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MULTICRITERIA METHODS IN RIVER BASIN PLANNING – A CASE STUDY

P. Anand Raj

Lecturer, Department of Civil Engineering, Regional Engineering College, WARANGAL - 506 004 Andhra Pradesh, South India

ABSTRACT

A large number of multicriteria decision making (MCDM) methods have been proposed in the past and applied to water resources planning. The development and application of systems analysis techniques to assist decision makers in evaluating project alternatives having more than one objective in river basin planning is of recent origin.

In this paper an attempt is made to demonstrate the use of ELECTRE (ELimination and (Et) Choice Translating REality) I and ELECTRE-II techniques for water resources planning in one of the major river basins (Krishna river basin) of South India. The river basin consists of 8 reservoirs and a diversion work. Formulation of the problem is provided leading to an array of 27 alternative systems (different combinations of reservoirs with a minimum of three in each alternative) with 6 criteria related to: (i) irrigation, (ii) power production, (iii) drinking water, (iv) environmental quality; (v) floods and (vi) cost of the project. Out of the six criteria two, namely environmental quality and floods, are qualitative in nature. A set of best alternative systems with their partial ordering is obtained from ELECTRE-I, which forms the input for ELECTRE-II. Complete ordering of the reduced alternatives is achieved with ELECTRE-II. Sensitivity analysis shows that changing the weights assigned to each criterion has greater effect on the results than does changing the scales. However, neither effect is significant. Therefore it is recommended that ELECTRE-I be used for screening alternatives under consideration and ELECTRE-II for complete ordering of the reduced set.

KEYWORDS

Basin planning, decision making, ELECTRE, multicriteria, multi-objectives, ranking alternatives, reservoir system, systems analysis, watershed planning, water resources.

INTRODUCTION

Since the advent of Operations Research (OR) as a scientific approach to decision making, a variety of mathematical tools have been developed and applied to problems in engineering, business, economics, government and the natural and social sciences. Traditionally, the decision maker (DM) has considered a single objective within the respective framework for the analysis. In the last two decades, however, there has been an increased awareness of the need to identify and consider simultaneously several objectives in the analysis and solution of problems, in particular those derived from the study of large-scale systems. In water resources (WR) development the design of projects and programs has focused traditionally on the estimation of national benefits and costs. A more realistic analysis would include environmental, social and regional objectives as well. The shifting of social values and norms has prompted the enactment of laws and regulation of the use and management of natural resources with explicit reference to multiple objectives and, therefore, the inclusion of multiple objectives in the study of resources allocation problems has motivated the development of Multi-objective Analysis.

Multi-objective analysis has developed in explicit form largely through the work of the Harvard Water Program (HWP). Much of the methodology and research findings of HWP were published by Maass *et al.* (1962). Prior to that, the problem of the formation of a single-optimality criterion from a number of noncommensurable elementary criteria was treated by Pareto (1896). The concept of "Pareto optimality" found its way into OR in the pioneering works of Koopmans (1951) and Markowitz (1959). A general approach to the vector-function maximization problem was also treated by Kuhn and Tucker (1951). Marglin (1967) contributed to the task of converting objectives into design criteria such as scheduling of projects, budget constraints, risk and uncertainty, interest rates and pricing policies. Haimes (1977) set forth the principles of regional WR planning to assist in the policy decision making process at various hierarchical levels - local, state, regional and federal. A review and evaluation of multi-objective programming methods was made by Cohon and Marks (1975). The political decision process appropriate to many WR problems is described by Major (1969). Valuable insight into the political decision process is also offered by Haith and Loucks (1976). The impact of "principles and standards" of the Water Resources Development Act (WRDA-1974) on the policy making process and review of some of the methodologies available to the planners in the definition and evaluation of multi-objectives were discussed by Loucks *et al.* (1981). Since those beginnings, multi-objective analysis has awakened widespread interest and acceptance in many applied areas. On the international scene, the United Nations Industrial Development Organisation (UNIDO, 1972) has issued guidelines for project evaluation that take into account multiple objectives and they are addressed primarily to government project evaluators and represent a determined commitment to multi-objective analysis for developing nations. Thus, the inclusion of multiple objectives in the planning process will broaden and complicate the decision making framework.

The purpose of multicriterion methods in WR planning is to help improve the quality of decisions by making decision making more explicit, rational and efficient. There are two major rules that these methods have played in WR planning: (i) to provide information on trade-offs by displaying how options perform on various criteria (this helps the users to better understand the nature of the choices they make); and (ii) to help users to articulate and apply their values to the problem rationally and consistently and document the process. The object is to inspire confidence in the soundness of the decision without making it unnecessarily difficult. Many studies for planning with multiple objectives considered either an aggregate index for all objectives or a single measure for different objectives to enable the formulation of applicable mathematical models. This kind of formulation has the disadvantage that each objective cannot individually be estimated in cardinal measure by relatively accurate mathematical models. In addition, many mathematical models postulated have a drawback of inability to consider the qualitative criteria in decision making. To overcome these difficulties Gershon *et al.* (1982) combined ELECTRE I (Benayoun *et al.*, 1966; Roy, 1971) and ELECTRE II (Roy, 1968, 1971 and 1974; Roy and Bertier 1971; Abi-ghanem *et al.*, 1978) methodologies into an overall method of ranking alternative systems in the presence of qualitative criteria and applied it to a water resources management study. David and Duckstein (1976), Mohan and Raipure (1991) and Reddy (1993) also used these methods for ranking large-range WR systems. This method has the advantage that it requires only an interval scale while the other methods require the use of cardinal scale which is very much subjective in nature. The techniques other than ELECTRE which have been designed to handle qualitative data and discrete systems include: concord analysis (Nijkamp and Vos, 1977), Q analysis (Duckstein and Kempf, 1979), lexicographic ordering (MacCrimmon, 1973) and a method given by Zionts (1977).

METHODOLOGY

The problem under consideration has two distinguishing characteristics. First it is necessary to screen the alternatives, which may be large in number, to choose a manageable subset of preferred systems. Then the task is to rank these preferred systems. Formulation of the problem includes criteria with both quantitative and qualitative data and discrete alternative systems (reservoir combinations). ELECTRE I and II techniques are well suited to deal with both these situations.

ELECTRE I

The idea in this algorithm is to choose those systems (alternatives represented as nodes) which are preferred for most of the criteria and yet do not cause an unacceptable level of discontent for any one criterion. The construction of the above subset is accomplished by defining a binary relationship called an "outranking relationship" which captures the preferences of the DM that can be well accounted for, by means of the available data. To synthesize these relationships three concepts, concordance matrix, discordance matrix and threshold values, are developed.

The concord index (an element of the concordance matrix), C(i,j), is the weighted measure of the number of criteria for which i is preferred to j or for which i and j are equally preferred. For this purpose weights are assigned to each criterion. Therefore C(i,j) can be viewed as a measure of the satisfaction that the DM receives in choosing i over j. The concord index is defined as:

$$C(i,j) = (W^{+} + 0.5W^{=}) / (W^{+} + W^{=} + W^{-}) \quad (1)$$

Where

W^{+} = Sum of the weights for which i is preferred to j
$W^{=}$ = Sum of the weights where i and j are equally preferred
W^{-} = Sum of the weights for which j is preferred to i.

The discord index, D(i,j), is viewed as a measure of the dissatisfaction of choosing i over j. To define the discord index, an interval scale common to all criteria is defined. This scale is used to compare the discomfort caused by going from level K1 to level K2 of criterion r with the discomfort of going from level K3 to level K4 of criterion s. Each of the criteria can have a different range of scales. For qualitative criteria where ordinal scales (best,..., worst) are given, numerical values are assigned in the same manner as grades are given to students.

The normalised discord interval is calculated for each criterion where alternative j is preferred to i and the largest value of these normalised discord intervals is defined as the discord index for alternatives i and j. Therefore, discord index is defined as:

$$D(i,j) = (\text{Max. interval where } i < j)/\text{Total range of scale.} \quad (2)$$

Then the outranking relationship is defined to select the preferred alternatives. For this purpose threshold values (p,q), both between 0 and 1, are defined by the DM. By choosing p DM specifies how much concordance he wants and by choosing q, he specifies the amount of discordance he is willing to tolerate. $p=1$ corresponds to full concordance, which means that i should be preferred to j in terms of all criteria, and $q=0$ means that DM is not willing to tolerate any amount of discordance. It is possible that some choice of p and q may yield an unfeasible solution and in this case p and/or q must be restated. It is also possible that a cycle may be formed (i.e. i is preferred to j, j is preferred to k and k is preferred to i). In such a case all the three alternatives (i,j and k) are collapsed into one new node, which means that the same rank is assigned to all the three systems.

The preference graph (similar to the graphs shown in Fig. 2) is then constructed with the help of the conditions in equation 3 and the kernel is found. The nodes in the kernel represent those alternatives which are preferred on the basis of the outranking relationship.

$$C(i,j) > p \text{ and } D(i,j) < q \quad (3)$$

ELECTRE II

The output from ELECTRE I represents partial ordering of the preferred systems and forms the input to ELECTRE II. In contrast to ELECTRE I, there are multiple levels of concordance ($0 < p^{-} < p^{0} < p^{*} < 1$) and discordance ($0 < q^{0} < q^{*} < 1$) that are specified to construct two outranking relationships (strong and weak relationships). These two relationships in turn are used to construct two graphs (strong graph and weak graph). Ranking of the alternatives is then achieved using these graphs. The concord index for ELECTRE II is defined as:

$$C(i,j) = (W^+ + W^=) / (W^+ + W^= + W^-) \tag{4}$$

whereas D(i,j) has the same definition as in ELECTRE I. The strong relationship is defined if and only if condition (5) or (6) or both holds. The weak relationship is defined if and only if condition (7) holds.

$$C(i,j) > p^* \; ; \; D(i,j) < q^* \text{ and } W^+ > W^- \tag{5}$$

or

$$C(i,j) > p^0 \; ; \; D(i,j) < q^0 \text{ and } W^+ > W^- \tag{6}$$

$$C(i,j) > p^- \; ; \; D(i,j) < q^* \text{ and } W^+ > W^-. \tag{7}$$

As a result of these relationships, two graphs can be constructed – one for strong and one for weak relationships. The strong graph is always a subgraph of the weak graph but the distinction between strong performance and weak performance must be made to assure a complete ranking of the alternatives. These graphs are then used in an iterative procedure to obtain the rankings. The ELECTRE II approach uses two separate rankings, which are called forward ranking and reverse ranking, to arrive at the final rankings of the alternatives.

There are five steps in the forward ranking procedure. *Step 1*: Identify all nodes having no precedent (i.e. those nodes that have no arcs directed towards them) in the strong graph and denote this set as set A. *Step 2*: Select all nodes in set A having no precedent in the weak graph and denote this set as set B. The nodes in set B are assigned rank one. *Step 3*: Reduce strong and weak graphs by eliminating all nodes in set B and all the arcs emanating from these nodes. *Step 4*: With the reduced graphs perform steps 1 to 3 and the reduced set of new nodes are given rank two. *Step 5*: This iterative procedure is continued till all nodes in both strong and weak graphs are eliminated and all systems are ranked.

In reverse ranking, the first step is to reverse the direction of the arcs in the strong and weak graphs. If a system i is preferred to j in forward ranking, the system j is preferred to i in reverse ranking and a high concord relationship becomes a low concordance and a low discord relationship becomes a high discordance. The remaining steps are identical to the steps outlined in forward ranking with one difference: the system which is ranked last is ranked one and the remaining systems are ranked in reverse order. This re-establishes the correct direction of the ranking process. The final ranking (r) is obtained, as suggested by Roy and Bertier (1971), by taking the average of the forward (r') and reverse (r'') rankings (i.e. $r=(r'+r'')/2$). The system which gets least average value is ranked first and the system having next value is ranked second and so on till all elements of the systems are ranked.

APPLICATION

The physical system under consideration in this study, the Krishna river basin, is one of the major peninsular rivers of south India. River Krishna, the total length of which is 1400 km, rises from a spring at Mahabalaswar and spans three states: Maharashtra, Karnataka and Andhra Pradesh. Its draining area is of the order of 258 948 km^2. The important tributaries of this river are Koyana, Ghataprabha, Malaprabha, Bhima and Tungabhadra. The river finally joins the Bay of Bengal at Machilipatnam. The Krishna river basin, reservoirs under consideration, their names, and their location are shown in Fig. 1. Salient features of the reservoirs in the basin are given by Central Board of Irrigation and Power (CBIP, 1989).

Most of these reservoirs in the basin were constructed initially as single purpose projects. Increase in population densities and in the number of industries along the river courses and around the reservoirs changed the land-use pattern over the years. This resulted in increased demand for water and the problems related to quantity and quality of water, floods and environmental quality. Therefore, for the sustained development of the basin one has to consider various objectives. In the present study the objectives are considered in the form of criteria.

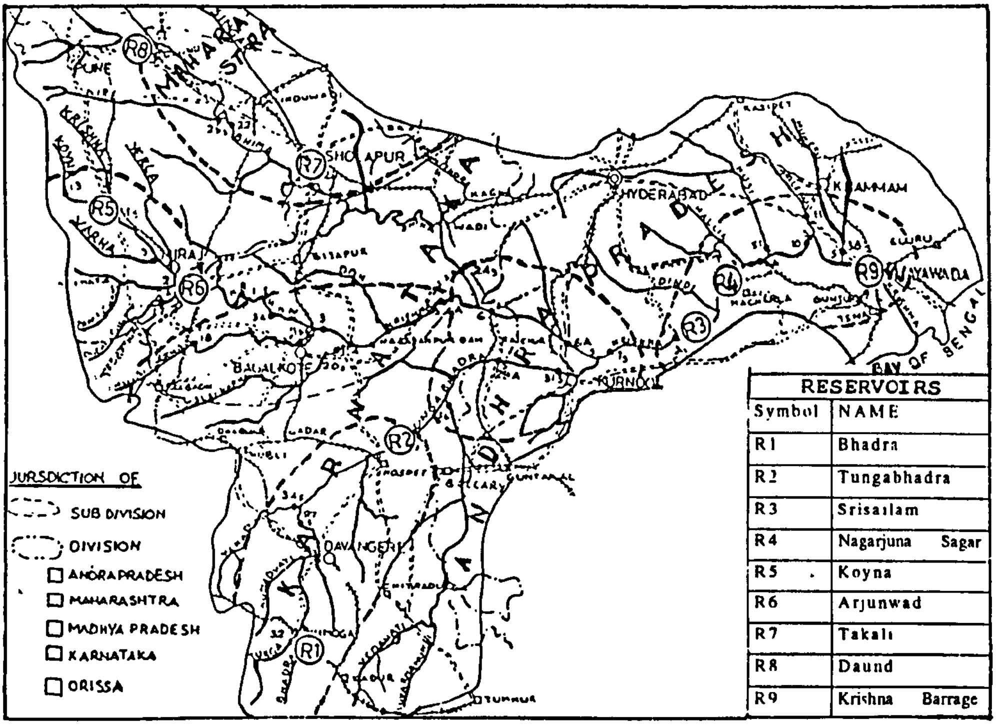

Figure 1. Krishna river basin.

Table 1. Reservoir alternative systems

Alt. no	Reservoir combination	Alt. no	Reservoir combination	Alt. no	Reservoir combination
1	R3, R4, R9	10	R4, R7, R8, R9	19	R2, R3, R6, R9
2	R2, R4, R5, R8, R9	11	R2, R4, R7, R9	20	R4, R5, R8, R9
3	R2, R4, R7, R9	12	R3, R5, R8, R9	21	R2, R3, R5, R7
4	R2, R3, R4	13	R4, R8, R9	22	R2, R5, R8, R9
5	R3, R5, R7, R9	14	R2, R4, R8	23	R2, R5, R8
6	R1, R5, R8, R9	15	R1, R4, R7	24	R5, R8, R9
7	R2, R4, R8, R9	16	R1, R3, R4, R5, R7, R8	25	R3, R5, R7
8	R1, R3, R4, R7	17	R2, R3, R4, R5, R9	26	R2, R5, R7
9	R2, R4, R5, R9	18	R2, R4, R5, R8	27	R2, R6, R9

The purpose of the study is to find out the most suitable planning of the reservoirs with their associated purposes, aimed at the development of the basin. A total of 27 alternatives (which do not represent all possible combinations of reservoirs) with six criteria (irrigation, power production, drinking water, environmental quality, flood control and cost of the project) are compared (see Table 1). Data related to drinking water quality and environmental quality are taken from the report by Abbasi (1991). Regarding the other criteria, the data are taken from various reports published by the Government of India. The performance of the different alternatives is an indication of the collective contribution from the individual reservoirs considered in each of the alternatives.

Table 2. Criteria, specifications, weights and scales

Criteria	Specifications	Wts	Interval scale	No of levels	Levels	Equal wts	Equal scales
Irrigation (IRR)	Million acres of area	10	0-80	8 (10)	0-0.5 0.5-1 1-1.5 1.5-2 2-2.5 2.5-3 3-3.5 >3.5	10	0-80
Hydropower (HP)	Thousand MW	8	0-40	4 (10)	0-1 1-2 2-3 >3	10	0-80
Drinking Water (DW)	Quality (good or average)	5	0-20	2 (10)	Average Good	10	0-80
Environmental Quality (EQ)	Preservation of designated areas and existing facilities, effect on wildlife and vegetation, effect on land environment, submergence and rehabilitation	8	0-30	2 (15)	Average Good	10	0-80
Flood Protection (F)	Expected flood losses (million dollars)	6	0-75	5 (15)	0-2.5 2.5-5 5-7.5 7.5-10 >10	10	0-80
Cost	Implementation, operation and maintenance (million dollars)	8	0-60	5 (12)	0-10 10-20 20-30 30-40 >40	10	0-80

*number given in the parenthesis refers to no. points assigned to each level

For the evaluation of the alternatives each criterion is given some specifications as shown in Table 2. For determining the discord matrix, all criteria have been assigned some scale intervals. Depending upon the number of levels of each criterion points can be assigned to various levels. For example, irrigation has 8 levels with the total scale interval 80 (i.e. each level has 10 points). The weighting, maximum scale intervals, number of levels and points assigned to each level are given in Table 2. Unit matrix (Table 3) gives the points assigned to each alternative under different criteria. The concordance and discordance matrices are shown in Table 4 and Table 5 respectively. Element C(1,2) in concordance matrix is calculated as C(1,2) = (8+0.5*31)/45 = 0.52. Similarly, discordance matrix element D(1,2) = (45-30)/80 = 0.19.

Table 3. Unit matrix

Crit-eria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
IRR	70	70	60	70	30	50	70	60	80	60	70	60	60	70	50	50	60	70	40	80	40	60	60	50	40	40	30
P	40	30	30	40	20	20	30	30	40	30	30	20	30	30	30	30	30	30	30	40	20	20	20	20	20	20	20
DW	20	20	20	20	10	20	20	10	10	10	10	20	10	10	10	10	10	10	10	10	10	20	10	10	10	10	10
EQ	15	15	15	16	30	15	15	15	15	15	15	15	15	15	30	30	30	15	15	15	15	15	15	15	15	30	30
F	45	30	45	45	60	60	45	60	60	45	45	60	60	60	60	60	60	45	75	60	60	60	60	75	75	60	60
Cost	12	12	12	24	60	24	12	24	12	24	12	36	24	24	24	36	24	24	48	12	36	36	36	36	48	36	48

Table 4. Concord matrix

*	.52	.70	.41	.64	.68	.59	.73	.51	.67	.59	.68	.73	.62	.64	.64	.64	.56	.73	.51	.73	.68	.73	.73	.73	.64	.64
.48	*	.68	.39	.64	.68	.57	.64	.42	.64	.57	.68	.64	.53	.56	.56	.56	.53	.64	.42	.73	.68	.73	.73	.73	.64	.64
.30	.32	*	.21	.64	.68	.39	.53	.42	.47	.39	.57	.53	.42	.56	.56	.44	.36	.64	.42	.73	.57	.62	.73	.73	.64	.64
.59	.61	.79	*	.64	.77	.68	.82	.60	.76	.68	.68	.82	.71	.73	.64	.73	.64	.73	.60	.73	.68	.73	.73	.73	.64	.64
.36	.36	.36	.36	*	.51	.36	.48	.48	.41	.36	.51	.48	.48	.39	.39	.39	.41	.54	.48	.57	.51	.57	.63	.63	.48	.59
.32	.32	.32	.23	.49	*	.32	.36	.44	.29	.32	.30	.36	.36	.38	.29	.27	.29	.56	.44	.58	.30	.36	.53	.64	.49	.49
.41	.43	.61	.32	.64	.68	*	.64	.42	.58	.50	.68	.64	.53	.56	.56	.56	.47	.64	.42	.73	.68	.73	.73	.73	.64	.64
.27	.36	.47	.18	.52	.64	.36	*	.39	.43	.36	.44	.50	.39	.52	.43	.41	.32	.59	.39	.61	.44	.50	.68	.68	.52	.52
.49	.58	.58	.40	.52	.56	.58	.61	*	.54	.58	.56	.61	.61	.52	.52	.52	.54	.68	.50	.61	.56	.61	.68	.68	.52	.52
.33	.36	.53	.24	.59	.71	.42	.57	.46	*	.42	.51	.57	.46	.59	.50	.48	.39	.59	.46	.68	.51	.57	.68	.68	.59	.59
.41	.43	.61	.32	.64	.68	.50	.64	.42	.58	*	.68	.64	.53	.56	.56	.56	.47	.64	.42	.73	.68	.73	.73	.73	.64	.64
.32	.32	.43	.32	.49	.70	.32	.56	.44	.49	.32	*	.56	.44	.58	.49	.47	.38	.56	.44	.67	.50	.56	.73	.64	.58	.49
.27	.36	.47	.18	.52	.64	.36	.50	.39	.43	.36	.44	*	.39	.52	.43	.41	.32	.59	.39	.61	.44	.50	.68	.68	.52	.52
.38	.47	.58	.29	.52	.64	.47	.61	.39	.54	.47	.56	.61	*	.52	.43	.52	.43	.59	.39	.61	.56	.61	.68	.68	.52	.52
.36	.44	.44	.27	.61	.62	.44	.48	.48	.41	.44	.42	.48	.48	*	.41	.39	.41	.68	.48	.70	.42	.48	.66	.77	.61	.61
.36	.44	.44	.36	.61	.71	.44	.57	.48	.50	.44	.51	.57	.57	.59	*	.48	.50	.68	.48	.79	.51	.57	.74	.77	.70	.61
.36	.44	.56	.27	.61	.73	.44	.59	.48	.52	.44	.53	.59	.48	.61	.52	*	.41	.68	.48	.70	.53	.59	.77	.77	.61	.61
.44	.47	.64	.36	.59	.71	.53	.68	.46	.61	.53	.62	.68	.57	.59	.50	.59	*	.59	.46	.68	.62	.68	.68	.68	.59	.59
.27	.36	.36	.27	.46	.44	.36	.41	.32	.41	.36	.44	.41	.41	.32	.32	.32	.41	*	.32	.61	.44	.50	.57	.59	.52	.54
.49	.58	.58	.40	.52	.56	.58	.61	.50	.54	.58	.56	.61	.61	.52	.52	.52	.54	.68	*	.61	.56	.61	.68	.68	.52	.52
.27	.27	.27	.27	.43	.42	.27	.39	.39	.32	.27	.33	.39	.39	.30	.21	.30	.32	.39	.39	*	.33	.39	.46	.48	.41	.43
.32	.32	.43	.32	.49	.70	.32	.56	.44	.49	.32	.50	.56	.44	.58	.49	.47	.38	.56	.44	.61	*	.56	.73	.64	.58	.49
.27	.27	.38	.27	.43	.64	.27	.50	.39	.43	.27	.44	.50	.39	.52	.43	.41	.32	.50	.39	.61	.44	*	.68	.59	.52	.43
.27	.27	.27	.27	.37	.47	.27	.32	.32	.32	.27	.27	.32	.32	.34	.26	.23	.32	.43	.32	.54	.27	.32	*	.52	.46	.37
.27	.27	.27	.27	.37	.36	.27	.32	.32	.32	.27	.36	.32	.32	.23	.23	.23	.32	.41	.32	.52	.36	.41	.48	*	.43	.46
.36	.36	.36	.36	.52	.51	.36	.48	.48	.41	.36	.42	.48	.48	.39	.30	.39	.41	.48	.48	.59	.42	.48	.54	.57	*	.52
.36	.36	.36	.36	.41	.51	.36	.48	.48	.41	.36	.51	.48	.48	.39	.39	.39	.41	.46	.48	.57	.51	.57	.63	.54	.48	*

Table 5. Discord matrix

*	.19	.00	.15	.60	.15	.00	.15	.13	.15	.00	.30	.15	.15	.19	.30	.19	.15	.45	.13	.30	.30	.30	.30	.45	.30	.45
.13	*	.00	.15	.60	.15	.00	.15	.13	.15	.00	.30	.15	.15	.19	.30	.19	.15	.45	.13	.30	.30	.30	.30	.45	.30	.45
.13	.19	.*	.15	.60	.15	.13	.15	.25	.15	.13	.30	.15	.15	.19	.30	.19	.15	.40	.25	.30	.30	.30	.30	.45	.30	.45
.00	.19	.00	*	.45	.00	.00	.00	.13	.00	.00	.15	.00	.00	.19	.19	.19	.00	.30	.13	.15	.15	.15	.15	.30	.19	.30
.50	.50	.38	.50	*	.25	.50	.38	.63	.38	.50	.38	.38	.50	.25	.25	.38	.50	.13	.63	.13	.38	.38	.25	.13	.13	.00
.25	.38	.19	.25	.45	*	.25	.13	.38	.19	.25	.15	.13	.25	.19	.19	.19	.25	.30	.38	.15	.15	.15	.15	.30	.19	.30
.13	.19	.00	.15	.60	.15	*	.15	.13	.15	.00	.30	.15	.15	.19	.30	.19	.15	.45	.13	.30	.30	.30	.30	.45	.30	.45
.19	.38	.19	.19	.45	.13	.19	*	.25	.19	.19	.15	.00	.13	.19	.19	.19	.19	.30	.25	.15	.15	.15	.15	.30	.19	.30
.19	.38	.19	.19	.60	.15	.19	.15	*	.19	.19	.30	.15	.15	.19	.30	.19	.19	.45	.00	.30	.30	.30	.30	.45	.30	.45
.13	.19	.13	.13	.45	.13	.13	.00	.25	*	.13	.15	.00	.13	.19	.19	.19	.13	.30	.25	.15	.15	.15	.15	.30	.19	.30
.13	.19	.00	.15	.60	.15	.00	.15	.13	.15	*	.30	.15	.15	.19	.30	.19	.15	.45	.13	.30	.30	.30	.30	.45	.30	.45
.25	.38	.19	.25	.30	.00	.19	.13	.25	.19	.19	*	.13	.13	.19	.19	.19	.19	.15	.25	.00	.00	.00	.00	.15	.19	.19
.19	.38	.19	.19	.45	.13	.19	.00	.25	.19	.19	.15	*	.13	.19	.19	.19	.19	.30	.25	.15	.15	.15	.15	.30	.19	.30
.19	.38	.19	.19	.45	.13	.19	.00	.13	.19	.19	.15	.00	*	.19	.19	.19	.19	.30	.13	.15	.15	.15	.15	.30	.19	.30
.25	.38	.19	.25	.45	.13	.25	.13	.38	.19	.25	.15	.13	.25	*	.15	.13	.25	.30	.38	.15	.15	.15	.15	.30	.15	.30
.25	.38	.19	.25	.30	.13	.25	.13	.38	.19	.25	.13	.13	.25	.00	*	.13	.25	.15	.38	.00	.13	.13	.00	.15	.00	.15
.19	.38	.19	.19	.45	.13	.19	.00	.25	.19	.19	.15	.00	.13	.00	.15	*	.19	.30	.25	.15	.15	.15	.15	.30	.15	.30
.13	.19	.13	.13	.45	.13	.13	.00	.13	.00	.13	.15	.00	.00	.19	.19	.19	*	.30	.13	.15	.15	.15	.15	.30	.19	.30
.38	.56	.38	.38	.19	.19	.38	.25	.50	.38	.38	.25	.25	.38	.19	.19	.25	.38	*	.50	.19	.25	.25	.13	.00	.19	.19
.19	.38	.19	.19	.60	.15	.19	.15	.00	.19	.19	.30	.15	.15	.19	.30	.19	.19	.45	*	.30	.30	.30	.30	.45	.30	.45
.38	.38	.25	.38	.30	.13	.38	.25	.50	.25	.38	.25	.25	.38	.19	.19	.25	.38	.15	.50	*	.25	.25	.13	.15	.19	.19
.25	.38	.19	.25	.30	.00	.19	.13	.25	.19	.19	.00	.13	.13	.19	.19	.19	.19	.15	.25	.00	*	.00	.00	.15	.19	.19
.25	.38	.19	.25	.30	.13	.19	.13	.25	.19	.19	.13	.13	.13	.19	.19	.19	.19	.15	.25	.00	.13	*	.00	.15	.19	.19
.38	.56	.38	.38	.30	.19	.38	.19	.38	.38	.38	.19	.19	.25	.19	.19	.19	.38	.15	.38	.19	.19	.19	*	.15	.19	.19
.38	.56	.38	.38	.19	.19	.38	.25	.50	.38	.38	.25	.25	.38	.19	.19	.25	.38	.13	.50	.19	.25	.25	.13	*	.19	.19
.38	.38	.25	.38	.30	.13	.38	.25	.50	.25	.38	.25	.25	.38	.13	.13	.25	.38	.15	.50	.00	.25	.25	.13	.15	*	.15
.50	.50	.38	.50	.15	.25	.50	.38	.63	.38	.50	.38	.38	.50	.25	.25	.38	.50	.13	.63	.13	.38	.38	.25	.13	.13	*

RESULTS AND DISCUSSION

The results of ELECTRE I for p = 0.65 and q = 0.25 for different cases are given in Table 6. With uniform weights and scales (case III) the preferred set is 1, 2, 4, 5, 15, 16, 17 and 27. All these nodes are present in all other cases with some other new nodes entering into the preferred set. For original weights, changing the scale resulted in selection of the same nodes in cases I and II (except node 17 in case II), which may be taken to show that the change in scales affects the reduced set marginally. In contrast, a change in weights (as in cases III and IV) considerably affects the preferred set. Therefore, it can be said that change in weights has greater effect on the result of ELECTRE I than changing scales. However, neither effect is of great significance.

Table 6. Results of ELECTRE I

Case	Combinations	Preferred alternatives
I	Original weights & scales	1, 2, 4, 5, 9, 16, 18 & 27
II	Original weights & scales	1, 2, 4, 5, 9, 16, 17 & 27
III	Equal weights & scales	1, 2, 4, 5 & 27
IV	Equal weights & scales	1, 2, 4, 5, 15, 16, 17 & 27

The results of ELECTRE II for $p^* = 0.8$, $p^0 = 0.65$ and $p^- = 0.5$; $q^0 = 0.2$, $q^* < 0.45$ are given in Fig. 2 in the form of strong and weak graphs. The final rankings are given in Table 8. Alternative 4 is given first rank in all the cases while node 1 in case I, nodes 1 and 17 in case II, and nodes 15 and 17 in case IV also get first rank. These alternatives (i.e. 1, 4, 15 and 17) can further be analysed with much rigour to arrive at a more precise ranking. Therefore alternative 4 seems to be the best option of them all. It is also found that, even if there is a slight change in the results of ELECTRE I, the final ranking in ELECTRE II yielded the same result. The change in weights has no effect on ELECTRE II results.

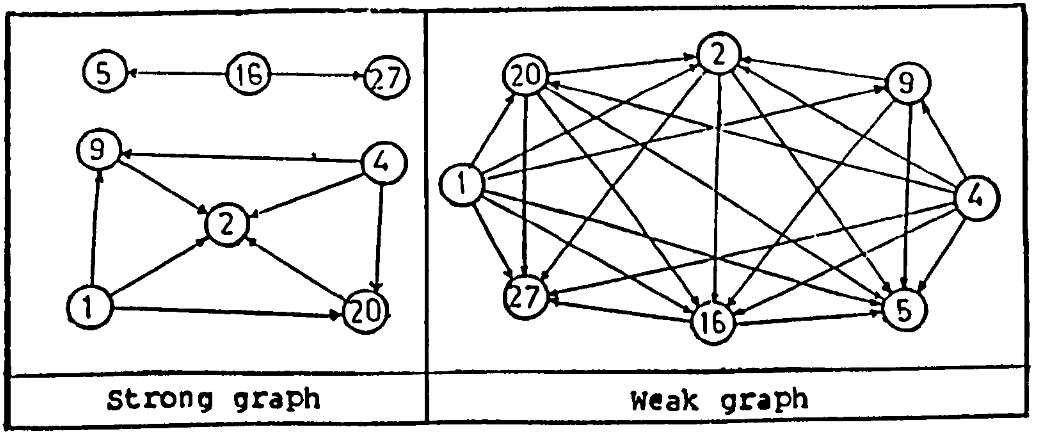

Figure 2. Strong and weak preference graphs.

The sensitivity of selection of alternatives with changes in threshold values (p and q) was also studied and the results of ELECTRE I for these changes are shown in Table 7. It is clear from Table 7 that the preferred alternatives have changed for different values of p and q. But nodes 1 and 4 are common on all occasions. It is also found that there was no significant change in final ranking of alternatives in ELECTRE II.

Table 7. Sensitivity analysis

Threshold values	Preferred alternatives
p = 0.6; q = 0.1	1, 2, 4, 5, 9, 12, 16, 17, 19, 20, 22, 23, 25 & 27
p = 0.6; q = 0.2	1, 4 & 5
p = 0.6; q = 0.3	1 & 4
p = 0.6; q = 0.4	1 & 4
p = 0.65; q = 0.25	1, 2, 4, 5, 9, 16, 18, 20 & 27
p = 0.65; q = 0.5	1, 2, 4, 5, 9, 16, 18, 20 & 27
p = 0.8; q = 0.2	All alternatives

Table 8. ELECTRE II rankings

Alternatives	1	2	4	5	9	15	16	17	18	20	27
Case 1	1	3	1	3	2	-	4	-	4	2	5
Case 2	1	2	1	3	2	-	2	1	3	2	3
Case 3	2	2	1	2	-	-	-	-	-	-	3
Case 4	2	3	1	2	-	1	2	1	-	-	3

CONCLUSIONS

ELECTRE I and II techniques have been applied to a river basin planning problem. The object of the problem is to find out the most suitable planning of the reservoirs for the development of the basin. Twenty seven alternatives with six criteria are considered for this purpose and the following conclusions are drawn.

(i) In ELECTRE I, change in weights has shown more considerable effect on the results than changing the scales. However, neither effect is significant. (ii) The results of ELECTRE II have shown that alternatives 1, 4, 15 and 17 are ranked highest. In these alternatives, node 4 is present in all the cases, whereas other nodes are present only in one or two cases. Therefore, alternative 4 can be considered as the best in this set. However, for further distinction among these alternatives some more data with rigourous analysis has to be done. It is also found that, even though there is a slight change in the results of ELECTRE I, the final ranking in ELECTRE II has not been affected. Moreover, change in weights also has an insignificant effect on ELECTRE II. (iii) Even though the preferred alternatives are different for different values of p and q, nodes 1 and 4 are present in all the outcomes. It is also seen that there is no significant change in the final ranking of alternatives in ELECTRE II for different values of p and q.

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