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Multicriterion decision making in irrigation planning

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Abstract

Selection of the best compromise irrigation plan is examined in the multi objective context. The study deals with three conflicting objectives: net benefits, agricultural production and labour employment. Three-stage procedure is adopted combining multi objective optimisation, cluster analysis and multicriterion decision-making (MCDM) methods. Two MCDM methods, namely, PROMETHEE-2 and a newly developed method EXPROM-2, are employed in the evaluation. Spearman rank correlation test is used to assess the correlation between the ranks. The above methodology is applied to a case study of Sri Ram Sagar Project, Andhra Pradesh, India. Sensitivity analysis studies indicated that ranking pattern is quite robust to parameter changes as far as the first two positions are concerned. It is found that net benefits, agricultural production and labour employment per hectare on average for the culturable command area are 8980 rupees ($225), 3.73 tonnes and 242 man-days, respectively, in the best compromise plan.

Keywords: Optimal cropping pattern; Irrigation planning; Linear programming; Multicriterion decision making

1. Introduction

Irrigation systems, particularly in developing countries, have generally been performing far below their potential. Thus, the levels of agricultural production and irrigation benefits are reduced making some of the systems financially and economically unattractive. This necessitated new methods for the irrigation planning and development. In this paper an irrigation planning model is developed incorporating net benefits, agricultural production and labour employment for selection of the best compromise irrigation plan.

Multicriterion decision-making (MCDM) methods are gaining importance because of their inherent ability to judge different alternative scenarios for the selection of the best alternative which may be further analysed in depth for its final implementation. Many MCDM methods are employed for different case studies, namely, river basin planning problem (Gershon and Duckstein, 1983; Ko et al., 1994; Anand Raj and Nagesh Kumar, 1996), hydropower operation (Duckstein et al., 1989), groundwater planning problems (Duckstein et al., 1994). Compared to the previous studies the present study incorporates new concepts, namely: (1) cluster analysis to reduce the size of the nondominated alternatives to a manageable subset; (2) correlation analysis to measure

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the correlation between the ranks; and (3) involving irrigation management expert as a decision maker for the process of decision making.

Three-stage procedure is employed to select the best compromise irrigation plan (alternative corresponds to the best tradeoff between the objectives). In the first stage constraint method of multi objective optimisation is employed to generate nondominated alternatives. In the second stage, nondominated alternatives are reduced to a manageable subset with the help of cluster analysis. In the third stage, two MCDM methods, namely, PROMETHEE-2 and newly developed EXPROM-2, are used to evaluate and select the best compromise irrigation plan. Here, policy or plan represents combination of different crop acreages, labour employment, agricultural production and net benefits.

The above methodology is applied to the case study of Sri Ram Sagar Project (SRSP), Andhra Pradesh, India. The culturable command area (CCA) of the project is 178,100 ha. The main crops grown in the command area are paddy, maize, sorghum, groundnut, vegetables, pulses, chillies and sugarcane. There is a practice of double cropping in the command area to utilise the available land more effectively. Thus, the irrigation intensity may as well be more than 100% in some cases. Location map of the project is presented in Fig. 1. Mathematical modelling of the three conflicting objectives with the corresponding constraints are briefly explained.

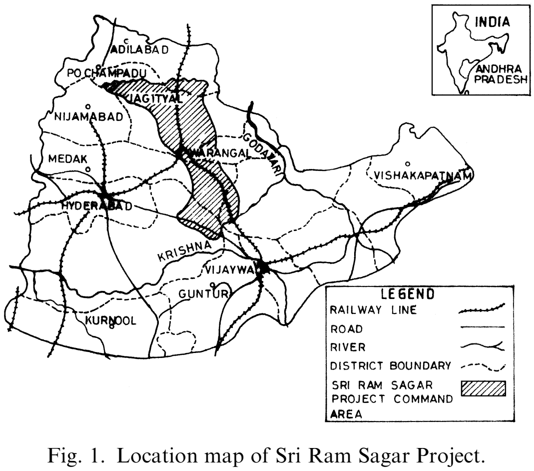

Fig. 1. Location map of Sri Ram Sagar Project.

2. Mathematical modelling

2.1. Objective 1: Maximisation of net benefits

The net benefits (BEM) from the irrigated as well as unirrigated area under different crops is obtained by subtracting the costs of surface water, groundwater, fertiliser and labour from the gross revenue for different crops. Maximisation of net benefits can be expressed as:

$$\text{Max BEM} = \sum_{i=1}^{16} B_i A_i - P_{\text{sw}} \sum_{t=1}^{12} R_t - P_{\text{gw}} \sum_{t=1}^{12} \text{GW}_t - \sum_{f=1}^{3}\sum_{i=1}^{16} F_{fi} A_i P_f - P_l \sum_{t=1}^{12}\sum_{i=1}^{16} L_{it} A_i, \tag{1}$$

in which i = crop index [1 = paddy(s), 2 = maize(s), 3 = sorghum(s), 4 = groundnut(s), 5 = vegetables(s), 6 = pulses(s), 7 = paddy(srf), 8 = groundnut(srf), 9 = paddy(w), 10 = groundnut(w), 11 = pulses(w), 12 = maize(w), 13 = sorghum(w), 14 = vegetables(w), 15 = chillies(w), 16 = sugarcane(ts)]; s = summer; w = winter; ts = two season; srf = summer rainfed; t = monthly index (1 = January, 2 = February, 3 = March, 4 = April, 5 = May, 6 = June, 7 = July, 8 = August, 9 = September; 10 = October, 11 = November, 12 = December); f = fertiliser index (1 = nitrogen, 2 = phosphorous, 3 = potash); A_i = area of crop i (ha); B_i = unit gross return from ith crop (Rs); P_{sw} = unit surface water cost (Rs/Mm^3); R_t = monthly canal water releases (Mm^3); P_{gw} = unit groundwater cost (Rs/Mm^3); GW_t = monthly groundwater requirement (Mm^3); F_{fi} = quantity of fertiliser of type f for crop i (tons/ha); P_f = unit cost of fertiliser type f (Rs); P_l = unit wage rate (Rs); L_{it} = labour-days required for each hectare of crop i in month t; Rs = rupees in Indian currency (US \$1 = Rs40).

2.2. Objective 2: Maximisation of agricultural production

Total agricultural production (PRM) of all the crops are to be maximised for meeting the demands:

$$\text{Max PRM} = \sum_{i=1}^{16} Y_i A_i, \tag{2}$$

where Y_i = yield of ith crop (tons/ha).

2.3. Objective 3: Maximisation of labour employment

The total labour employed (LAM) under all the crops for the whole year is maximised to increase the level of their economic status and can be expressed as:

$$\text{Max LAM} = \sum_{t=1}^{12}\sum_{i=1}^{16} L_{it} A_i.$$

The above given objectives are subject to the following constraints:

1. Continuity equation—The monthly continuity equation for the reservoir storage (Mm^3) is expressed as:

$$S_{t+1} = S_t + Q_t - \mathrm{EV}_t - R_t - \mathrm{RDS}_t - \mathrm{OSR}_t;\; t = 1, 2, \ldots, 12. \tag{4}$$

   where S_{t+1} = end of month reservoir storage volume; Q_t = monthly net inflow volume; EV_t = monthly net evaporation volume; RDS_t = downstream requirements; OSR_t = spilled volume. By incorporating the stochasticity in the inflow terms, the above equation changes to:

$$S_{t+1} - S_t + \mathrm{EV}_t + R_t + \mathrm{RDS}_t + \mathrm{OSR}_t \geqslant q_t^{\alpha};\; t = 1, 2, \ldots, 12. \tag{5}$$

   where q_t^{α} is the inverse of the cumulative distribution function of inflows at dependable level α.
2. Crop land requirements—The total area allocated for different crops in a particular season should be less than or equal to the CCA.

$$\sum_i A_i \leqslant \mathrm{CCA};\quad i = 1, 2, 3, 4, 5, 6, 7, 8, 15, 16 \quad \text{for summer crops} \tag{6}$$

$$\sum_i A_i \leqslant \mathrm{CCA};\; i = 9, 10, 11, 12, 13, 14, 15, 16 \quad \text{for winter crops} \tag{7}$$

   Crops of two seasons, namely, chillies and sugarcane (indices 15 and 16) are included in both the equations because they occupy the land in both seasons.
3. Water requirements of crops—Monthly crop water requirements should not exceed the maximum available water from both surface and groundwater sources:

$$\sum_{t=1}^{12}\sum_{i=1}^{16} A_i\ \mathrm{CWR}_{it} \leqslant R_t + \mathrm{GW}_t, \tag{8}$$

   where CWR_{it} is crop water requirement for unit area of crop i in month t.
4. Groundwater withdrawals—The total groundwater withdrawals in a year should be less than or equal to the estimated annual groundwater potential (TGW) of the aquifer, i.e.:

$$\sum_{t=1}^{12} \mathrm{GW}_t \leqslant \mathrm{TGW}. \tag{9}$$

5. Water quality—The concentration of total dissolved solids (TDS) of the groundwater pumped from the aquifer and reservoir water in the canal network must fulfil a specified irrigation water quality standard (QS) and can be expressed as:

$$\mathrm{CGW}_{\mathrm{GW}_t} + \mathrm{CRW}_{R_t} \leqslant \mathrm{QS}_{(\mathrm{GW}_t + R_t)}, \tag{10}$$

   where CGW and CRW are average concentration of TDS in groundwater and reservoir water (mg/l).

The other constraints incorporated in the model include canal capacity restrictions, minimum and maximum reservoir storages, crop diversification considerations, downstream water requirements, labour and fertiliser availability, etc. (Pillai and Srinivasa Raju, 1996). Cost coefficients, crop yield and other input parameters are obtained from

SRSP reports but are not presented due to space limitation.

In the planning model, stochastic nature of inflows is considered through chance-constrained programming. The monthly inflows into the Sri Ram Sagar reservoir are assumed to follow the log-normal distribution. Twenty-three years of historical inflow data is used to obtain the various dependability levels of inflows. In the present study, 90% dependability level inflows are considered. These are 132.10, 372.88, 798.50, 812.70, 352.02, 56.9 and 36.00 Mm^3, respectively, from June to December. The inflows of other months are not significant and are neglected. Remaining results are presented elsewhere (Srinivasa Raju, 1995).

Analytic hierarchy process (AHP) is employed to assess weightage of each criteria (Saaty and Gholamnezhad, 1982). Ninety-two farmers and 18 officials are involved in the process. Geometric mean approach is used to aggregate the views of farmers and officials. It is observed that net benefits are given higher importance (56.13%), followed by agricultural production (31.24%) and labour employment (12.63%).

3. Individual optimisation

Optimisation of each individual objective (labour employment, agricultural production and net benefits) is performed with a linear programming (LP) algorithm that gave the upper and lower bounds for the multi objective analysis (Loucks et al., 1981). Results are presented in Table 1. Maximum (Z_U) and minimum values (Z_L) that can be obtained by each objective are denoted with symbol (+) and (−), respectively. Total irrigated area is maximum in labour employment maximisation case and minimum in net benefits maximisation case. The reason for more acreage of paddy(s), groundnut(srf) and groundnut(w) in the case of net benefits maximisation is due to the large net returns per unit area. In agricultural production maximisation case, maize and sorghum (both in summer and winter) have large acreage compared to those in the remaining planning objectives because of their higher yield per unit area. In the irrigation planning model, there is no significant change in acreage of groundnut, vegetables, pulses in summer season, paddy, pulses, vegetables in winter season and sugarcane for all the three planning objectives.

Irrigation intensity (irrigated area/CCA) in labour employment, agricultural production and net benefits maximisation cases are 152.34, 142.13 and 101.96%, respectively. Cropping intensity [(irrigated + rainfed)/CCA)] is 197.92, 173.87 and 154.33%. Net benefits (in Indian rupees) in the case of benefit maximisation are 1.54 times of that in agricultural production maximisation whereas it is 1.18 times of that in labour employment maximisation. The agricultural production (in tonnes) in agricultural production maximisation case is 1.14 times of that in net benefits maximisation whereas it is 1.4 times of that in labour employment maximisation. The total labour utilisation (man-days) in labour employment maximisation case is 1.14 times of that in net benefits maximisation, whereas, it is 1.31 times of that in agricultural production maximisation.

Calculations (not presented) have shown that the surface water utilisation is 1577.38, 1602.72 and 1627.87 Mm^3 for labour employment maximisation, agricultural production maximisation and net benefits maximisation, respectively. The groundwater is fully utilised in all the three planning objectives even though the amounts utilised in individual months are different. In the case of net benefits maximisation and agricultural production maximisation, the groundwater utilisation is from February to June whereas it is from February to May in the case of labour employment maximisation. In net benefits maximisation case the model resulted in large acreages of paddy thereby requiring more water. Due to nonavailability of sufficient surface water in the month of June the groundwater utilisation becomes compulsory. 30.7% of total irrigation demand is satisfied through surface water and the remaining from groundwater in net benefits maximisation. Similarly, 76.4% of total demand is satisfied through surface water and rest through groundwater in agricultural production maximisation case. In labour employment maximisation case, the model depends on chillies(ts) which

Table 1
Crop plans from the planning model

Crops and related parameters[a]	Units	Solution for maximization of:			Solution for best plan G5 (P29)
		Labour employment	Agricultural production	Net benefits	
1. Paddy(s)	1000 ha	2.000	2.000	62.93	34.06
2. Maize(s)	1000 ha	5.000	54.65	5.000	5.000
3. Sorghum(s)	1000 ha	22.87	50.00	1.900	1.900
4. Groundnut(s)	1000 ha	1.500	1.500	1.500	1.500
5. Vegetables(s)	1000 ha	2.000	2.000	2.100	2.000
6. Pulses(s)	1000 ha	4.200	4.200	4.200	4.200
7. Paddy(srf)	1000 ha	51.20	51.20	0.000	19.14
8. Groundnut(srf)	1000 ha	29.97	5.340	93.26	88.74
9. Paddy(w)	1000 ha	14.70	14.70	14.70	14.70
10. Groundnut(w)	1000 ha	5.700	5.700	15.81	11.90
11. Pulses(w)	1000 ha	39.85	39.85	39.85	39.85
12. Maize(w)	1000 ha	13.00	22.33	13.00	13.00
13. Sorghum(w)	1000 ha	40.00	40.00	4.500	32.33
14. Vegetables(w)	1000 ha	1.800	1.800	1.700	1.800
15. Chillies(ts)	1000 ha	55.25	3.100	3.100	17.46
16. Sugarcane(ts)	1000 ha	4.100	4.100	4.100	4.100
Irrigation intensity	%	152.34	142.13	101.96	115.30
Cropping intensity	%	197.92	173.87	154.33	175.87
Payoff matrix					
Net benefits (million rupees)		1418.60	1084.00^{-}	1672.90^{+}	1599.400
Agricultural production (million tonnes)		0.55^{-}	0.78^{+}	0.68	0.67
Labour employment (million man-days)		46.23^{+}	35.16^{-}	40.43	43.23

[a] s, Summer; w, winter; srf, summer rainfed; ts, two season.

is more labour intensive and less water consuming than paddy and is managed with surface water alone in the month of June. Groundwater is utilised to meet 20.13, 19.87 and 19.62% of the total irrigation demand for all three planning objectives.

It is observed that the three planning objectives conflict with one another. There is a need to develop a tradeoff relationship and to select the best compromise alternative cropping plan(s) and the corresponding water allocation policies in the multi objective irrigation planning context to meet the chosen levels of satisfaction in the decision-making process.

4. Constraint method of multi objective optimisation

Constraint method is a plan generation technique. It operates by optimising one objective while all others are constrained to some value. Mathematically it can be expressed as:

$$\text{Max } f_h(x)$$

subjected to:

$$f_r(x) \geqslant L_r; \quad r = 1, 2, \ldots, \; h-1, h, \; h+1, \ldots, p.$$

and existing constraints.

In the method, hth objective function is chosen for maximisation from among p objectives. f_h (x) and f_r (x) are objective functions corresponding to objectives h and r. Maximum (Z_{U}) and minimum values (Z_{L}) that can be obtained by each objective can be used to formulate different values of L_r (L_r is bound on objective r which is later transformed as constraint in the constraint method) for the generation of nondominated solutions based on decision maker and analyst preference.

In the present study constraint method of multi objective optimisation is employed. Maximisation of net benefits is selected as the main objective in the constraint method of multi objective optimisation formulation because of its higher importance attributed. In this method the other two objectives, agricultural production and labour employment are placed as the constraints in the constraint set. The nondominated set of alternatives are generated by parametrically varying the bounds of the constraints (transformed objective functions of agricultural production and labour employment) obtained from the individual optimal solutions. The number of generated nondominated alternatives are reduced to a chosen few, based on consultations between the analyst (first author) and the decision maker. Thirty-seven policies labelled P01 to P37 are adopted after such consultations and are shown in Table 2. It is observed that with the increase of labour employment and the decrease of agricultural production, the net benefits gradually increased to a maximum level (policy P26) and then decreased.

Table 2
Proposed policies for Sri Ram Sagar Project

Policy number	Labour employment (million man-days)	Agricultural production (million tonnes)	Net benefits (million rupees)
P01	35.157	0.77781	1084.00
P02	35.170	0.77779	1110.50
P03	35.190	0.77758	1136.80
P04	35.250	0.77718	1152.00
P05	35.309	0.77659	1172.50
P06	35.428	0.77600	1197.60
P07	35.495	0.77550	1216.20
P08	35.657	0.77485	1238.70
P09	35.820	0.77419	1261.20
P10	35.983	0.77354	1283.60
P11	36.300	0.77250	1301.80
P12	36.596	0.77110	1322.40
P13	36.892	0.76970	1343.00
P14	37.482	0.76910	1365.90
P15	37.777	0.76705	1391.80
P16	38.072	0.76500	1417.80
P17	38.492	0.76386	1439.50
P18	38.913	0.76272	1460.20
P19	39.423	0.76216	1481.50
P20	39.932	0.76159	1502.70
P21	40.322	0.75700	1531.40
P22	40.326	0.74929	1559.00
P23	40.331	0.74119	1586.50
P24	40.336	0.73309	1613.40
P25	40.349	0.72305	1645.40
P26	40.432	0.68076	1672.90
P27	41.716	0.68000	1650.20
P28	42.477	0.67187	1624.90
P29	43.239	0.66374	1599.40
P30	44.000	0.65561	1573.80
P31	44.374	0.63958	1553.90
P32	44.748	0.62340	1532.40
P33	45.124	0.60665	1505.60
P34	45.500	0.58989	1478.70
P35	45.750	0.57781	1459.10
P36	46.000	0.56573	1438.30
P37	46.229	0.55420	1418.60

5. Cluster analysis

The number of reduced nondominated alternatives obtained from multi objective optimisation (37 in this case) are still considerably large and it is difficult manually to reduce further as there is a threshold beyond which the difference between the two alternatives is imperceptible to manual capabilities when compared to the machine. The method of cluster analysis can be used to reduce the number of alternatives to a more manageable subset (Morse, 1980). Cluster analysis offers several advantages over a manual grouping process such as: (1) the clustering program can apply a specified objective function criterion consistently to form the groups avoiding the inconsistency due to human error; and (2) the clustering algorithm can form the groups in a small fraction of the time that is required for manual grouping, particularly if a long list of criteria is associated with each alternative (Jain and Dubes, 1988).

Cluster analysis partitions nondominated alternative set N into K clusters (groups) of relatively homogeneous alternatives. In clustering, alternatives in a cluster are more similar to each other than alternatives of different clusters. K-means clustering algorithm (Hartigan, 1975; Jain and Dubes, 1988) is used to minimise within-cluster sums of squares of differences (error) based on the initial partitions to obtain final partitions. In this method, normalised alternatives are grouped so that each alternative is assigned to one of the fixed number of groups K. The sum of the squared differences of each criterion from its assigned cluster mean, is used as the criterion for the assignment. Alternatives are transferred from one cluster to another, so that, within-cluster sum of squared differences (error) decreases. In a pass through the entire data set, if no transfer occurs, the algorithm stops. The total square error value for cluster group K, E_K is given by:

$$E_K = \sum_{K=1}^{12} e_K^2, \tag{11}$$

where e_K = error value for each cluster group K.

K-means clustering, with more than one value of K, is performed and the value of K which best fits the data is used. Burn (1989) proposed F-statistic value as bench mark to select optimal number of clusters. This value of F is a measure of the reduction in variance from K to $K+1$ clusters and value of F greater than 10, justifies a transition from K to $K+1$ clusters (Burn, 1989). The F-statistic can be defined as:

$$F = [E_K/E_{K+1} - 1](N - K + 1) \tag{12}$$

where E_{K+1} = total square error value for all cluster groups $(K+1)$ and N = number of nondominated alternatives.

Thirty-seven proposed policies (P01 to P37) are normalised (also weighting) by the difference between maximum and minimum values of each criterion. Selection of initial partitions is performed by Ward's method (Jain and Dubes, 1988) of hierarchical clustering. Several runs are made by K-means algorithm for each clustering, with different numbers in the initial partitions, until no decrease in square error value is observed for that clustering. Fig. 2 presents square error and F-statistic values for clustering having partitions varying from 3 to 9. Clustering containing 1 and 2 partitions is not done since it will narrow the band of results abnormally. It is observed that the values of square error and F-statistic are decreasing with the increase in number of clusters. The optimum number of cluster groups is taken as six corresponding to F-statistic value of 10 (Burn, 1989).

After fixing the optimal number of clusters as six, the representative policy for each cluster is determined as shown in Table 3. For this purpose the square error values between group mean and the weighted normalised proposed policy values for each criterion in that group are calculated. The summation of these square error values for all criteria gave the total square error value corresponding to each proposed policy in that group. For example, the values of three criteria,

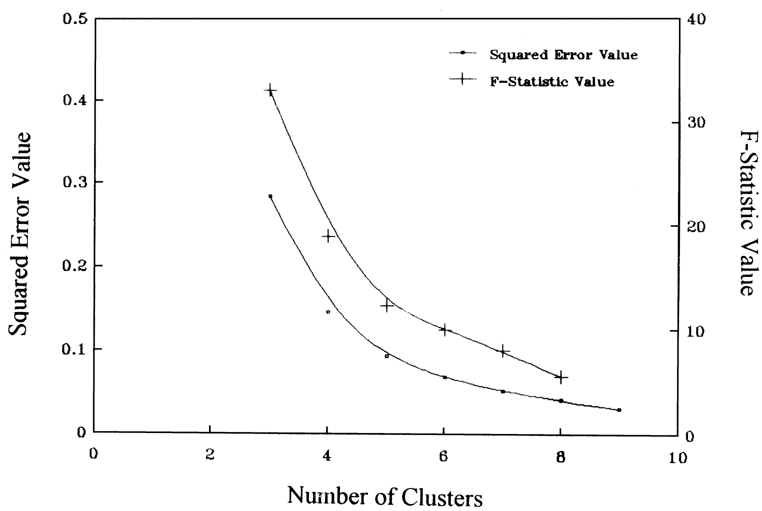

Fig. 2. Squared error and F-statistic values for different clusters.

Table 3
Weighted normalised proposed policy values and corresponding square error values

Group number	Policy number	Labour employment	Agricultural production	Net benefits	Square error values
1	P01	0.4010	1.0867	1.0335	0.0043004
	P02	0.4012	1.0866	1.0586	0.0016388
	P03	0.4014	1.0863	1.0836	0.0002383
	P04[a]	0.4021	1.0858	1.0981	0.0000014(MIN)[b]
	P05	0.4028	1.0850	1.1177	0.0003493
	P06	0.4041	1.0841	1.1416	0.0018177
	P07	0.4049	1.0834	1.1593	0.0036450
	Group mean	0.4020	1.0850	1.0990	
2	P08	0.4067	1.0825	1.1808	0.0037089
	P09	0.4086	1.0816	1.2022	0.0015537
	P10	0.4105	1.0807	1.2235	0.0003293
	P11[a]	0.4141	1.0792	1.2409	0.0000009(MIN)[b]
	P12	0.4174	1.0773	1.2605	0.0003902
	P13	0.4208	1.0753	1.2801	0.0015795
	P14	0.4275	1.0745	1.3020	0.0039036
	Group mean	0.4150	1.0790	1.2410	
3	P15	0.4309	1.0716	1.3267	0.0030889
	P16	0.4343	1.0688	1.3514	0.0009371
	P17[a]	0.4391	1.0672	1.3722	0.0000863(MIN)[b]
	P18	0.4439	1.0656	1.3919	0.0001247
	P19	0.4497	1.0648	1.4122	0.0010398
	P20	0.4555	1.0640	1.4324	0.0028366
	Group mean	0.4420	1.0670	1.3810	
4	P21	0.4599	1.0582	1.4597	0.0033723
	P22	0.4600	1.0468	1.4860	0.0008673
	P23[a]	0.4600	1.0355	1.5123	0.0000007(MIN)[b]
	P24	0.4601	1.0242	1.5380	0.0007395
	P25	0.4603	1.0102	1.5684	0.0036903
	Group mean	0.4600	1.0350	1.5130	
5	P26	0.4612	0.9511	1.5948	0.0044890
	P27	0.4758	0.9500	1.5730	0.0018616
	P28	0.4845	0.9387	1.5489	0.0002412
	P29[a]	0.4932	0.9273	1.5246	0.0001964(MIN)[b]
	P30	0.5019	0.9159	1.5002	0.0017472
	P31	0.5062	0.8935	1.4812	0.0047330
	Group mean	0.4870	0.9290	1.5370	
6	P32	0.5104	0.8709	1.4608	0.0061250
	P33	0.5147	0.8475	1.4351	0.0018749
	P34[a]	0.5190	0.8241	1.4095	0.0000698(MIN)[b]
	P35	0.5219	0.8072	1.3909	0.0002886
	P36	0.5247	0.7904	1.3710	0.0018648
	P37	0.5273	0.7743	1.3523	0.0046195
	Group mean	0.5200	0.8190	1.4030	
	Total squared error				0.06835

[a] Alternatives representing the groups are P04, P11, P17, P23, P29, P34.
[b] MIN represents minimum square error value from group mean.

labour employment, agricultural production and net benefits for P17 are 0.4391, 1.0672 and 1.3722, and corresponding group mean for cluster group 3 are 0.4420, 1.0670 and 1.3810. Then, deviation of P17 with group mean (square error) can be calculated as $[(0.4391-0.4420)^2+(1.0672-1.0670)^2+(1.3722-1.3810)^2]=0.0000863$. The policy that gives the minimum total square error value is chosen as the representative policy for that group. The policies P04, P11, P17, P23, P29 and P34 of Table 2 having minimum total square error values of 0.0000014, 0.0000009, 0.0000863, 0.0000007, 0.0001964 and 0.0000698 are found to be the representative ones of the six cluster groups (Table 3). The above groups are denoted as G1, G2, G3, G4, G5 and G6. Alternative policies versus criteria array (payoff matrix) is presented in Table 4.

6. MCDM methods

The two different MCDM methods, PROMETHEE-2 and a newly developed method, EXPROM-2, are employed in the present study. The use of more than one MCDM method enhances the selection process (Duckstein et al., 1994). Brief details of methods are as follows.

PROMETHEE-2 (Preference Ranking Organisation METHod of Enrichment Evaluation) is of out ranking nature. The method uses preference function $P_j\ (a,b)$ which is a function of the difference d_j between two alternatives for any criterion j, i.e. $d_j=f(a,j)-f(b,j)$ where $f(a,j)$ and $f(b,j)$ are values of two alternatives a and b for criterion j (Brans et al., 1986). Six types of functions based on the notions of criteria, namely, usual criterion, quasi criterion, criterion with linear preference, level criterion, criterion with linear preference and indifference area and gaussian criterion are proposed and presented in Fig 3. The indifference and preference thresholds q' and p' are also defined depending on the type of criterion function. Two alternatives are indifferent for criterion j as long as d_j does not exceed the indifference threshold q'. If d_j becomes greater than p', there is a strict preference. Multicriterion preference index, $\Pi(a,b)$, weighted average of the preference functions $P_j\ (a,b)$ for all the criteria is defined as:

$$\Pi(a,b) = \sum_{j=1}^{J} w_j P_j(a,b) / \sum_{j=1}^{J} w_j \tag{13}$$

$$\Phi^+(a) = \sum_A \Pi(a,b) \tag{14}$$

$$\Phi^-(a) = \sum_A \Pi(b,a) \tag{15}$$

$$\Phi(a) = \Phi^+(a) - \Phi^-(a) \tag{16}$$

Table 4
Alternative policies versus criteria array

Policy number	Labour employment (million man-days)	Agricultural production (million tonnes)	Net benefits (million rupees)
G1	35.250	0.77718	1152.00
G2	36.300	0.77250	1301.80
G3	38.492	0.76386	1439.50
G4	40.331	0.74119	1586.50
G5	43.239	0.66374	1599.40
G6	45.500	0.58989	1478.70

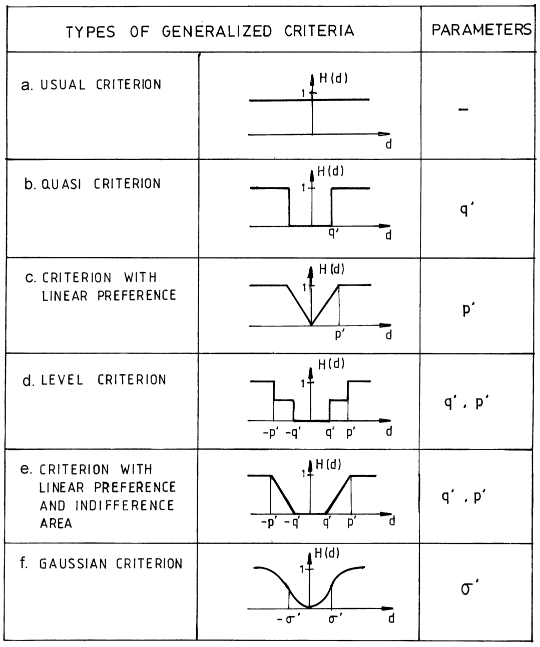

Fig. 3. Different types of criterion functions.

where w_j = weight assigned to the criterion j; $\Phi^+(a)$ = outranking character of a in the alternative set A; $\Phi^-(a)$ = outranked character of a in the alternative set A; $\Phi(a)$ = net ranking of a in the alternative set A. The value having larger $\Phi(a)$ is considered as the best.

$$a \text{ outranks } b \text{ iff } \Phi(a) > \Phi(b)$$

$$a \text{ is indifferent to } b \text{ iff } \Phi(a) = \Phi(b)$$

EXPROM-2 is the modified and extended version of PROMETHEE-2 method which is based on the notion of ideal and anti ideal solutions. The relative performance of one alternative over the other is defined by two preference indices, one by weak preference index (based on outranking, i.e. multicriterion preference index in PROMETHEE-2), and the other by strict preference index (based on the notion of ideal and anti ideal). Ideal and anti ideal values are directly derived from the existing alternative choices which represent extreme limits. Strict preference function is based on the comparison of the difference dm_j with the range of values defined by the evaluations of the whole set of alternatives under this criterion. The strict preference function $\mathrm{SP}_j\ (a,b)$ is defined as:

$$\mathrm{SP}_j(a,b) = [\mathrm{Max}(0, d_j - L_j)]/(\mathrm{dm}_j - L_j) \tag{17}$$

Strict preference index SP(a,b), weighted average of strict preference functions is defined as:

$$\mathrm{SP}(a,b) = \sum_{j=1}^{J} w_j\ \ \mathrm{SP}_j(a,b) / \sum_{j=1}^{J} w_j. \tag{18}$$

The total preference index TP(a,b), i.e. summation of strict and weak preference indices in the fuzzy environment, gives an accurate measure of the intensity of preference of one alternative over the other for all criteria (Diakoulaki and Koumoutsos, 1991).

$$\mathrm{TP}(a,b) = \mathrm{Min}[1; \mathrm{SP}(a,b) + \mathrm{WP}(a,b)], \tag{19}$$

where L_j = limit of preference (0 for usual criterion and indifference values q' and p' in case of other five criterion functions; dm_j = difference between extreme limits (ideal and anti ideal values of the criterion j); WP(a,b) = weak preference index (multicriterion preference index of PROMETHEE-2). The remaining procedure is same as PROMETHEE-2 method.

6.1. Final rankings and correlation coefficients

An irrigation management expert (Director, Water and Land Management, Training and Research Institute, Andhra Pradesh, India) has been consulted for the decision-making process mainly with reference to indifference and preference threshold values. Parameters employed in various MCDM methods are as follows: in PROMETHEE-2, usual criterion function is adopted (Brans et al., 1986). In EXPROM-2, parameters are based on PROMETHEE-2, ideal and anti ideal values (Table 2) from the existing alternatives. Table 5 presents the multicriterion preference index values and $\Phi^+(a)$, $\Phi^-(a)$, $\Phi(a)$, ranking pattern corresponds to PROMETHEE-2. It may be noted that in multicriterion preference index diagonal values are zero because of

Table 5
Multicriterion preference index and ranking pattern for PROMETHEE-2

	Multicriterion preference index values						$\Phi^+(a)$	$\Phi^-(a)$	$\Phi(a)$	Ranks
	1	2	3	4	5	6				
1	0.000	0.312	0.312	0.312	0.312	0.312	1.560	3.440	−1.880	6
2	0.688	0.000	0.312	0.312	0.312	0.312	1.936	3.064	−1.128	5
3	0.688	0.688	0.000	0.312	0.312	0.312	2.312	2.688	−0.376	4
4	0.688	0.688	0.688	0.000	0.312	0.874	3.250	1.750	1.500	2
5	0.688	0.688	0.688	0.688	0.000	0.874	3.626	1.374	2.252	1
6	0.688	0.688	0.688	0.126	0.126	0.000	2.316	2.684	−0.368	3

comparison of one alternative over the same alternative. For example, in Table 5, summation of row 5, i.e. $\Phi^+(5)$ is 3.626 and summation of column $\Phi^-(5)$ is 1.374. The resulting value $\Phi(5)$ is the difference between $\Phi^+(5)$ and $\Phi^-(5)$ [3.626−1.374 = 2.252]. Similarly other values are computed. Alternative having the highest Φ value is considered as the best. It is observed from Table 5 that alternative G5 having the highest Φ value of 2.252 is the best followed by G4 having Φ value of 1.5. Alternative G1 is least ranked due to its low Φ value of −1.880. Table 6 presents the total preference index values and $\Phi^+(a)$, $\Phi^-(a)$, $\Phi(a)$, ranking pattern corresponding to EXPROM-2.

It is observed from Tables 5 and 6 that both the methods PROMETHEE-2 and EXPROM-2 show slightly different ranking pattern. Alternatives G5 (P29) and G4 (P23) occupied first and second positions in both PROMETHEE-2 and EXPROM-2. It is observed that alternative policy G1 (P04) is least ranked in PROMETHEE-2 and EXPROM-2. It is concluded that alternatives G4 (P23) and G5 (P29) are potential policies for further investigation. There is slight change in the ranking pattern in EXPROM-2 due to the contribution of strict preference index when compared to PROMETHEE-2.

6.2. Spearman rank correlation coefficient

Spearman rank correlation coefficient (R) is useful to determine the measure of association between ranks obtained by different MCDM methods (Gibbons, 1971). If U_a and V_a denote the ranks achieved by two different MCDM methods for same alternative a, then coefficient R is defined as:

$$R = 1 - \frac{6\sum_{a=1}^{A} D_a^2}{A(A^2-1)}, \tag{20}$$

where a = number of alternatives; a = 1,2,...,A; A = total number of alternatives; D_a = difference between ranks ($U_a - V_a$); R = 1 represents perfect association between the ranks; R = 0 represents no association between the ranks; R = −1 represents perfect disagreement between the ranks.

The value of R always lies between −1 and +1. Spearman rank correlation coefficient (R) is computed to assess the degree of correlation between different MCDM methods. From Table 5 the value of U_a (ranking by PROMETHEE-2 method) is 6, 5, 4, 2, 1, 3. Similarly the value of V_a from Table 6 (ranking by EXPROM-2 method) is 6, 5, 3, 2, 1, 4. The squared difference between U_a and V_a, i.e. $\Sigma D_a{}^2$ is $[(6-6)^2+(5-5)^2+(4-3)^2+(2-2)^2+(1-1)^2+(3-4)^2] = 2$. With number of alternatives (A = 6 in this case), R value between PROMETHEE-2 and EXPROM-2 is 0.9428 indicating nearly perfect association between the methods.

6.3. Sensitivity analysis

Sensitivity analysis on different indifference (q'), preference thresholds (p'), ideal, anti ideal values and type of preference functions (six in this case) are performed for both PROMETHEE-2 and EXPROM-2 to observe the robustness in the

Table 6
Total preference index and ranking pattern for EXPROM-2

	Total preference index values						$\Phi^+(a)$	$\Phi^-(a)$	$\Phi(a)$	Ranks
	1	2	3	4	5	6				
1	0.000	0.319	0.331	0.363	0.460	0.574	2.047	4.841	−2.794	6
2	0.842	0.000	0.324	0.356	0.453	0.568	2.543	4.124	−1.581	5
3	0.999	0.844	0.000	0.344	0.441	0.555	3.183	3.219	−0.036	3
4	1.000	1.000	0.849	0.000	0.409	1.000	4.258	1.997	2.261	2
5	1.000	1.000	0.910	0.749	0.000	1.000	4.659	1.924	2.735	1
6	1.000	0.961	0.805	0.185	0.161	0.000	3.112	3.697	−0.585	4

ranking pattern. Six types of criterion functions and three criteria (net benefits, agricultural production and labour employment) resulting in 6^3, i.e. 216 combinations are evaluated for various indifference, preference thresholds, ideal and anti ideal values. The rankings obtained have shown that (results are not presented due to space limitation) G5 (P29) and G4 (P23) occupied first and second positions, respectively. The ranking pattern is quite robust to small parameter changes as far as the first two positions are concerned. It is also observed that Spearman rank correlation coefficient between PROMETHEE-2 and EXPROM-2 varies between 0.85 to 0.95.

Considering the cases of equal and varying weightages together with extensive sensitivity analysis studies, it is concluded that alternative policy G5 referring to policy P29 of Table 2 is the most suitable one for further investigation and implementation. Next best is found to be G4 (P23). In the best compromise plan more importance is given to sorghum(s), paddy(srf), groundnut(srf) and groundnut(w) by the model. Irrigation intensity has reached 126.4%. Net benefits, agricultural production and labour employment per hectare on average for the CCA are 8980 rupees ($225), 3.73 tonnes and 242 man-days, respectively. With the present inflow scenario, groundnut has emerged as the suitable crop both for summer and winter seasons with second best crop being paddy.

7. Conclusions

Based on the analysis of the results of a real-world irrigation planning problem of Sri Ram Sagar Project, Andhra Pradesh, India, the following conclusions are drawn.

1. A new MCDM method EXPROM-2 is developed to include the considerations of ideal and anti ideal values in the PROMETHEE-2.
2. Cluster analysis is found to be an effective tool to reduce the large number of the nondominated alternatives to a manageable set.
3. The ranking pattern is quite robust to small parameter changes as far as the first two positions are concerned.
4. Alternative policy G5 referring to policy P29 is the most suitable one for further investigation. Net benefits, agricultural production and labour employment per hectare on average for the CCA are 8980 rupees ($225), 3.73 tonnes and 242 man-days, respectively, in the best compromise plan.
5. Spearman rank correlation coefficient is found to be very useful to assess the correlation between two ranking methods.

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