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Ranking of river basin alternatives using ELECTRE

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Abstract Ranking of river basin planning and development alternatives under a multi-criterion environment, including both qualitative and quantitative aspects, is examined. The purpose is to find the most suitable planning for reservoirs with their associated purposes aimed at the development of the major peninsular river (Krishna) basin in India. A total of seven reservoirs and a diversion network are considered for the formulation of 24 alternative systems with 18 criteria, of which nine are qualitative and the remainder are quantitative in nature. A set of best alternatives with their ordering is obtained using **ELECTRE** (**EL**imination **E**t (and) **C**hoice **T**ranslating **RE**ality).

Classement par la méthode ELECTRE de plans d'aménagement de bassins fluviaux

Résumé Cet article présente le classement des solutions envisagées pour la planification et l'aménagement de bassins fluviaux. Ce classement a été effectué dans un environnement multicritères, tant qualitatifs que quantitatifs. L'objectif de cette étude était de déterminer le plan d'aménagement et de gestion d'un système de réservoirs le plus satisfaisant dans le but de développer le bassin fluvial péninsulaire majeur de l'Inde - celui du fleuve Krishna. Un ensemble de sept réservoirs et un réseau de dérivations ont été pris en compte pour définir 24 solutions d'aménagement appréciées selon 18 critères, neuf étant qualitatifs alors que les autres étaient de nature quantitative. Le classement des meilleures alternatives a été établi grâce à ma méthode **ELECTRE** (**EL**imination **E**t **C**hoix **T**raduisant la **RE**alité).

INTRODUCTION

Multi-objective analysis has developed in explicit form largely through the work of the Harvard Water Program (HWP) with its research findings published by Maass *et al.* (1962). The concept of "parieto optimality" was presented in the pioneering works of Koopmans (1951) and Markowitz (1959). A general approach for the vector-function maximization problem was treated by Kuhn & Tucker (1951). Marglin (1967) contributed to the task of converting objectives into design criteria. The political decision process appropriate to

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many water resources (WR) problems was described by Major (1969) and a valuable insight into the political decision process offered by Haith & Loucks (1976). 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. Cohon & Marks (1975) reviewed and evaluated some of the multi-objective programming methods. On the international scene, the United Nations Industrial Development Organization (UNIDO, 1972) issued guidelines for project evaluation that take into account multiple objectives. They are addressed primarily to government evaluators and represent a determined commitment to multi-objective analysis for developing nations. The impact of "principles and standards" of the Water Resources Development Act (WRDA, 1974) on the policy making process and a review of some of the methodologies available to planners in the definition and evaluation of multiple objectives were discussed by Loucks *et al.* (1981).

The purpose of multi-criterion methods in WR planning is to help improve the quality of decisions by making decision making more explicit, rational and efficient. Many studies for planning with multiple objectives consider either an aggregate index for all objectives or a single measure for different objectives to enable the formulation of an applicable mathematical model. 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 the drawback of an inability to consider 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; Roy & Bertier, 1971; Abi-Ghanen *et al.*, 1978) methodologies into an overall method of ranking alternative systems in the presence of qualitative criteria and applied the combined method to a water resources management study. David & Duckstein (1976), Mohan & Raipuri (1991) and Anand (1994, 1995) also have used these methods for ranking large range WR systems. This method has an advantage that it requires only an interval scale while other methods require the use of a cardinal scale which is very subjective in nature. Techniques other than ELECTRE which have been designed to handle qualitative data and discrete systems include: concord analysis (Nijkamp & Vos, 1977), Q analysis (Duckstein & Kempf, 1979) lexicographic ordering (MacCrimmon, 1973) and a method given by Zionts (1977).

METHODOLOGY

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

ELECTRE I

The idea in this algorithm is to choose those nodes (i.e. alternative systems) which are preferred for most of the criteria and yet do not cause an unacceptable level of discontent for any one criterion. For this purpose each criterion is given some weight (W) according to its relative importance. The construction of the above mentioned subset is accomplished by defining a binary relationship, an "outranking relationship", which captures the preferences of the decision maker (DM) that can be well accounted for by means of the available data. To synthesize these relationships, three concepts are developed: concordance matrix; discordance matrix and threshold values.

The concord index (an element of the concordance matrix) $C(i,j)$, is the weighted measure of the numbers i and j of the criteria for which i is preferred to j or for which i and j are equally preferred. 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:

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

where W^{+} = the sum of the weights for which i is preferred to j; $W^{=}$ = the sum of the weights where i and j are equally preferred; and W^{-} = the 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 the 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 criterion can have a different range of scales. For qualitative criteria where an ordinal scale (best, ..., worst) is given, numerical values are assigned in the same manner as grades are given to students.

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

$$D(i,j) = (\text{max. interval where } i < j) / \text{total range of scale} \qquad (2)$$

The outranking relationship is then defined to select the non-dominated alternatives. For this purpose threshold values (p, q), both between 0 and 1 are defined by the DM. By choosing p, the DM specifies how much concordance he wants and by choosing q, he specifies the amount of discordance he is willing to tolerate. Specifying $p = 1$ corresponds to full concordance, which means that i should preferred to j in terms of all criteria, and $q = 0$ means that the DM is not willing to tolerate any amount of discordance. It is possible that some choices of p and q may yield an infeasible solution and in this case p and/or q must be restated. It is also possible that a loop may be formed (i.e. i

is preferred to j is preferred to k and k is preferred to i). In such a case all three alternative (i, j and k) are collapsed into one new node, which means that the same rank is assigned to all three systems.

A preference graph 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 relationships.

$$C(i,j) \geq p \text{ and } D(i,j) \leq q \tag{3}$$

ELECTRE II

The output from ELECTRE I represents a 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 $D(i,j)$ is defined the same as in ELECTRE I. A strong relationship is defined if and only if condition (5) or (6) (or both) holds. A weak relationship is defined if and only if condition (7) holds.

$$C(i,j) \geq p^* \quad D(i,j) \leq q^* \text{ and } W^+ \geq W^- \tag{5}$$

or $$C(i,j) \geq p^0 \quad D(i,j) \leq q^0 \text{ and } W^+ \geq W^- \tag{6}$$

$$C(i,j) \geq p^- \quad D(i,j) \leq q^* \text{ and } W^+ \geq W^- \tag{7}$$

As a result of these relationships, two graphs can be constructed, one for a strong relationship and one for a weak relationship. The strong graph is always a sub-graph of the weak graph but the distinction between a strong performance and a 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 ranking. The ELECTRE II approach uses two separate rankings, which are called forward ranking and reverse ranking, to arrive at the final ranking 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 the strong and weak graphs by eliminating all nodes in set B and all the arcs emanating from those nodes.

Step 4: With the reduced graphs perform again steps 1 to 3; the reduced set of new nodes is given rank two.

Step 5: This iterative procedure is continued till all the nodes in both the strong and weak graphs are eliminated and all systems are ranked.

In the reverse ranking, the first step is to reverse the direction of the arcs in the strong and weak graphs. If system *i* is preferred to system *j* in forward ranking, then system *j* is preferred to *i* in reverse ranking, a high concord relationship becomes 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 ranked last is ranked one and the remaining systems are ranked in the reverse order. This re-establishes the correct direction of the ranking process. The final ranking (r) is obtained, as suggested by Roy & Bertier (1971), by taking the average of the forward (r') and reverse (r'') rankings (i.e. $r = (r' + r'')/2$). The system which gets the least average value is ranked first, the system having the next value is ranked second and so on till all the systems are ranked. A computer program is used to perform the above steps and the flow charts of this program are given in Fig. 1.

APPLICATION

The physical system, the Krishna River basin, under consideration in this study is one of the major peninsular rivers of south India. The Krishna has a length of 1400 km and rises from a spring at Mahabalaswar and flows through three states: Maharashtra, Karnataka and Andhra Pradesh. Its drainage area is of the order of 260 000 km^2. The important tributaries of this river are the Koyna, Ghataphrabha, Malaprabha, Bhima and Tungabhadra. The river finally enters the Bay of Bengal at Machilipatnam in Andhra Pradesh. The Krishna River basin, the reservoirs under consideration, their names, their location and the alternatives considered in the study are shown in Fig. 2. Salient features of the reservoirs considered are presented in a Central Board of Irrigation and Power report (CBIP, 1989).

Problems in the river basins

The Bhadra, Tungabhadra, Nagarjunasagar and Ghataprabha reservoirs are dual purpose projects (irrigation and hydropower) while the Srisailam and Koyna reservoirs are hydropower projects. The Almathi reservoir is an irrigation project. With the increase in population and in the number of industries, the demand for water has increased enormously. This has resulted in the need for the development of the reservoirs for the required water resources and to consider various objectives for the sustained development of the entire basin.

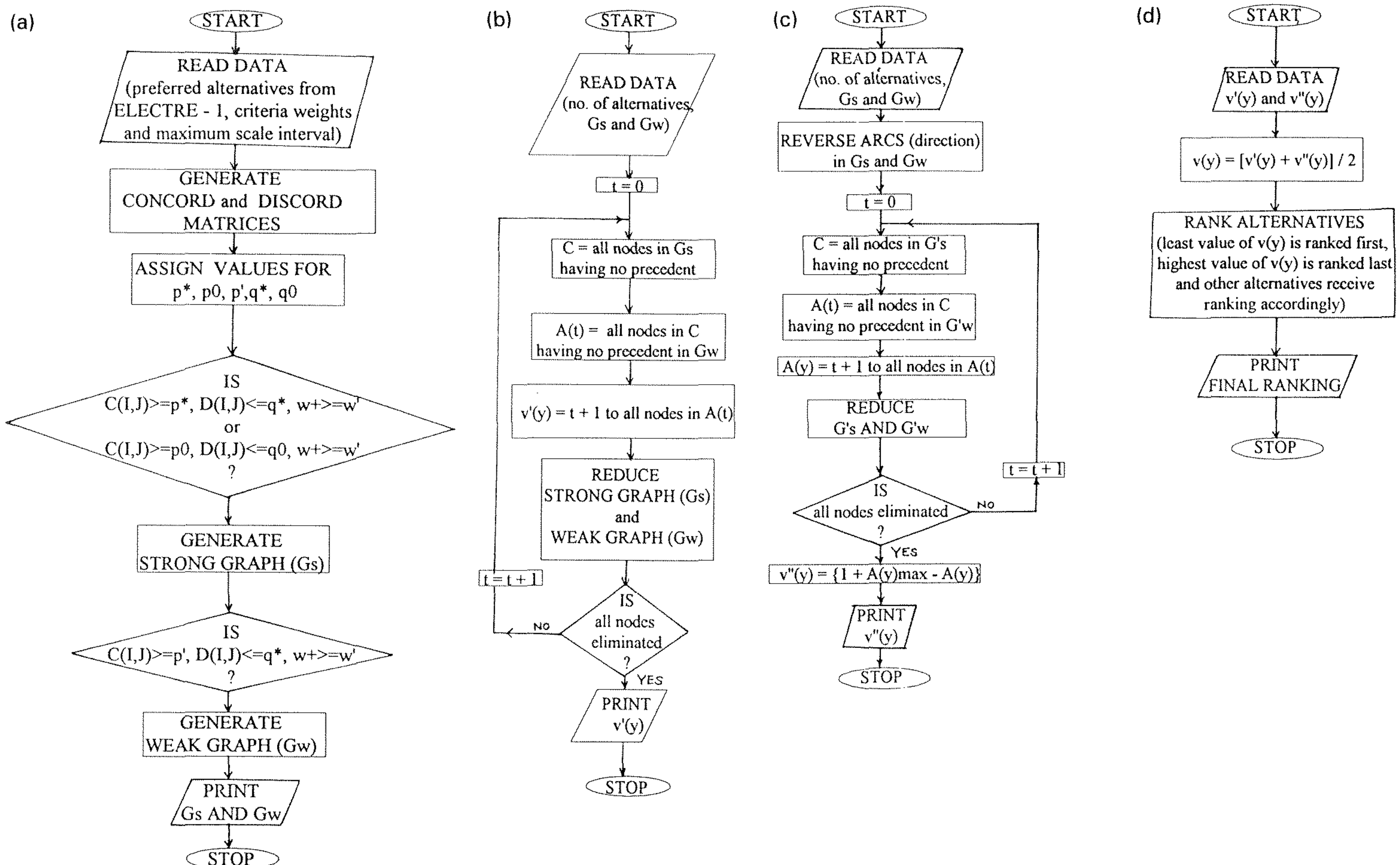
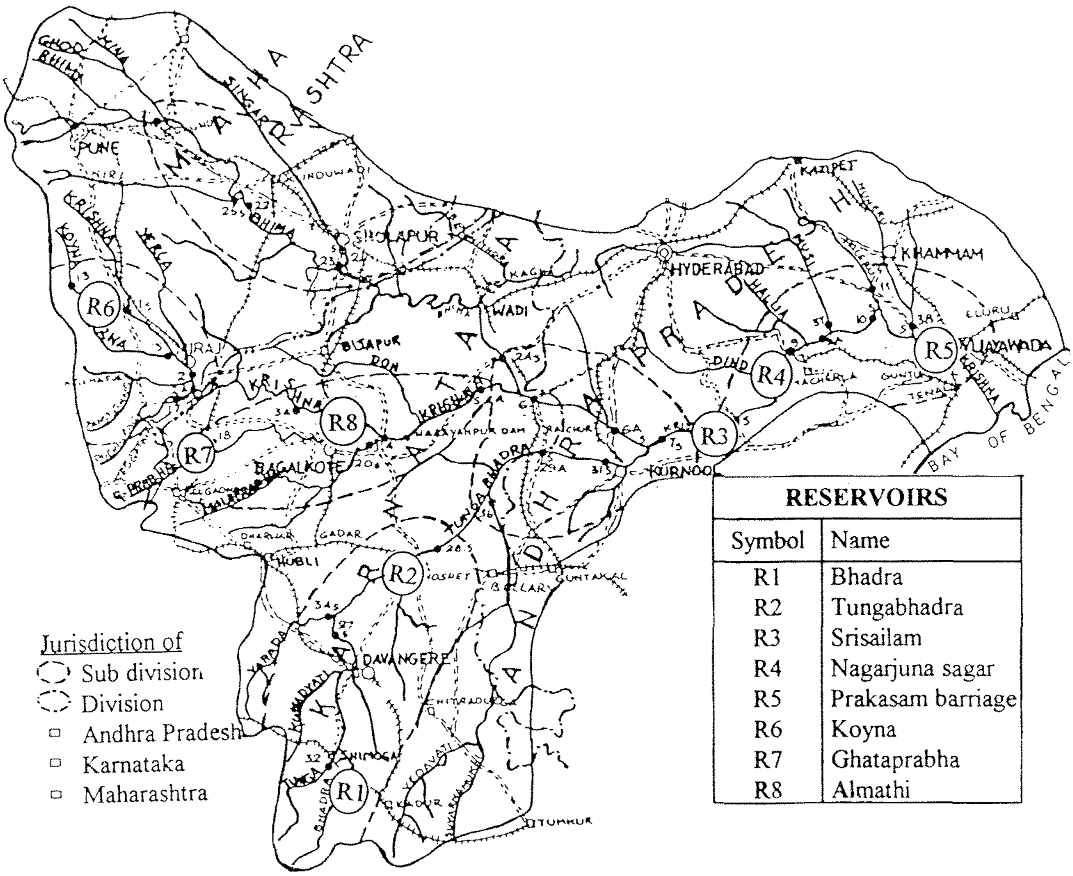


Fig. 1 Flow charts for ELECTRE II: for (a) strong and weak graphs; (b) forward ranking; (c) reverse ranking; and (d) final ranking.



RESERVOIRS	
Symbol	Name
R1	Bhadra
R2	Tungabhadra
R3	Srisailam
R4	Nagarjuna sagar
R5	Prakasam barriage
R6	Koyna
R7	Ghataprabha
R8	Almathi

<u>Reservoir system alternatives</u>: (1) R3, R4, R5; (2) R2, R4, R6, R8; (3) R2, R4, R7; (4) R2, R3, R4; (5) R1, R2, R7; (6) R2, R6, R7, R8; (7) R6, R7, R8; (8) R1, R2, R7, R8; (9) R2, R7, R8; (10) R3, R7, R8; (11) R1, R3, R4, R5; (12) R2, R3, R4, R5; (13) R3, R4, R5, R8; (14) R1, R6, R7; (15) R4, R6, R7, R8; (16) R4, R5, R8; (17) R4, R7, R8; (18) R1 R2, R3, R4, R5; (19) R2, R3, R8; (20) R5, R6, R7, R8; (21) R2, R3, R4, R5, R8; (22) R3, R4, R8; (23) R2, R6, R8; (24) R2, R3, R8;

Fig. 2 Krishna River Basin.

This has led to various problems in the basin. Some of the problems are: waterlogging, making a large portion of the irrigated area unproductive; increase in alkalinity and salinity of the subsoil resulting in health problems to livestock which consume the produce of the affected land; land submergence and the associated rehabilitation problems, etc. A detailed account of these problems, both qualitative and quantitative, is presented by Abbasi (1991) and in some Government of India reports.

The objective of the study was to find out the most suitable planning of the reservoirs with their associated purposes aimed at the development of the basin. A total of 24 alternatives (not all possible combinations of the reservoirs) with 18 criteria falling under eight main objectives were considered in this study. Each of the criteria was given a weight and further subdivided into a number of levels. Depending upon the number of levels, points could be

Table 1 Criteria and specifications

Sl. no.	Objective	Criteria	Criterion weight	Max. scale	No of level	Levels	Code	Points
I	National or regional development	C1: Irrigation (Lakh Acres)	10	100	5	<5	10	20
						5 - 10	20	40
						10 - 15	30	60
						15 - 20	40	80
						>20	50	100
		C2: Power generation (MW × 10^3)	10	100	5	<0.5	5	20
						0.5 - 1.0	10	40
						1.0 - 1.5	15	60
						1.5 - 2.0	20	80
						>2.0	25	100
		C3: Relative regional techno, socio-economic improvement	7	10	4	Fair	D	25
						Good	C	50
						Very good	B	75
						Excellent	A	100
II	Water requirement	C4: Quality of water	4	75	5	Best	A	75
						Very good	B	60
						Good	C	45
						Average	D	30
						Worst	E	15
		C5: Annual sediment load (tons × 10^6)	4	60	6	<4	5	60
						4 - 8	10	50
						8 - 12	15	40
						12 - 16	20	30
						16 - 20	25	20
						>20	30	10
		C6: Gross storage capacity (m^3 × 10^9)	6	180	12	<2	10	15
						2 - 4	20	30
						4 - 6	30	45
						6 - 8	40	50
						8 - 10	50	75
						10 - 12	60	90
						12 - 14	70	105
						14 - 16	80	120
						16 - 18	90	135
						18 - 20	100	150
						20 - 22	110	165
						>22	120	180
III	Flood protection	C7: Max. flood discharge allowed ($m^3 s^{-1}$ × 10^3)	4	150	5	<10	10	30
						10 - 20	15	60
						20 - 30	20	90
						30 - 40	25	120
						>40	30	150
		C8: Expected frequency per year	5	150	5	<0.002	10	150
						0.002 - 0.004	20	120
						0.004 - 0.006	30	90
						0.006 - 0.008	40	60
						0.008 - 0.010	50	30

assigned to various levels with a maximum scale interval specified to each criterion. Further, for each level a code (number or alphabet) was given. For example, water quality criterion under the water requirement objective had a criterion weight of 4, a maximum scale interval of 0 to 75, a number of levels

Table 1 *continued*

Sl. no.	Objective	Criteria	Criterion weight	Max. scale	No of level	Levels	Code	Points
IV	Utilization of resources	C9: Implementation costs (Rupees × 10^7)	2	200	8	<50	10	200
						50 - 100	20	175
						100 - 150	30	150
						150 - 200	40	125
						200 - 250	50	100
						250 - 300	60	75
						300 - 350	70	50
						>400	80	25
		C10: Operation and maintenance costs (Rupees × 10^6)	2	50	5	<2.5	10	50
						2.5 - 5.0	20	40
						5.0 - 7.5	30	30
						7.5 - 10.0	40	20
						>10.0	50	10
		C11: Natural resources	2	75	5	Best	A	75
						Very good	B	60
						Good	C	45
						Average	D	30
						Worst	E	15
V	Enhancement of environment	C12: Preservation of designated areas and existing facilities	5	75	3	No effect	A	75
						Little effect	B	50
						More effect	C	25
		C13: Effect on wildlife and vegetation	5	75	3	No effect	A	75
						Little effect	B	50
						More effect	C	25
		C14: Effect on land and environment	5	75	3	No effect	A	75
						Little effect	B	50
						More effect	C	25
		C15: Rehabilitation and submergence	5	60	4	Few areas	A	60
						Some areas	B	45
						Many areas	C	30
						Very many areas	D	15
VI	Recreational enhancement	C16: Tourism and recreational facilities	2	45	3	Very good	A	45
						Good	B	30
						Average	C	15
VII	Returns	C17: Returns on the investment	8	90	6	0.71 - 0.81	10	15
						0.81 - 0.91	20	30
						0.91 - 1.01	30	45
						1.01 - 1.11	40	60
						1.11 - 1.21	50	75
						1.21 - 1.31	60	90
VIII	Flexibility	C18: Flexibility of the system	2	60	2	Highly flexible	A	60
						Little flexible	B	40
						Not flexible	C	20

of 5 with 15 points assigned to each level and a code A to E (A = best; B = very good; C = good; D = average; and E = worst). These specifications are given in Table 1. 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 Alternatives *vs* criteria array

Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
C1	50	40	40	40	20	20	20	20	20	20	30	30	30	40	40	40	40	30	20	20	30	40	20	10
C2	15	10	10	10	5	5	10	5	5	20	15	10	25	10	10	10	10	10	10	10	10	15	10	10
C3	A	C	C	D	C	C	C	C	C	C	B	B	B	C	C	C	C	B	C	C	D	B	C	B
C4	D	C	C	D	B	C	C	C	C	D	C	D	D	C	C	D	A	D	C	D	D	D	C	E
C5	30	5	5	30	5	5	5	5	5	30	30	30	30	5	5	15	5	30	30	10	30	30	5	30
C6	120	40	30	50	20	20	20	20	20	30	90	100	100	20	30	120	40	80	40	80	80	50	30	100
C7	25	15	15	20	5	10	10	10	10	15	20	20	25	5	15	20	15	20	20	10	15	20	10	15
C8	50	30	30	40	30	20	20	30	10	30	40	40	40	20	30	40	30	40	30	20	40	30	20	40
C9	60	40	70	50	40	40	40	30	40	50	40	40	40	10	50	40	80	40	30	30	40	50	20	20
C10	20	40	40	40	30	30	40	30	40	50	10	40	50	30	40	30	50	30	30	30	40	50	30	40
C11	A	B	B	A	B	B	B	B	B	A	B	B	A	B	B	A	A	B	A	B	A	A	B	B
C12	C	C	B	C	B	C	B	C	C	C	B	C	C	B	B	A	B	B	C	B	C	C	C	C
C13	C	C	C	C	B	C	B	C	C	C	C	C	C	A	A	B	B	B	C	B	C	C	C	C
C14	C	C	C	C	B	C	B	C	C	B	B	C	C	A	C	C	C	C	C	B	C	C	C	C
C15	D	C	C	D	A	C	B	C	C	C	D	D	D	B	D	D	C	D	C	B	D	D	C	D
C16	C	C	A	B	B	B	B	B	B	B	C	C	C	C	A	B	A	C	B	C	B	B	B	C
C17	60	50	40	50	20	40	40	30	40	50	50	50	60	10	40	60	50	40	50	40	50	50	40	50
C18	C	C	B	C	B	C	C	B	B	C	C	C	C	B	C	C	C	B	C	C	C	C	C	C

A, B, C, D and E is an ordinal scale with A = best; B = very good; C = good; D = average and E = worst

Table 3 Unit Matrix

Criteria	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
C1	100	80	80	80	40	40	40	40	40	40	60	60	60	40	80	80	80	60	40	40	60	80	40	20
C2	60	40	40	40	20	20	40	20	20	80	60	40	100	40	40	40	40	40	40	40	40	60	40	40
C3	100	50	50	75	50	50	50	50	50	50	75	75	75	50	50	50	50	75	50	50	25	75	50	75
C4	30	45	45	30	60	45	45	45	45	30	45	30	30	45	45	30	75	30	45	30	30	30	45	15
C5	10	60	60	10	60	60	60	60	60	10	10	10	10	60	60	40	60	10	10	50	10	10	60	10
C6	180	60	45	75	30	30	30	30	30	45	135	150	150	30	45	180	60	120	60	120	120	75	45	150
C7	150	90	90	120	30	60	60	60	60	90	120	120	150	30	90	120	90	120	120	60	90	120	60	90
C8	30	90	90	60	90	120	120	90	150	90	60	60	60	120	90	60	90	60	90	120	60	90	120	60
C9	75	125	50	100	125	125	125	150	125	100	125	125	125	200	100	125	25	125	150	150	125	100	175	175
C10	40	20	20	20	30	30	20	30	20	10	50	20	10	30	20	30	10	30	30	30	20	10	30	20
C11	75	60	60	75	60	60	60	60	60	75	60	60	75	60	60	75	75	60	75	60	75	75	60	60
C12	25	25	50	25	50	25	50	25	25	25	25	50	25	25	50	75	50	50	25	50	25	25	25	25
C13	25	25	25	25	50	25	50	25	25	25	25	25	25	75	75	50	50	50	25	50	25	25	25	25
C14	25	25	25	25	50	25	50	25	25	50	50	25	25	75	25	25	25	25	25	50	25	25	25	25
C15	15	30	30	15	60	30	45	30	30	30	15	15	15	45	15	15	30	15	30	45	15	15	30	15
C16	15	15	45	30	30	30	30	30	30	30	15	15	15	15	45	30	45	15	30	15	30	30	30	15
C17	90	75	60	75	30	60	60	45	60	75	75	75	90	15	60	90	75	60	75	60	75	75	60	75
C18	20	20	40	20	40	20	20	40	40	20	20	20	20	40	20	20	20	40	20	20	20	20	20	60

Table 4 Concordance matrix

***	.66	.64	.72	.56	.65	.57	.64	.64	.55	.61	.71	.55	.60	.63	.56	.61	.67	.66	.60	.72	.66	.65	.75
.34	***	.54	.49	.55	.66	.51	.67	.66	.55	.44	.53	.46	.51	.55	.41	.42	.53	.51	.47	.64	.42	.60	.56
.36	.46	***	.49	.60	.67	.51	.73	.67	.51	.44	.53	.50	.56	.50	.43	.39	.52	.49	.48	.65	.41	.58	.56
.28	.51	.51	***	.55	.64	.51	.63	.64	.52	.41	.51	.41	.53	.51	.36	.45	.50	.53	.47	.57	.43	.59	.57
.44	.45	.40	.45	***	.55	.42	.56	.55	.49	.41	.44	.45	.48	.36	.39	.33	.39	.49	.40	.52	.43	.45	.55
.35	.34	.33	.36	.45	***	.34	.55	.47	.40	.30	.34	.36	.41	.34	.32	.23	.34	.37	.34	.43	.36	.40	.46
.43	.49	.49	.49	.58	.66	***	.71	.63	.51	.38	.47	.44	.52	.44	.42	.40	.47	.53	.50	.56	.44	.56	.59
.36	.33	.27	.37	.44	.45	.29	***	.45	.38	.32	.36	.38	.40	.28	.34	.22	.31	.36	.29	.45	.34	.34	.46
.36	.34	.33	.36	.45	.53	.37	.55	***	.41	.31	.34	.37	.44	.34	.32	.24	.34	.37	.37	.43	.37	.43	.45
.45	.45	.49	.48	.51	.60	.49	.62	.59	***	.44	.46	.33	.49	.49	.38	.39	.47	.48	.45	.57	.46	.57	.64
.39	.56	.56	.59	.59	.70	.62	.68	.69	.56	***	.56	.39	.61	.57	.42	.47	.63	.64	.64	.69	.50	.69	.64
.29	.47	.47	.49	.56	.66	.53	.64	.66	.54	.44	***	.40	.53	.48	.29	.41	.53	.53	.54	.60	.42	.59	.61
.45	.54	.50	.59	.55	.64	.56	.62	.63	.67	.61	.60	***	.57	.51	.43	.48	.59	.64	.58	.68	.57	.63	.68
.40	.49	.44	.47	.52	.59	.48	.60	.56	.51	.39	.47	.43	***	.42	.47	.41	.44	.53	.49	.55	.41	.49	.59
.38	.45	.50	.49	.64	.66	.56	.72	.66	.51	.43	.52	.49	.58	***	.45	.41	.54	.48	.52	.64	.41	.57	.56
.44	.59	.57	.64	.61	.68	.58	.66	.68	.62	.58	.71	.57	.53	.55	***	.54	.66	.63	.59	.79	.56	.61	.73
.39	.58	.61	.55	.67	.77	.60	.78	.76	.61	.53	.59	.52	.59	.59	.46	***	.60	.63	.55	.71	.48	.71	.63
.33	.47	.48	.50	.61	.66	.53	.69	.66	.53	.37	.47	.41	.56	.46	.34	.40	***	.54	.51	.57	.41	.60	.57
.34	.49	.51	.47	.51	.63	.47	.64	.63	.52	.36	.47	.36	.47	.52	.38	.38	.46	***	.41	.57	.39	.55	.60
.40	.53	.52	.53	.60	.66	.50	.71	.63	.55	.36	.46	.42	.51	.48	.41	.45	.49	.59	***	.58	.48	.58	.59
.28	.36	.35	.43	.48	.57	.44	.55	.57	.43	.31	.40	.32	.45	.36	.21	.29	.43	.43	.42	***	.35	.51	.51
.34	.58	.59	.57	.57	.64	.56	.66	.63	.54	.50	.58	.43	.59	.59	.44	.52	.59	.61	.52	.65	***	.64	.64
.35	.40	.42	.41	.55	.60	.44	.66	.57	.43	.31	.41	.37	.51	.43	.39	.29	.40	.45	.42	.49	.36	***	.53
.25	.44	.44	.43	.45	.54	.41	.54	.55	.36	.36	.39	.32	.41	.44	.27	.37	.43	.40	.41	.49	.36	.47	***

Table 5 discordance matrix

***	.30	.30	.15	.30	.45	.45	.38	.60	.30	.25	.25	.25	.63	.30	.25	.30	.25	.38	.45	.25	.30	.50	.50
.60	***	.15	.15	.15	.15	.15	.13	.30	.20	.38	.45	.45	.38	.25	.60	.15	.30	.15	.30	.30	.15	.25	.45
.68	.38	***	.25	.38	.38	.38	.50	.38	.25	.45	.52	.52	.75	.25	.68	.15	.38	.50	.50	.38	.25	.63	.63
.52	.25	.25	***	.25	.30	.30	.25	.45	.20	.30	.38	.38	.50	.25	.52	.25	.22	.25	.30	.22	.15	.38	.38
.75	.30	.30	.45	***	.15	.15	.15	.30	.30	.52	.60	.60	.38	.30	.75	.30	.45	.45	.45	.45	.45	.25	.60
.75	.20	.20	.30	.15	***	.13	.13	.15	.30	.52	.60	.60	.38	.25	.75	.20	.45	.30	.45	.45	.30	.25	.60
.75	.20	.20	.30	.10	.05	***	.13	.15	.20	.52	.60	.60	.38	.20	.75	.20	.45	.30	.45	.45	.30	.25	.60
.75	.20	.20	.30	.15	.15	.15	***	.30	.30	.52	.60	.60	.25	.25	.75	.20	.45	.30	.45	.45	.30	.15	.60
.75	.20	.20	.30	.15	.05	.13	.13	***	.30	.52	.60	.60	.38	.25	.75	.20	.45	.30	.45	.45	.30	.25	.60
.68	.25	.25	.20	.25	.25	.25	.25	.30	***	.45	.52	.52	.50	.25	.68	.25	.38	.25	.38	.38	.20	.38	.52
.22	.25	.25	.10	.25	.30	.30	.25	.45	.15	***	.13	.20	.38	.25	.25	.25	.13	.15	.30	.08	.15	.30	.25
.20	.25	.25	.10	.25	.30	.30	.25	.45	.20	.15	***	.30	.38	.25	.15	.25	.13	.15	.30	.08	.15	.30	.25
.20	.25	.25	.10	.25	.30	.30	.25	.45	.15	.20	.13	***	.38	.25	.25	.25	.13	.15	.30	.38	.15	.30	.25
.75	.30	.30	.45	.13	.22	.22	.15	.22	.30	.52	.60	.60	***	.30	.75	.30	.45	.45	.45	.45	.45	.22	.60
.68	.13	.10	.15	.22	.15	.15	.25	.30	.20	.45	.52	.52	.50	***	.68	.15	.38	.25	.38	.38	.15	.38	.52
.25	.15	.15	.13	.22	.30	.30	.15	.45	.20	.13	.13	.30	.38	.15	***	.22	.13	.15	.30	.00	.15	.30	.25
.60	.50	.13	.38	.50	.50	.50	.63	.50	.38	.50	.50	.50	.88	.38	.60	***	.50	.63	.63	.50	.38	.75	.75
.30	.25	.25	.10	.25	.30	.30	.25	.45	.20	.13	.15	.30	.38	.25	.30	.25	***	.15	.30	.08	.15	.30	.25
.60	.25	.25	.20	.25	.25	.25	.25	.30	.20	.38	.45	.45	.25	.25	.60	.25	.30	***	.30	.30	.20	.25	.45
.45	.20	.20	.30	.15	.08	.08	.10	.15	.20	.30	.30	.45	.25	.20	.30	.22	.30	.30	***	.15	.30	.13	.20
.38	.25	.25	.25	.25	.30	.30	.25	.45	.20	.25	.25	.30	.38	.25	.30	.25	.25	.15	.30	***	.25	.30	.25
.52	.25	.25	.05	.25	.25	.25	.25	.30	.13	.30	.38	.38	.50	.25	.52	.25	.22	.25	.25	.22	***	.38	.38
.68	.20	.20	.30	.15	.00	.13	.10	.15	.20	.45	.52	.52	.25	.25	.68	.20	.38	.30	.38	.38	.30	***	.52
.40	.30	.30	.30	.25	.30	.30	.25	.45	.20	.20	.20	.30	.30	.30	.30	.30	.20	.15	.30	.20	.30	.30	***

The evaluation of each alternative with respect to each criterion is summarized in Table 2. The unit matrix (Table 3) gives the points assigned to each alternative under the different criteria. The concord and discord matrices are shown in Table 4 and Table 5 respectively. Element C(1, 4) in the concord matrix was calculated as $C(1,4) = (47 + 0.5 \times 32)/88 = 0.72$. Similarly, the discord matrix element $D(3,4) = \text{Max}\{(75 - 50)/200, (75 - 45)/200, (120 - 90)/200, (100 - 50)/200, (75 - 60)/200 \text{ and } (75 - 50)/200\} = 0.25$.

RESULTS AND DISCUSSION

The results of ELECTRE I for $p = 0.55$ and $q = 0.15$ for different cases are given in Table 6. The original weights and scales are given in Table 1, while a uniform weight of 10 and a uniform scale interval of 0–200 were used in this study. With the original weights and scales (case I), the preferred set was 1, 13, 14, 16, 17, 20 and 24. All these nodes were present in all other cases with some other new nodes entering into the preferred set. For the given weights, changing the scale considerably affected the preferred set, where as changes in the weights marginally affected the preferred set for the given scales. Therefore, it can be said that change in scales had greater effect on the

Table 6 Results of ELECTRE I

Cases	Combination of weights and scales	Preferred alternatives
I	Original weights and original scales	1, 13, 14, 16, 17, 20 and 24
II	Original weights and uniform scales	1, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23 and 24
III	Uniform weights and original scales	1, 5, 7, 13, 14, 16, 17, 20, 23 and 24
IV	Uniform weights and uniform scales	All except 6 and 21

Table 7 Sensitivity analysis for ELECTRE I

Threshold values		Preferred alternatives
p	q	
0.50	0.15	1, 13, 14, 16, 17, 20 and 24
0.50	0.20	1, 13, 14, 16, 17 and 20
0.55	0.15	1, 13, 14, 16, 17, 20 and 24
0.55	0.20	1, 13, 14, 16, 17 and 20
0.60	0.25	1, 2, 7, 13 to 17, 20 and 23
0.65	0.25	1 to 3, 5, 7, 9, 11, 13 to 17, 19 and 20
0.65	0.35	1, 3, 5, 7, 11, 13 to 17 and 19
0.70	0.30	1 to 24 except 4, 6, 8, 12 and 21
0.80	0.10 to 0.35	all alternatives

Table 8 Sensitivity analysis for ELECTRE II (Case I)

Sl. no.	Threshold values					Ranks of the alternatives						
	p^*	p^0	p^-	q^*	q^0	1	13	14	16	17	20	24
1	0.75	0.60	0.50	0.45	0.30	1	3	2	2	4	4	5
2	0.75	0.65	0.50	0.45	0.30	1	3	2	2	4	4	5
3	0.75	0.60	0.50	0.45	0.25	1	3	2	2	4	4	5
4	0.85	0.75	0.60	0.45	0.30	1	3	2	2	4	4	5
5	0.75	0.65	0.50	0.30	0.25	1	3	2	2	4	4	5
6	0.80	0.60	0.50	0.45	0.30	1	3	2	2	4	4	5

results of ELECTRE I than changing weights. However, all the nodes present in the preferred set of case I (i.e. nodes 1, 13, 14, 16, 17, 20 and 24) were present in all cases. The sensitivity of selection of alternatives with changes in threshold values (*p* and *q*) was also studied and the results of ELECTRE I and ELECTRE II are shown in Tables 7 and 8 respectively.

The results of ELECTRE II for $p^* = 0.75$, $p^0 = 0.6$ and $p^- = 0.5$; $q^0 = 0.3$ and $q^* = 0.45$ are given in Fig. 3 in the form of strong and weak graphs. Even though the preferred alternatives were different for different values of *p* and *q*, nodes 1, 13, 14, 16, 17, 20 and 24 were common on all occasions and there was no change in the final ranking of alternatives in ELECTRE II. The final ranking is given in Table 9. Alternatives 1, 14 and 16 ranked first or second in all the cases and can be said to be the best. However, these alternatives (i.e. 1, 14 and 16) could further be analysed with much rigour to arrive at a more precise ranking. Though there is a slight change in the results of ELECTRE I, final ranking in ELECTRE II yielded the same result and a change in weights has not shown any effect on the results of ELECTRE II.

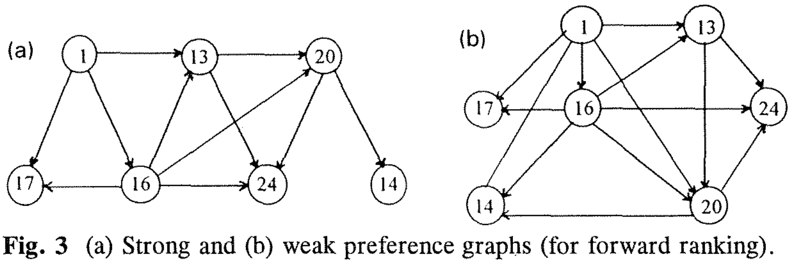


Fig. 3 (a) Strong and (b) weak preference graphs (for forward ranking).

Table 9 Final ranking for all cases

Reservoir alternative systems (nodes)				
Ranks	Case I	Case II	Case III	Case IV
1	1	1 & 16	16	14 & 16
2	16 & 14	13	1 & 14	1 & 17
3	13	17 & 20	20	20
4	17 & 20	14	13 & 17	13
5	24	24	24	24

CONCLUSIONS

ELECTRE I and II techniques have been applied to a river basin planning problem. The aim of the study was to find the most suitable planning of the reservoirs for the development of the river (Krishna) basin. Twenty four alternatives with eighteen criteria were considered for this purpose and the following conclusions drawn:

(i) In ELECTRE I, changes in weights showed less effect on the results than changing the scales. However, all the preferred alternatives in case I were present in all the cases.

(ii) The results of ELECTRE II showed that alternatives 1, 14 and 16 were ranked first or second. Therefore, alternatives 1, 14 and 16 could be considered as the best. However, for further distinction among these alternatives some more data with rigorous analysis has to be done. Even though there was slight change in the results of ELECTRE I, the final ranking in ELECTRE II was not affected. Moreover, changes in weights and scales also had insignificant effect on ELECTRE II.

(iii) Even though the preferred alternatives were different for different values of p and q, nodes 1, 13, 14, 16, 17, 20 and 24 were present on all occasions in ELECTRE I and there was no change in the final ranking of alternatives in ELECTRE II for different values of p and q.

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