RANKING MULTI CRITERIA RIVER BASIN PLANNING AND DEVELOPMENT ALTERNATIVES USING ELECTRE AND RANFUW

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ABSTRACT

A comparative study of ranking river basin planning and development alternatives under a multi-criterion environment, including both qualitative and quantitative aspects using ELECTRE and RANFUW methodologies, is presented in this paper. The purpose is to find the most suitable planning for reservoirs with their associated purposes aimed at the sustained development of one of the major peninsular river (Krishna) basins in India. Formulation of the problem is provided with 7 reservoirs and a diversion headwork leading to an array of 24 alternative systems with 8 main objectives which are further divided into 18 criteria. Of these 24 alternatives, 7 are found to be preferred over others. These 7 alternatives and 8 main objectives are considered in this study for ordering or ranking them. Sensitivity analysis shows that changing both scales and weights assigned to each criterion has affected the final ranking, while there is no change in ranking for different threshold values p and q in ELECTRE methodology. In RANFUW methodology, ranking is not affected by the changes in the scale and weights. Therefore, it is recommended that ELECTRE be used for the screening and RANFUW for the complete ordering or ranking of the reduced set.

KEY WORDS

Basin planning, fuzzy order, fuzzy weights, multi criteria decision making, multi objectives, ranking alternatives, reservoir system, systems analysis, water resources, watershed planning.

1. INTRODUCTION

Decision making is one of the major problems in Engineering, Economics, Business, Natural and Social Sciences as it involves decision making under conditions of risk and uncertainty. In most complicated cases, the quantitative basis for decision making may be obtained by mathematical optimization methods (mathematical programming) while the final decisions should give adequate consideration to the whole series of various conditions and factors (i.e., qualitative aspects) such as legal, social, moral, prestige and those related to traditions, emotional aspects etc., which can not be mathematically formulated. It is the proper combination of the mathematical approach of operations research and the intuitive knowledge & experience of the experts, the only possible method for resolving such multi-disciplined, multi-criterion problems.

Water Resources (WR) planning processes over the years have become increasingly complex and will become more and more so in the future.Therefore there is a need for the new tools and concepts to resolve these complexities. In WR planning & development projects and programs, a more realistic analysis would be to include environmental, social, regional objectives etc., as opposed to single objective (estimation of national benefits and costs) which was the case of the past practices.

The development and application of systems analysis techniques to assist the Decision Maker (DM) in evaluating the project alternatives having more than one objective in river basin planning were of recent origin. A large number of Multi Criteria Decision Making (MCDM) methods were proposed in the last three decades and applied to the WR problems. Many of these methods 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 measures 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 over come these difficulties, Gershon et. al. (1982) combined ELECTRE (ELimination Et(and) Choice Translating REality) methodologies (ELECTRE I - Benayoun et al., 1966; Roy, 1971 & ELECTRE II - Roy, 1968, 1974; Roy and Bertier, 1971; Abi-granem et al., 1978) into an overall method of ranking alternative systems in the presence of both qualitative and quantitative criteria and applied the combined method to a WR management study. David & Duckstein (1976) and Anand Raj (1995) had applied these methods for ranking large range river basin systems. The advantage of this method is that it requires an interval scale with various discrete levels (with level points) for each criterion while other methods require a cardinal scale which is very subjective. The draw back of this method is that it considers single judge's (DM's) preference structure and each level of all the criteria is assigned some points (i.e., discontinuous scales) which is unrealistic.

More recently, with the advent of Fuzzy Set Theory (Zadeh, 1965), many methods were proposed (Jain, 1976, 1977; Baas & Kwakernaak, 1977; Adamo, 1980; Change, 1981; Watson et al., 1979; Yager, 1981; Kerre, 1982 and Dubois & Prade, 1980) to rank the alternatives under fuzzy environment with multiple objectives and were applied to various fields of engineering, business, economics and social sciences. A review of some of these methods was presented by Bortolan et al. (1985). Cano et al. (1991) and Requena et al. (1994) presented methods of automatic ranking of fuzzy numbers using the artificial neural networks. The advantage of these methods over ELECTRE techniques is that they use a single continuous interval scale. Most of the above mentioned methods suffer at least from one of the following drawbacks: (1) The procedure is computationally complex and hence difficulty in implementation; (2) unintutive, which also hinders implementation; (3) assume one criterion or one expert; (4) presupposes existence of some fuzzy relation or other function, across the alternatives or (5) produce a crisp ranking from fuzzy data. To overcome these difficulties and to make the problem simple and straight forward the authors (Anand Raj and Nagesh Kumar, 1995(b)) proposed a method (RANFUW: RANking FUzzy Weights) and applied to a case study (Anand Raj and Nagesh Kumar, 1995(c)). This method is intuitive, computationally simple and easy to implement. In this method the fuzzy weights of the alternatives were arrived at by the fuzzy information (opinions or preference structure) supplied by the multiple experts on the alternatives and the criteria. The alternatives were then ranked using the concepts of the Maximizing Set, the Minimizing Set and the Total Utility or Order Values.

Ranking of river basin planning and development alternatives under a multi-criterion environment, including both qualitative and quantitative aspects is examined using ELECTRE and RANFUW methodologies and a comparative study is attempted. A brief review of these methods is presented in the following section.

2. METHODOLOGIES

The problem under consideration has two distinguishing features. 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 then to rank these preferred systems. Formulation of the problem includes criteria with both qualitative and quantitative data and discrete alternative systems. ELECTRE I and II techniques are well suited to deal with both these situations.

2.1 ELECTRE I

The idea in this algorithm is to choose those systems (alternatives) 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 preferred subset is accomplished by defining a binary relationship 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 were developed: Concordance index, Discordance index and Threshold values.

The concord index C(i,j), is the weighted measure of the number of criteria for which alternative i is preferred to j or i and j are equally preferred. For this purpose weights are assigned to each criterion. 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 (discrete) common to all the criteria is defined. The normalized discord interval is calculated for all the criteria where alternative j is preferred to i and the largest of these discord intervals is defined as the discord index for the alternatives i and j.

Then outranking relationship is then 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 wishes and by choosing q, he specifies the amount of discordance he is willing to tolerate. A preference graph is then constructed using the condition $C(i,j) \geq p$ and $D(i,j) \leq q$ and the kernel is found. The nodes (alternatives) in the kernel represent those alternatives which are preferred on the basis of the outranking relationships.

2.2 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 were multiple levels of concordance ($0<p^-<p^0<p^*<1$) and discordance ($0<q^0<q^*<1$) specified to construct the strong and the weak outranking relationships. As a result of these relationships, two graphs could be constructed, one for a strong and one for a weak relationship. These graphs were then used in an iterative procedure to obtain the ranking. The ELECTRE II approach uses two separate rankings called a forward ranking and a reverse ranking. The final ranking of the alternatives was obtained by averaging the forward and the reverse rankings. The alternative which gets the least average value was ranked first, the one having the next value was ranked second and so on till all the alternatives were ranked.

2.3 RANFUW

Consider the problem that a DM wishes to select the best alternative from amongst m alternatives (A_i; i = 1,2, ...,m), with the help of the information supplied by n experts (E_j; j = 1,2, ...,n) about the alternatives for each of k criteria (C_k; k = 1,2, ...,K) and also the relative importance of each criterion with respect to an overall objective. For this kind of problem RANFUW methodology is best suited. There are a number of issues to be addressed before the final ranking. They were: (i) defining and specifying the type of fuzzy numbers that the experts were allowed to use; (ii) when and how to pool, average or aggregate the fuzzy numbers across the experts; (iii) how to compute the fuzzy weights (w_i) and (iv) the final ranking of the alternatives.

Let a_{ij}^k be the fuzzy number assigned to an alternative A_i by an expert E_j for the criterion C_k and c_{kj} be the fuzzy number assigned to a criterion C_k by an expert E_j. Let these fuzzy numbers be a subset of **F** described by

$$a_{ij}^k = (\alpha_{ij}^k / \beta_{ij}^k , \gamma_{ij}^k / \delta_{ij}^k) \quad \text{and} \quad c_{kj} = (\varepsilon_{kj} / \zeta_{kj} , \eta_{kj} / \theta_{kj}) \qquad (1)$$
$$\text{where } \alpha<\beta<\gamma<\delta \text{ and } \varepsilon<\zeta<\eta<\theta \quad \in \quad \mathbf{L}(1,2, ...,L)$$

In equation (1) **L** is a linearly ordered continuous scale of preference information to be used by the experts designed by the DM and L is a positive integer sufficiently large (L = 10 is used in this paper) to accommodate the information of the preference structure of the experts. The experts could use an ordinal scale (i.e., small, medium high etc.) rather than an exact interval scale, specially when some of the criteria might be vaguely understood or imprecisely defined.

Let $\mu_{Ai}(x)$ and $\mu_{Ck}(x)$ be the membership (general triangular) functions of a_{ij}^k and c_{kj} respectively. Given the above mentioned information the DM computes the fuzzy weights (w_i; i = 1,2, ...,m) of all the alternatives using

$$w_i = (1/KL)O[(m_{i1}On_1)\oplus(m_{i2}On_2)\oplus \ldots \oplus(m_{ik}On_k)] \qquad (2)$$
$$\text{where} \quad m_{ik} = 1/nO[a_{i1}^k\oplus a_{i2}^k\oplus \ldots \oplus a_{in}^k] \text{ and}$$
$$n_k = 1/nO[c_{k1}\oplus c_{k2}\oplus \ldots \oplus c_{kn}]$$

In equation (2) ⊕ represents the fuzzy addition and O represents the fuzzy multiplication. The fuzzy weight w_i could be computed using standard fuzzy arithmetic and then one could arrive at it's membership function, $\mu_{wi}(x) = (\alpha_i / \beta_i , \gamma_i / \delta_i)$. This function has a parabolic variation between α_i , β_i & γ_i , δ_i and a straight line between β_i , γ_i.

The triangular membership functions of the maximizing set, $\{\mu_M(x)\}$ and the minimizing set, $\{\mu_m(x)\}$ were then defined. These functions could be linear, convex curved (risk-prone) or concave curved (risk-averse) and in general covers the three types of preferences: fair; adventurous and conservative; respectively.

The total utility value or the order value, $\{U_T(i)\}$ of the membership function, $\mu_{wi}(x)$ was then determined using

$$U_T(i) = \{U_M(i) + 1 - U_m(i)\} / 2 \qquad (3)$$
$$\text{where} \quad U_M(i) = \sup_x\{\mu_{wi}(x) \cap \mu_M(x)\} \text{ and } U_m(i) = \sup_x\{\mu_{wi}(x) \cap \mu_m(x)\}$$

Using $U_T(i)$ one can rank the alternatives. If two alternatives have the same utility values ($U_T(1) = U_T(2)$), one might use the vertices of the graphs of the corresponding membership functions to make the decision. That is, the vertex farther right is the largest, with decreasing size from the right to the left.

3. APPLICATION

The physical system under consideration in this study, the Krishna river basin, is one of the major peninsular rivers of southern India. The Krishna has a total length of 1400 km., and rises from a spring at Mahabaleswar and flows through three states: Maharashtra, Karnataka and Andhra Pradesh. It's drainage area is of the order of 260 000 km^2. The important tributaries of this river are the Koyna, Ghataprabha, Malaprabha, Bhima and Tungabhadra. The river finally enters Bay of Bengal at Machilipatnam in Andhra Pradesh.

Most of the reservoirs in the basin are constructed as either single or dual purpose projects. The Bhadra, Tungabhadra, Nagarjuna Sagar and Ghataprabha are dual purpose (irrigation and hydropower) projects while the Srisailam and Koyna are hydropower projects and the Almathi reservoir is an irrigation project. Increase in population densities and in the number of industries along the river course and around the reservoirs changed the landuse pattern over the years. This had resulted in the demand for water enormously. Therefore, a need arose for the development of the existing and new the reservoirs for the required water resource and to consider various conflicting objectives for the sustained development of the entire basin. This has led to problems related to both quality and quantity of water such as waterlogging making a large portion of the irrigated area into unproductive, increase in alkalinity and salinity of subsoil resulting in health problems to both the human and the animal livestock which consumed the produce of the affected land, land submergence and associated rehabilitation problems etc. A detailed assessment of these problems, both qualitative and quantitative, are presented by Abbasi (1991).

The purpose of the study was to find the most suitable planning of the reservoirs with their associated purposes aimed at the sustained development of the basin. For this purpose seven reservoirs and a diversion headwork were considered by Anand Raj and Nagesh Kumar (1995(a)) for the formulation of 24 alternative systems (i.e., various combinations of reservoirs) with eight objectives which were further sub divided into 18 criteria. Of these 24 alternative systems, a subset of seven alternatives were found to be preferred over the others. These seven alternatives and the eight objectives are considered in this study for ordering or ranking using both the ELECTRE and the RANFUW methodologies. The Krishna river basin, the location of the reservoirs, their names and the preferred alternatives were shown in fig. 1. Table 1 gives the objectives and the sub criteria considered in the study.

Alternatives: (A_1) R_4, R_5, R_8; (A_2) R_2, R_3, R_8; (A_3) R_1, R_6, R_7; (A_4) R_3, R_4, R_5; (A_5) R_4, R_7, R_8; (A_6) R_5,R_6,R_7,R_8; (A_7) R_3,R_4,R_5,R_8;

Figure 1: Krishna river basin

Table: 1 Objectives of the study

Criteria	Main objective	Sub objective
C_1	National or Regional Development	Irrigation (Lakh Acres) Power Generation (Th. MW) Relative Regional Techno, Socio -economic Improvement*
C_2	Water Requirement	Quality of Water* Annual Sediment Load (Million Tons) Gross Storage Capacity (Th. M. Cum.)
C_3	Flood Protection	Max. Flood Discharge Allowed (Th. Cumecs.) Expected Frequency per Year
C_4	Utilization of Resources	Implementation Costs (Million Rs.) Operation and Maintenance Costs (Million Rs.) Natural Resources*
C_5	Enhancement of Environment*	Preservation of Designated Areas and Existing Facilities Effect on Wildlife and Vegetation Effect on Land and Environment Rehabilitation and Submergence
C_6	Recreational Enhancement	Tourism and Recreational Facilities*
C_7	Returns	Returns of the Investment (Million Rs.)
C_8	Flexibility	Flexibility of the System*

* qualitative criteria (i.e., Best; Very Good; Good; Average and Worst)

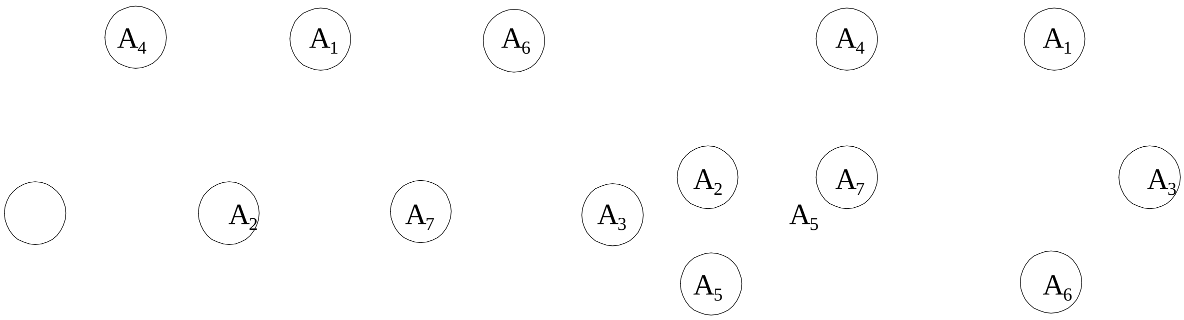
4. RESULTS AND DISCUSSION

4.1 ELECTRE

For the evaluation of the alternatives with respect to each criterion, each criterion was given a weight. For example, irrigation (million acres) was given a criterion weight of 10 while gross storage capacity (th. M. cum.) was given 6 and so on. Each criterion was further sub divided into different levels and points were assigned to these levels. For example, water quality criterion under water requirement objective had a criterion weight of 4, a scale interval of 0 to 75 and a number of levels of 5 with 15 points assigned to each level. The performance of the different alternatives is an indication of the collective contribution from individual reservoirs considered in each of the alternatives.

To study the sensitivity of the results to the weights, scales and threshold values four cases were considered: case I - different weights and different scales; case II - different weights and uniform scale; case III - uniform weight and different scales and case IV - uniform weight and uniform scale.The results of ELECTRE I indicated that the change in weights, scales and/or the threshold values had affected the preferred set. Out of 24 alternatives considered, seven (A_1, A_2, A_3, ... , A_7) were found to be preferred over the others. These seven alternatives were considered for the final ranking by ELECTRE II and RANFUW methods.

The results of ELECTRE II for $p^* = 0.75$, $p^0 = 0.60$, $p^- = 0.50$, $q^0 = 0.30$ and $q^* = 0.45$ are given in fig. 2 in the form of strong and weak graphs. Even though the preferred alternatives were different for different values of p and q, there was no change in the final ranking of the alternatives (see table 2).



(a) Strong graph (b) Weak graph

Figure 2: Strong and weak preference graphs (for forward ranking)

Table 2: Sensitivity analysis for ELECTRE II (Case - I)

S.No.	Threshold values					Ranks of the alternatives						
	p^*	p^0	p^-	q^*	q^0	A_1	A_2	A_3	A_4	A_5	A_6	A_7
1	0.75	0.60	0.50	0.45	0.30	2	5	2	1	4	4	3
2	0.75	0.65	0.50	0.45	0.30	2	5	2	1	4	4	3
3	0.75	0.60	0.50	0.45	0.25	2	5	2	1	4	4	3
4	0.85	0.75	0.60	0.45	0.30	2	5	2	1	4	4	3
5	0.75	0.65	0.50	0.30	0.25	2	5	2	1	4	4	3
6	0.80	0.60	0.50	0.45	0.30	2	5	2	1	4	4	3

Table 3 gives the final rankings for all the cases. It could be seen that for case I the alternative A_4 ranked first, the alternatives A_5 and A_7 ranked second and alternative A_1 ranked third. Where as for case IV the alternatives A_5 and A_7 ranked first, the alternatives A_2 and A_4 ranked second and the alternative A_6 ranked third and so on. If one considers different cases, the alternatives A_5 and A_7 in case I, A_1 in case II, A_4 and A_5 in case III and the alternatives A_4 and A_2 in case IV were ranked second. This led to a confusion and one could not say for certain which alternative was the best. Therefore, for further distinction among these alternatives a rigorous analysis has to be done with some more inputs. Even then it might not be sure that the DM comes out with a unique solution.

Table 3: Final ranking in ELECTRE for all the cases

	Reservoir alternative systems (nodes in the kernel)			
Rank	Case - I	Case - II	Case - III	Case - IV
1	A_4	A_1 and A_4	A_1	A_1 and A_3
2	A_1 and A_3	A_7	A_3 and A_4	A_4 and A_5
3	A_7	A_5 and A_6	A_6	A_6
4	A_5 and A_6	A_3	A_5 and A_7	A_7
5	A_2	A_2	A_2	A_2

4.2 RANFUW

For the evaluation of the alternatives, three experts (Ei; i = 1,2,3), one academician, one field engineer and an official from ministry of WR were consulted to give their opinion (preference structure) about the alternatives and the criteria in the form of fuzzy numbers within a range L (L = 1 to 10). The experts were supplied with the relevant information about the reservoirs, alternative systems and the associated purposes, advantages, disadvantages and the other aspects. They were also supplied with the relevant information about the criteria before evaluation. A typical evaluation, for example, is given in table 4. It could be seen that the experts had given highest priority to the criterion C_1 and then to criterion C_7, while least priority was given to the criteria C_6 and C_8. Similar data was received from all the experts about the alternatives for each of the criterion (see Anand Raj and Nagesh Kumar, 1995(c)). Then the fuzzy weights (w_i; i = 1, 2, ... ,7) were arrived at using the equation (2) and were given by

w_1 = (2.438 / 2.924 , 3.121 / 3.708); w_2 = (1.911 / 2.419 , 2.639 / 3.064)
w_3 = (1.675 / 2.099 , 2.265 / 2.699); w_4 = (2.826 / 3.367 , 3.582 / 4.150)
w_5 = (2.147 / 2.590 , 2.715 / 3.168); w_6 = (1.778 / 2.257 , 2.414 / 2.840)
w_7 = (2.468 / 3.026 , 3.156 / 3.650);

The linear membership functions of the maximizing set and the minimizing set were given by

$$\mu_M(x) = \begin{cases} \{(x - 1.675) / (4.150 - 1.675)\} & 1\ 675 < x < 4.150 \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

$$\mu_m(x) = \begin{cases} \{(x - 4.150) / (1.675 - 4.150)\} & 1.675 < x < 4.150 \\ 0 & \text{otherwise} \end{cases} \tag{5}$$

Table 4: Evaluation of criteria by experts

Criteria	E_1	E_2	E_3
C_1	(9/10 , 10/10)	(10/10 , 10/10)	(9/9 , 9/10)
C_2	(5/5 , 6/7)	(5/6 , 6/6)	(6/6 , 6/6)
C_3	(4/5 , 6/6)	(4/5 , 5/6)	(5/5 , 5/5)
C_4	(2/2 , 2/3)	(2/3 , 3/3)	(3/3 , 3/3)
C_5	(5/5 , 5/5)	(4/5 , 5/6)	(5/5 , 5/6)
C_6	(2/2 , 2/2)	(2/3 , 3/3)	(2/2 , 2/2)
C_7	(7/8 , 8/9)	(8/8 , 8/9)	(7/8 , 8/8)
C_8	(1/2 , 2/3)	(2/2 , 2/3)	(2/2 , 2/3)

A typical representation of the membership functions of the fuzzy weight, $\{\mu_{wi}(x)\}$, the maximizing set, $\{\mu_M(x)\}$ and the minimizing set, $\{\mu_m(x)\}$ were shown in fig.3. Then using equation (3) the total utility values, ($U_T(i)$) were determined and the alternatives were ranked as shown in table 5. It was found that the alternative A_4 was the best and the alternative A_7 the next best while the alternative A_3 the last. Since a single continuous scale was used for all the alternatives and criteria, the final ranking was unique and changes in scale did not affect the results. More over the intuitive knowledge of the experts in addition to the quantitative data available was effectively used in the analysis. This kind of analysis is more rational and realistic.

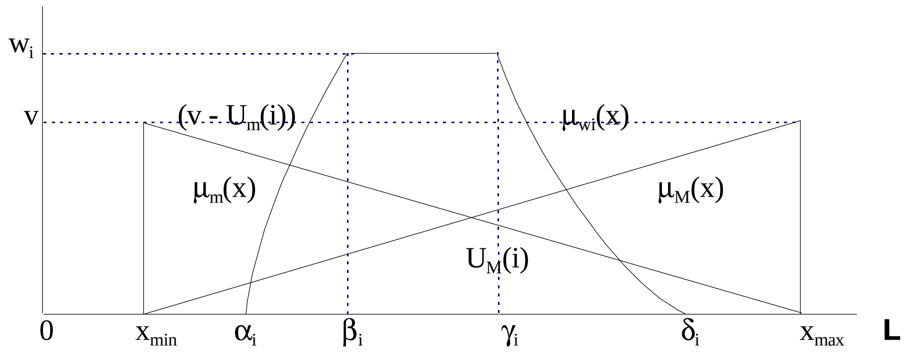


Figure 3: Graphical representation of $\mu_{wi}(x)$, $\mu_m(x)$ and $\mu_M(x)$.

Table 5: ranking and utility values of the alternatives

Rank	Utility Value	Alternative
1	0.67940	A_4
2	0.54546	A_7
3	0.51610	A_1
4	0.37544	A_5
5	0.35754	A_2
6	0.27158	A_6
7	0.23966	A_3

5. CONCLUSIONS

The ranking of the river basin planning and development alternatives under a multi-criterion environment, including both qualitative and quantitative aspects using the ELECTRE and the RANFUW methodologies, is examined and a comparative study was attempted. For this purpose a major peninsular river (Krishna) basin in India was considered. Formulation of the problem was provided with seven reservoirs and a diversion headwork leading to an array of 24 alternative systems with eight objectives. The objectives were further sub divided into 18 criteria. Of these 24 alternatives, seven were found to be preferred over the others. These seven alternatives were finally considered for the ranking using both the methods mentioned above.

In the ELECTRE, the DM was the one that assigns the weights, scales, number levels and the level points for all the criteria. While doing so he might elicit the information from the experts. The final results might be affected if the preference structure of the DM changes and therefore the results were very subjective. More over the weights and scales were crisp and discontinuous leading to a sudden jump from one level to the other. This led to assigning different level points to the alternatives which were more or less close to each other, specially when the evaluation is close to the boundary of levels.

The sensitivity analysis showed that changing weights and scales had affected the final ranking, while there was no effect of the threshold values on the ranking in the ELECTRE method. More over the final ranking led to a confusion in selecting the best alternative amongst the reduced set. Therefore some more data is to be collected and rigorous analysis is to be performed. Even then the DM might not be sure that he will arrive at a unique solution.

In the RANFUW method, the information given by the experts was directly incorporated into the analysis. This information could be quantitative, qualitative or intuitive in nature. A single and continuous scale was used for both the alternatives and criteria eliminating subjectivity of assigning the weights and scales by the DM. On this scale the preference information of the experts is elicited in the form of fuzzy numbers. Even if the scale was changed the results were not affected. As the number of experts increases, the additional information could easily be incorporated and the results would be more confident and realistic. Since ranking was unique the DM could easily take a decision to implement the best alternative.

It is therefore recommended that the ELECTRE be used for screening a large number of alternatives to arrive at a manageable subset and the RANFUW for complete ordering or ranking of the reduced set.

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