risk. Although the main objective of risk analysis is the management of the system, this is not possible if risk has not been quantified.

The risk assessment process involves the following steps:

Step 1: Risk or hazard identification
Step 2: Assessment of loads and resistance
Step 3: Uncertainty Analysis
Step 4: Risk Quantification.

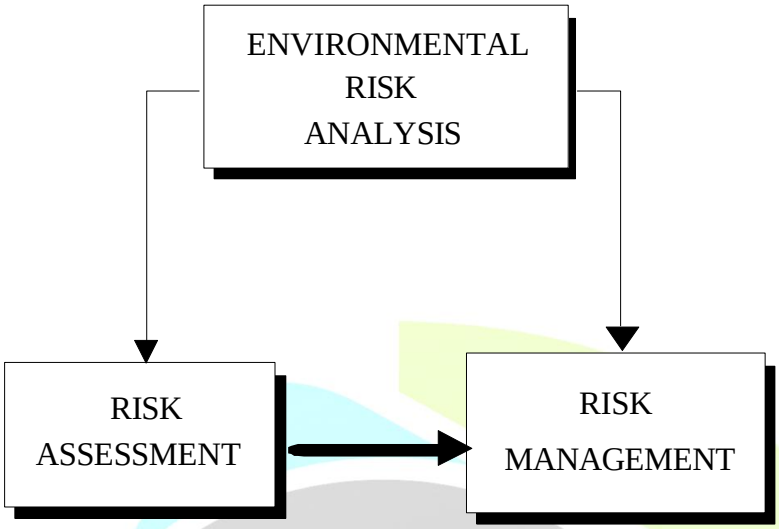

Fig. 3 Risk assessment and risk management as elements of environmental risk analysis.

When it is possible to assess the risk under a given set of assumptions, then the process of risk management may begin.

The various steps that should be followed for risk management, are:

Step 1: Identification of alternatives and associated risks
Step 2: Assessment of costs in various risk levels
Step 3: Technical feasibility of alternative solutions
Step 4: Selection of acceptable options according to the public perception of risk
Step 5: Implementation of the optimal choice.

Due to the aspects involving human and social issues, risk management is both the most important and most difficult part of the whole process to develop. From an engineering point of view, theories and algorithms of optimisation under uncertainty, multi-criterion optimisation and decision making under risk are useful tools.

WASTEWATER REUSE

For the management of risk related to wastewater reuse, 4 steps may be distinguished:

(1) *Collection of existing data.*

Data concerning not only wastewater reuse and the behaviour of major water pollutants but also reflecting the physical and socio-economic environment should be collected (topography, land use, river discharges, aquifer properties, human activities, agriculture, industries and urbanism).

(2) *Data organisation.*

Data collected and information available may be processed and structured using a GIS. Groups of interrelated data will be formed in order to examine cause and effect relationships.

(3) *Risk assessment.*

Various methods are used, such as

* Statistical analysis of data

* Probabilistic modelling, and

* The fuzzy arithmetic approach.

These methodologies will allow the health risk to be evaluated for different exposure scenarios.

(4) *Risk management.*

Expected benefits and costs will be expressed as a function of risk. The incremental benefits will be evaluated in terms of the risk, considering

* Alternative actions

* Different states of nature and

* Preferences or criteria.

These problems should be considered while taking into account various technologies and different irrigation systems and also the local socio-economic conditions. In fact, wastewater reuse involves *alternative technologies* for sewage treatment (biological oxidation, nitrification-denitrification, use of lagoons and aquifer recharge), *different states of nature* (climatic conditions, type of soils, irrigated crops, irrigation systems, socio-economic environments) and *various preferences or criteria* (economic, environmental, aesthetics, etc.).

The objectives of a related research project may be classified in two groups. Those of the first group concern mainly the technical and socio-economic aspects of wastewater reuse including:

- developing a *Decision Support System (DSS,)* which may help local authorities to choose between alternatives of wastewater reuse, decide quickly about the risk and feasibility of a proposal and better adapt the solution to local conditions.

- using the *risk assessment and management* framework in order to minimise risks to public health from wastewater reuse. Different scenarios should be developed to quantify public health risks due to wastewater reclamation and reuse. Different exposure assessments should be evaluated including groundwater recharge, food crop irrigation, landscape irrigation and recreational impoundment.

The second group of objectives deals with the applicability and diffusion of the results among potential users. Such objectives are:

- identification of potential users from public and private sectors
- organisation of regular contact and exchange between users and research institutions
- follow up of the evolution of research and evaluation of its adequacy to solve practical problems
- creation of a network of regional operational institutions, in order to improve the distribution of results of wastewater reuse within the professional field.

EXAMPLE OF APPLICATION

In environmental engineering the treatment and disposal of sewage is subject not only to the minimisation of environmental impacts, but also to the minimisation of costs, and the minimisation of adverse reaction from environmentalists and possibly other social groups. These objectives are usually conflicting. Improvement of one is obtained with the deterioration of another. Moreover, the objectives may be of varying degrees of importance. In the case of a Wastewater Treatment Plant (WTP) even if we restrict ourselves only to economic objectives, these could be in conflict, whether or not they are defined by the owner or operator of the regulatory agency.

This example of application should be treated as a *decision-making problem under uncertainty or imprecision*. We can evaluate the outcome, but we are not able to express the probabilities of occurrence objectively and quantitatively. Imprecision may also exist in the choice or evaluation of criteria, or in the evaluation of the outcome according to the potential user.

The set of criteria may contain *quantified* criteria and *non-quantified* criteria. For example, costs, technical characteristics and efficiencies may be measured in terms of money or other quantitative measures. Non-quantitative criteria are related to aesthetics, human comfort or environmental values. The following example refers to the Wastewater Treatment Plant in Thessaloniki, Greece.

The city of Thessaloniki disposes part of its total sewage untreated into the sea. An existing WTP could function with:

primary treatment and/or

secondary treatment

+ chlorination

+

nitrification/denitrification.

In a multi-objective decision-making process, we may consider the Decision Matrix (Tab. 1), the Criteria and the Meaning of the Criteria Values (Tab. 2) as inputs, and the Pay-off Matrix (Tab. 3) and the Compromise Solution (Fig. 5) as outputs.

The different disposal sites represent the *States of Nature*, in the first line of the Decision Matrix (Tab. 1). The disposal site could be in the bay of Thessaloniki as it is now (site A), in the Axios River (site B), in the sea with an underwater pipe-line (site C), or in the fields for food crop or non-food crop irrigation (site D). These different possibilities form the possible "Alternatives" (Tab. 1). These are environmental conditions in which the actions should operate, and called "nature". In a decision-making situation, nature can include technical, physical, political, social and economic considerations. The members of the set are mutually exclusive and exhaustive.

In the first column of the Decision Matrix, we list the *Alternative Actions*. These are alternative design solutions that engineers can select as potential solutions to the problem. Because of the various limitations, such as technological or modelling constraints, it is not possible to find all the possible alternative actions. This means that the set of the actions is not exhaustive. However the members of the set are mutually exclusive. In this case the actions are the different degrees of sewage treatment.

For every combination between an Action and a State of Nature, we obtain an *Outcome* in Table 1, from A1 to A14.

Tab. 1 DECISION MATRIX FOR THESSALONIKI WTP.

Disposal Sites (States of Nature) / **Actions**	Thessaloniki Bay	Axios River	Open Sea	Food-crop Irrigation	No Food-crop Irrigation
	Site A	Site B	Site C	Site D	Site D
No Treatment	No	No	A1	No	No
Primary Treatment	No	No	A2	A3	A4
Secondary Treatment and Chlorination	A5	A6	A7	A8	A9
Secondary Treatment (+chlorine) and Nitrification-Denitrification	A10	A11	A12	A13	A14

*Alternatives that concern irrigation are underlined.

Each management alternative is associated with economic, ecological and social impacts, expressed by means of some *Basic Indicators (BI)* or *Criteria*. The basic indicators are grouped (Fig. 4) into smaller, more general groups, called second-level indicators or objectives. This grouping continues until only two indicators, such as *economy* and *environmental risk*, remain.

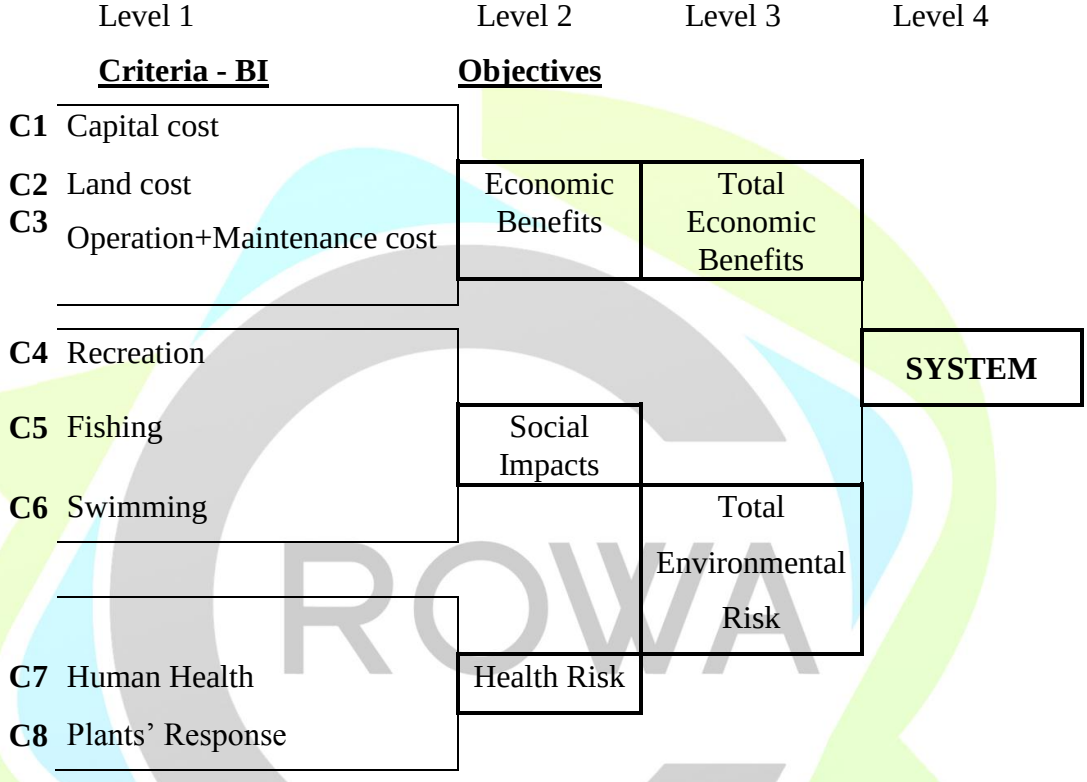

Fig. 4 Composite structure of criteria.

By defining the objectives of the problem, it is possible to choose the Criteria or Basic Indicators (BI), that may be economic, social, or public health risk (Fig. 4). After the indicators have been grouped into such a structure (Fig. 4), weights are assigned to the indicators representing their relative importance to the decision maker. For example a moderate risk to humans may be considered more important than a more severe risk to a non-endangered species of fish.

The criteria may be quantified or non-quantified. The capital, land and function costs may be measured in money. Nevertheless the characterisation of A= cheap, or B= not expensive, etc. may be subjective, according to the user or the decision maker. Recreation

(C4), is a non-quantified criterion, that we may measure according to the odour nuisance to people.

The Criteria C7 and C8 refer to the European Environmental quality standards. C7 is measured by the presence of fecal coliforms at the exit of the WTP and the limits correspond to the acceptable limits for food crop irrigation and no-food crop irrigation. Measurement in situ may generate other uncertainties, related to climate conditions, (summer, winter, river flow, etc.).

Tab. 2 MEANING OF THE CRITERIA VALUES

C1	A=cheap	B=not expensive	C=fair price	D=expensive	
C2	A=cheap	B=not expensive	C=fair price	D=expensive	
C3	A=cheap	B=not expensive	C=fair price	D=expensive	
C4	A=excellent	B=a little nuisance from time to time	C=a little nuisance	D=frequent nuisance	
C5	A=a lot of fish and diversity of species	B=a lot of fish	C=few fish	D=fishing is forbidden	E=dead sea
C6	A=excellent	B= good for swimming	C=possible to swim off season	D=dangerous	
C7	A=<14/100ml	B=<100/100ml	C=≤1000/100ml	D=≤100000/100ml	E=>100000/100ml
C8	A= promotes growth	B=no change	C=toxic or overgrowth		

*C7 ↔ «Water Stabilisation Ponds, Design Manual for Mediterranean Europe, (WHO)»

The difficult part is to determine the numerical values A, B, C, etc. These values may be the results of an environmental model (pollutant concentrations), an economic investigation, a poll, or constraints according to environmental standards for each alternative solution. On the other hand, the weights may vary according to the potential user or the decision maker. We may limit this variation using sensitivity analysis. The units of basic indicators are different and thus it is difficult to make direct comparisons; their values should be normalised onto the 0 to 1 interval.

Tab. 3 PAY-OFF MATRIX

	CRITERIA	W	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14
30%	C1 capital cost	w_1	A	B	B	B	C	C	C	C	C	C	D	D	D	D
	C2 land cost	w_2	A	B	B	B	B	B	B	B	B	C	C	C	C	C
	C3 function	w_3	B	B	B	B	B	C	C	C	C	C	C	D	D	D
20 %	C4 recreation	w_4	D	B	B	B	B	B	B	B	B	A	A	A	A	A
	C5 fishing	w_5	C	B	A	A	B	B	B	A	A	A	A	A	A	A
	C6 swimming	w_6	B	B	A	A	C	C	A	A	A	A	A	A	A	A
50 %	C7 human health (coliform.)	w_7	E	E	E	E	A	A	A	A	A	A	A	A	A	A
	C8 plants' response	w_8	B	B	C	C	B	B	B	A	A	B	B	B	B	B

Representing the A, B, C, D, and E normalised values with S_i and the different weights assigned to each criterion by w_i, the following relationship (Eq. 3) gives the general rule by which we move up from a specific level to a more general level.

$$L_i = \left(\sum_{i=1}^{n} w_i \left(S_i \right)^p \right)^{1/p} \quad (3)$$

where L_i represents the normalised values for every more general group and p is the balancing factor among indicators for a group. The balancing factor reflects the importance of the maximal deviation of the indicators, where the maximal deviation means the maximum difference between an indicated value and the best value for the indicator (Dahab and Lee, 1991).

The final composite indicator is obtained by applying the above rule to the two general indicators, the Total Environmental Risk and the Total Economic Benefit. The result is a vector. Ranking among alternatives is based on the *minimum composite distance*, as explained later.

This is a simple example that shows the perception of such a problem and which may be resolved with the help of a Multi Criteria Decision Making (MCDM) program. In this case, many other factors will be included, such as risk and reliability, fuzzy set theory and uncertainty. Some of the techniques used to apply MCDM are *ELECTRE* (Elimination Et Choix Traduissant la Realite) (Nachtnebel H.P, 1994) and the one mentioned above, the technique of *Minimum Distance from the Ideal Point*.

There are two different distance-based techniques, *goal programming* and *composite programming*. The first allows the decision maker (DM) to obtain results by defining a *preferred solution* as the one that minimises the sum of the deviations from the prescribed set of target values. The second first normalises the objectives and then identifies solutions which are closest to the ideal point as determined by some measure of distance.

The ELECTRE method is used when the outcomes of alternatives cannot be quantitatively assessed and whilst with the use of the distance based technique the DM may see that one alternative is better that the other, he cannot quantify how much better. The ELECTRE technique is applied as I, II and III, according to the information about the preference structure.

The Compromise Solution

One of the more promising methods is that of Composite Programming. Having arrived at some composite economic benefit and total environmental risk indicators, we should choose one solution. An example of ranking between different strategies-solutions based on the *minimum composite distance* from the ideal point follows. In this case the ideal point is 0 (zero risk), as we are looking for the lowest environmental risk and the least economic impact. The final system indicators can be formed by composing environmental and economic risk. Developing composite programming software is a tool for ranking alternatives and determining the «best» compromise solution from all the alternative solutions.

In the following Fig 5, we give an example of calculating the minimum distance from the ideal point, on an x, y axis system, where x values stand for «economic risk indicator» values and y for «environmental risk indicator» values. We may see that after this example we arrive at the point where, beyond a certain level of wastewater treatment, the two different irrigation solutions of food crop and no-food crop could be treated as one (A8, A9) and (A13, A14). Ranking of alternative solutions results as follows:

1. Secondary Treatment + Chlorination – Food Crop, No Food Crop Irrigation (A8, A9)
2. Secondary Treatment + Chlorination – Axios River (A6)
3. Tertiary Treatment - Food Crop, No Food Crop Irrigation (A13, A14)
4. No Treatment – Open Sea (A1)

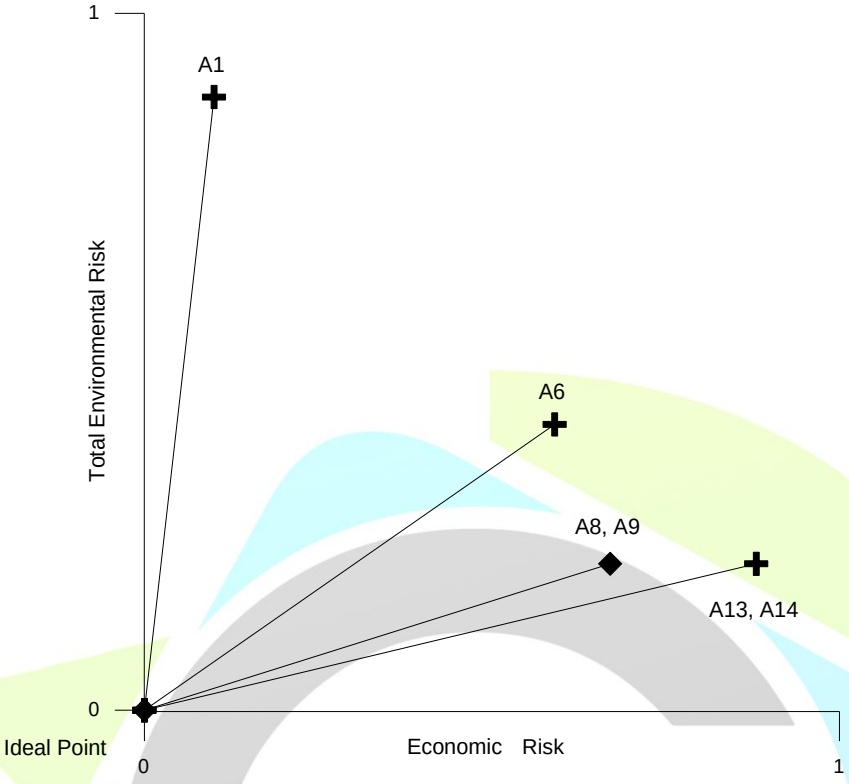

Fig. 5 Ranking among different alternatives, expressed in terms of economic and environmental risk.

CONCLUSIONS

Risk Analysis is an integrated framework for wastewater reclamation and reuse consisting of risk assessment (physical system, loads, uncertainties, risk quantification), and risk management (alternative risks, costs, social and health aspects). The main advantage of this approach is the combination with a MCDA methodology, in order to take into account different criteria of wastewater reuse. The final goal is the development of a Decision Support System (DSS), leading to a *Compromise Solution*, which is defined not as an optimum but as a «non-inferior» solution, which is the one for which all objective functions are improved.

For the design of wastewater reuse and the control of the associated risks, data of maximum pollutant concentrations play a major role. These values should be taken into consideration when various alternatives of wastewater reclamation and reuse are studied. In this paper it is shown how risk analysis may be used in order to quantify the risk of wastewater reuse. The methodology should lead to a decision support system to be applied by local authorities responsible for wastewater treatment and disposal.

REFERENCES

Angelakis A.N. (1993) The necessity of reclamation and reuse of municipal wastewater effluent in the Mediterranean region. *Proc. HELECO'93, Technical Chamber of Greece, Athens, Greece*, Vol. 1, 315-330 (in Greek).

Duckstein L., Szidarovszky F. (1994) Distance Based Techniques in Multicriterion Decision Making.,*Multicriterion Decision Analysis in Water Resources Management*, 86-112, Edited by J. Bogardi anh H. P. Nachtnebel, UNESCO, Paris.

EPA (1992) *Guidelines for Water Reuse*, EPA/625/R-92/004.

Ganoulis J. (2003) Evaluating alternative strategies of wastewater recycling and reuse in the Mediterranean area, *Water Science Technology: Water Supply, Vol.3, No 4, 11-19, IWA Publishing*

Ganoulis J. (2009) *Risk Analysis of Water Pollution*. WILEY-VCH, Weinheim, 312 pp.

Nachtnebel H. P. (1994) Multicriterion Decision Making Methods with Ordinal and Cardinal Scales: ELECTRE I-III, *Multicriterion Decision Analysis in Water Resources Management*, 113-150, Edited by J. Bogardi anh H. P. Nachtnebel, UNESCO, Paris.

Dahab M.F. and Y.W. Lee (1991) Risk management for nitrate-contaminated groundwater under imprecise conditions. *NATO ASI on Risk and Reliability in Water Resources and Environmental Engineering*, Porto Karras, Greece.

Papadopoulos I. (1989) Reuse of treated effluent for irrigation in Cyprus. CEFIGRE, CEF-206/ST04.

Pettygrove and Asano (eds.) (1985) *Irrigation with Reclaimed Municipal Wastewater-A Guidance Manual.* Lewis Publishers.

Saied M. and Koundi, A. (1990) Reutilisation des eaux épurées en Tunisie. 2nd Int. Symp. on Sea Protection, Marseille.

Sne M. (1990) Transfer of Technology: the Israeli Experience. Role and Function of Extension in Irrigation. *Report to the Ministry of Agriculture.*

Tremea L.and Soulie, M. (1991) Technologie pour le Traitement et la Reutilisation des Eaux Usées. *Report, 3èmes Rencontres de l' ARPE*, Marseille, 145 pp.