

AN ENVIRONMENTAL IMPACT ASSESSMENT DECISION ANALYSIS SYSTEM FOR IRRIGATION SYSTEMS

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ABSTRACT

In this paper an Environmental Impact Assessment Multicriteria Decision Analysis System for irrigation projects (EIAMDAS) used as a comprehensive tool that enables comparison between irrigation project alternatives is presented. The comparison is based upon all relevant aspects of the surrounding environment during irrigation systems operation. The decision is case dependent, and relies on the compromise between positive and negative impacts associated with the project, and the relative importance (weights) of the different factors involved. Inputs to the EIAMDAS include are information of the existing system operation derived from selected answers for a set of multiple choice questions that provide sufficient information to describe the baseline conditions and the general design for several project alternatives. On the other hand, the EIAMDAS outputs, in the form of positive and negative scores, allow the user to evaluate different impacts criteria on neighbouring and project areas. The user is also required to input importance weights to these categories of impacts. The different impacts criteria are categorised as environmental social and economic impacts using compromise programming. The final output is an overall environmental index for each project alternative. Two years of real time control data are used to illustrate system performance. Conclusively the EIAMDAS is an efficient tool for supporting the decision making process, especially in the trade-off between project alternatives according to anticipated environmental impacts including economic aspects. Although this EIAMDAS was developed for irrigation projects applications, the software was designed in a flexible manner to allow for future adaptation to other applications using the same technique.

KEYWORDS: environmental impact assessment, decision analysis systems, irrigation systems

INTRODUCTION

The implementation of irrigation practices in large-scale irrigation projects may be associated with adverse impacts on environmental conditions, which may affect the sustainability of irriga-

tion projects. Environmental Impact Assessment (EIA) has been recognized as an integral part of the early planning studies but also during project operation and management of irrigation projects in order to identify any expected negative impacts

and suggest the necessary mitigation actions to reduce these impacts. Historically the main components of the environment used to be defined were economic criteria. The last ten years sustainability related criteria such as social and environmental together with economic criteria have been included in irrigation planning. These criteria are classified in most checklists according to the likely time of impact whether during construction, operation or in the long run. However, there is no standard classification of the environmental impacts criteria due to the complex interrelationships between the parameters. Usually the situation evolves a confrontation between water resources at the region of influence of the project, protecting the legitimate rights of local residents, safeguarding against deterioration of water quality and threats to biodiversity, changes in soil fertility and drought management and expansion in agriculture sector.

Conflicts and disputes related to environmental issues may arise over strategies for resource management, expected environmental impacts of the project or development plan, operation of existing projects and environmental restoration efforts for degraded resources (Bidol, 1986).

Traditional approaches for conflict management have included the use of legislation and/or regulation, administrative procedures, and arbitration. Newer techniques for the management and resolution of environmental conflicts involve mediation and negotiation between the parties in conflict (Canter, 1996).

These techniques provide wider scope of objectives that may support the decision-making by weighing environmental effects on common basis with economic costs and benefits. Accordingly, targeted users for the different techniques vary to include specialists and non-specialists planners, designers and decision-makers.

This paper presents an Environmental Impact Assessment Multicriteria Decision Analysis System (EIAMDAS) that assists high-level decision-makers in trading-off between management options, by assessing different alternatives for irrigation projects. One of the main advantages of this EIAMDAS is that non-specialists may use it. The criteria used for comparing project alternatives are not limited to the impacts of the project on the physical environment such as natural resources and biological life, but also include the

impacts on socio-economics as well as economics. Meanwhile, the method is flexible enough to account for the user's preferences in weighing the main categories of impacts' criteria. Besides, and due to the nature of the targeted users, the technique is easy to use, comprehensive and consumes little time to reach a final decision.

EIAMDAS DESCRIPTION

Multicriteria Decision analysis is based on the Composite programming. Composite programming was introduced by (Zeleny, 1973) and uses a single level analysis and a non-normalised distance. The first step behind the conceptual basis of the EIAMDAS was to identify the environmental criteria that are susceptible to change due to irrigation projects operation, and then categorize these criteria under main headings. The physical factors that were known to be responsible for changing the criteria conditions were then identified. After these basic indices have been identified, the process of building the main headings from its elementary components by defining the structure of the composite programming model begins. The process can be characterised as grouping the basic indicators into clusters based on either similar characteristics or the desire to contrast different features through trade-off analysis. The initial set of indicators that result from grouping basic indicators are called first level indicators. After the first level indicators have been specified, the grouping process continues until the highest-level indicators have been specified. In the case of the irrigation management this final level may describe the trade-off between on farm level sustainable performance and efficiency or the operational sustainability performance and efficiency.

The weight assigned to the particular management performance index reflects the relative preference of that element compared to other elements within the same group. Composite programming uses a double weighting scheme to reflect the importance of the maximal deviation between the indices used. Therefore the decision maker must specify a value for the balancing factors.

The ideal and worst values for each of the indicators are final components needed to describe the composite programming model structure.

The impact relationship is a measure of the basic index value for each of the management options

and serves as an input to the management system model. Values for basic indices are obtained from the simulation modelling of different alternatives. Evaluation of the various management options is accomplished by calculating the composite distance within each group of indicators, beginning at the basic level and then progressing to successively higher levels.

The preferred management option is then identified from the candidates by locating the system nearest the ideal point in terms of the composite distance.

The Environmental Impact Assessment Multicriteria Decision Analysis System for irrigation projects (EIAMDAS) presented here is software for personal computers developed for the comparison between irrigation project alternatives based on all relevant aspects of the surrounding environment of an irrigation project. All possible conditions of these factors were determined and compiled in a multiple-choice questionnaire. The expected positive and negative impacts to be relatively associated with the different factors conditions were integrated in the EIAMDAS to represent the initial output to the user's answers to the

multiple choice questionnaire (Barrow, 1997). The conditions of each factor when selected by the user should indicate its individual positive or negative impact on the criteria. Meanwhile, the cumulative effect of the factors determines the impact on each criterion. The impact on each main environmental category is then calculated assuming equal weights for all criteria impact. However, the overall impact for the project alternatives are calculated according to the given importance weights for each of the four main categories.

In this context, the four main environmental categories were natural resources, biological life, socio-economic and economic impacts (Table 1). Environmental criteria relevant to irrigation projects were categorized carefully under the appropriate main headings in order to avoid replication or double counting. The criteria and the physical factors influencing them were compiled from the available literature. They are believed to be covering all possible criteria of impacts of irrigation projects and all factors in irrigation projects that may be affecting these criteria.

Table 1. Table of possible impacts.

| 1. NATURAL RESOURCES IMPACTS | 2. BIOLOGICAL LIFE IMPACTS | 3. SOCIO-ECONOMIC IMPACTS | 4. ECONOMIC IMPACTS |
|---|---------------------------------------|--------------------------------------|-----------------------------------|
| Soil | 2.1 Plants -Trees | 3.1 Adequacy | 4.1 Net Production/Irrigated Area |
| 1.1 Soil Salinity | 2.2 Fish | 3.2 Users satisfaction | 4.2 Net Production/Water Volume |
| Water | 2.3 Aquatic Life | | |
| 1.2 Soil Pollution | 2.4 Eutrophication | | |
| 1.1 Surface Water Quantity | 2.5 Pests and Rodents | | |
| 1.2 Surface Water Quality | | | |
| 1.3 Groundwater Level | | | |
| 1.4 Groundwater Quantity | | | |
| 1.5 Groundwater Quality | | | |

EIAMDAS OPERATION

The user of EIAMDAS is required to answer a set of multiple choice questions via a user-friendly graphical interface. The design of the questions considered that the answers provide sufficient information to describe the baseline conditions and the general design for several project alternatives. In this sense, the selected answers by the user reflect the impact of the physical factors on the different criteria in the project area as well as the neighboring area. Consequently, a positive score is assigned for each factor inducing a positive impact and conversely a negative score is given for every anticipated negative impact. Assigning the scores is performed through an Expert System, which was developed especially for this EIAMDAS to associate an appropriate score with every selected answer to the multiple-choice questions. The scores were designed to reflect the expected impact of each factor relative to its all-possible impacts.

The scores of the impacts on the project area and neighbouring area are then summoned for each criterion separately. Depending on the sign of the total impact score of each criterion, it will be divided by the maximum possible positive or negative score of that criterion to give a normalized +/- impact on a scale from "-100%" to "+100%". The normalized impacts, $R(x)$, for each of the basic indicators, and for each management alternative, x , can be calculated:

$$R(x) = \frac{R(i)}{R(i) - R(w)} \quad (1)$$

where $R(w)$ and $R(i)$ are the worst and ideal values respectively.

for all criteria are then averaged over the criteria for each environmental impact category to obtain the impacts on the main environmental categories. The pre-defined importance weights for each environmental category are used to calculate the overall environmental impact for each project alternative. The detailed method of computation can be obtained from (Manoliadis *et al.*, 2001).

For the economic impacts, the user has to insert estimated values for some of the economic parameters required to calculate the indicators. The indicators included in the evaluation are based on

the prime economic objectives of the project and the scarce resources in the economy as identified by the user (Bergmann and Boussard, 1976). The economic indicators enter into the final evaluation as a ratio relative to the highest values among the project alternatives. The economic impacts category, similar to the other environmental categories, are weighed according to their importance by the decision maker and added to the overall impact.

EIAMDAS OUTPUT

The main output of the EIAMDAS is an overall environmental index for each project alternative based on the selected answers and the values of the economic indicators as well as the importance weights set by the user for each environmental impact (Table 2). The higher the positive values the better the impact on the environment and consequently the best project alternative is that of the highest positive overall impact. Figure 1 shows how reports, in tabular and graph formats, can be viewed on screen for comparison purposes of impacts of different project alternatives on different environmental impacts criteria in the project area and the neighbouring area. The EIAMDAS is provided with an option to print a final report where the value of the overall environmental impact is supported by a brief information about the impact of various factors on the criteria and the project description and assumptions as set by the user. The final report presents the output in a tabular, graphical and text format.

EXAMPLE

A simplified example is used to illustrate systems operation. In this example two irrigation policy alternatives are compared. The impacts used were groundwater quantity in terms of natural resources impacts, yield reduction in terms of biological impacts, adequacy and users satisfaction in terms of social impacts. The structure and graphical representation is presented in Figure 1. Table 2 illustrates the calculation of each alternative based on the weight of each impact and the normalized value. As can be seen alternative 2 scores higher (1.557) than alternative 1 (0.877).

CONCLUSIONS

The need for a systematic methodology for evaluating the various impacts associated with any

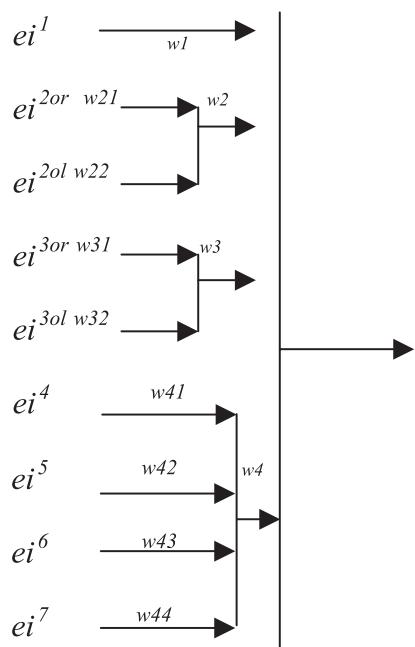


Figure 2. Graphical representation of the results

Table 2. Numerical representation of the results

| IMPACT | Importance Weights (set by the user) | Alt. 1 (NORMALIZED VALUE) | Alt. 2 (NORMALIZED VALUE) |
|---------------------------|---|---------------------------------|--|
| Natural Resources Impacts | w1 | N1 (0,80) N1 (0,90) | |
| Biological Life Impacts | w2 | B1 W21 W22 | B1 B11(0,35) B12(0,39) |
| Socio-Economic Impacts | w3 | S1 W31 W32 | S1 S31(-0,40) S32(-0,38) |
| Economic Impacts | w4 | E1 W41 W42 W43 W44 | E1 E41(-0,54) E42(0,17) E43(0) E44(0,76) |
| Overall Impact | 100 | W1*N1+B11*W21+... =0.877 | W1*N2+B21*W21+... =1.557 |

water resources management project is inevitable. The ever lasting dispute around water resources development plans, could be objectively guided to reasonable decisions through following a consistent methodology for assessment of environmental impacts.

EIAMDAS, an Environmental Impact Assessment Decision Support System for irrigation projects, was developed. It is an efficient tool to assist high-level planners and decision-makers, especially non-specialists, in trading-off between the project and no project options or between the different project alternatives. In this context, comparison of alternatives covers four main environmental impacts' categories including natural resources, biological life, socio-economic, political and economic impacts. The EIAMDAS allows the decision-maker to assign relative weights to the four environmental impacts' categories according to the decision maker priorities.

The EIAMDAS was based on a comprehensive checklist containing most criteria susceptible to change, due to irrigation projects construction or

operation, coupled with suggested mitigation measures. The user is asked to reply to a series of multiple choice questions through a user-friendly graphical interface operating under Windows environment. The multiple-choice questions were designed so that the selected answers should give sufficient information on the baseline conditions and the general design of the project alternatives. The built-in Expert System utilizes this information to retrieve positive and negative scores cor-

responding to the user's selected answers, and reflecting the impact of the project design on the baseline conditions. These scores are manipulated to calculate an overall environmental index for each project alternative. The final output generated by the EIAMDAS may be presented in tabular, graphical, and descriptive text formats allowing quick decision making and comprehensive comparison between different project alternatives.

REFERENCES

- Barrow, C.J. (1997). Environmental and Social Impact Assessment. Arnold, London.
- Bergmann, H. and J. Boussard. (1976). Guide to the Economic Evaluation of Irrigation Project. Organization for Economic Co-operation and Development, Paris.
- Bidol, P. (1986). An Adaptive Conflict Management Model. Proceedings of Engineering Foundation Conference on Social and Environmental Objectives in Water Resources Planning and Management, Santa Barbra, Ca, ASCE.
- Canter, L.W. (1996). Environmental Impact Assessment. McGraw-Hill Int. Editions, NY.
- Cohon, J.L. (1975). Multiobjective Programming and Planning. Academic Press, New York.
- Manoliadis, O., Baronos, A., Tsolas L, Vatalis K. (2001). Environmental impact assessment of irrigation systems using sustainability related indices. Procedings of the seventh international conference on environmental science and technology, held in Hermoupolis Syros. Greece, 2, 291-297.
- Zeleny M. (1973). Multiple criteria decision making. McGraw-Hill Book Company New York.