# PARTICIPATORY IRRIGATION MANAGEMENT USING FUZZY LOGIC

K. SRINIVASA RAJU

Department of Civil Engineering, Birla Institute of Technology and Science, Pilani

333 031, Rajasthan, India. Email: ksraju@bits-pilani.ac.in

D. NAGESH KUMAR*

Department of Civil Engineering, Indian Institute of Science, Bangalore - 560 012, India.

Email: nagesh@civil.iisc.ernet.in

*Corresponding author

**Abstract**

*Participatory Irrigation Management (PIM) is gaining importance as it enables the involvement of farmers for selecting and improving chosen irrigation systems, which will reduce the gap between irrigation potential created and utilised. Fuzzy logic based Multicriterion Decision Making (MCDM) has emerged as effective methodology due to its ability to integrate quantitative and qualitative criteria for selection of the best alternative among available alternatives. A case study of Sri Ram Sagar Project (SRSP), Andhra Pradesh, India is analysed with reference to the concept of PIM in the form of farmers' response survey in four irrigation subsystems (canal distributories) of the project to assess their opinion on various facets of irrigation management. Based on the above analysis 6 performance criteria (indicators), namely, (1) environmental impact (2) conjunctive use of surface and ground water resources (3) participation of farmers (4) social impact (5) productivity (6) economic impact, are identified. These criteria are evaluated for four irrigation subsystems of the project to select the best among them. It is concluded that integration of fuzzy logic with real world irrigation planning problem found to be effective.*

## 1 INTRODUCTION

Participatory Irrigation Management (PIM) is gaining importance (Groenfeldt, 1997) as it enables the involvement of farmers for selecting and improving chosen irrigation systems, which will reduce the gap between irrigation potential created and utilised. On the other hand, Multicriterion Decision Making (MCDM) has emerged as effective methodology due to its ability to integrate quantitative and qualitative criteria for selection of the best alternative (Raju and Nagesh Kumar, 1999, 2000). In the present study four irrigation sub systems of Sri Ram Sagar Project (SRSP), Andhra Pradesh, India are evaluated for 6 performance criteria (indicators) using fuzzy multicriterion decision support system. In the next section methodology of MCDM is explained followed by case study, farmer's response survey, formulation of payoff matrix, results, discussion and conclusions.

## 2 FUZZY MULTICRITERION DECISION MAKING

In the present study fuzzy logic based multicriterion decision making (MCDM) methodology is employed to select the best irrigation sub system due to its flexibility of handling subjective data. The methodology uses the concept of degree of similarity measure and an alternative with a higher degree of similarity with respect to a reference alternative is considered as the best (Chen, 1994).

In this methodology, criteria are represented by interval valued fuzzy sets (real interval) as compared to crisp real values between zero and one. Characteristics of the alternative $a$ [$a$=1,2,…A] for various criteria $C_1$, $C_2$, ……., $C_J$ (with weightage of the criteria $W=w_1, w_2, \ldots w_j$) are represented as interval-valued fuzzy sets as below.

$$a = \{(C_1[y_{a1}, y'_{a1}]),\ (C_2[y_{a2}, y'_{a2}], \ldots\ldots, C_J[y_{aJ}, y'_{aJ}])\} \quad (1)$$

where $[y_{aJ}, y'_{aJ}]$ represents fuzzy interval for $a^{th}$ alternative for $J^{th}$ criteria with the ranges of $[0 \le y_{aJ} \le y'_{aJ} \le 1]$ with $1 \le a \le$ A. Here A and $J$ represents number of alternatives and criteria. Equation (1) can also be represented in matrix notation as below:

$$A= [y_{a1}, y'_{a1} ], [y_{a2}, y'_{a2}], \ldots\ldots, [y_{aJ}, y'_{aJ}] \quad (2)$$

The objective is to choose an alternative as best whose characteristics are most similar to the interval-valued fuzzy reference alternative set, R, which is expressed in the matrix notation as below.

$$R= [x_1, x'_1 ], [x_2, x'_2], \ldots\ldots, [x_J, x'_J] \quad (3)$$

where $[x_J, x'_J]$ represents fuzzy interval for reference alternative for $J^{th}$ criteria. Similarity measure $S(A,R,W)$ of alternative A with reference to R is given by

$$S(A,R,W) = \frac{\sum_{j=1}^{J}[(1-(|\, y_{aj} - x_j \,| + |\, y'_{aj} - x_j' \,|)/2 * w_j]}{\sum_{j=1}^{J} w_j} \quad (4)$$

Higher degree of similarity measure is preferred for selection of best alternative.

# 3 CASE STUDY

Sri Ram Sagar Project (SRSP) is a state sector major irrigation project of Andhra Pradesh, India located on river Godavari. The project is mainly meant for irrigation. Global co-ordinates of the site are $18^0 58'$ Latitude North and $70^0 20'$ Longitude East. The SRSP project has three canal distribution systems, namely, Kakatiya, Saraswati and Lakshmi canals serving number of irrigation sub systems (distributories). Crops grown in the command area are Paddy (rice), Jowar, Maize, Groundnut, Sugarcane and Pulses in both summer (Kharif) and winter (Rabi) seasons. Soils of the command area are categorised under red soils and black soils. Climate of the area is sub tropical and semi arid. There is extreme variation in temperature with average maximum and minimum values of $42.2^0$ and $28.6^0$ . The relative humidity varies from 65 to 80%. In the present study four irrigation subsystems (canal distributories) under Kakatiya canal are considered and these are denoted as I1, I2, I3, I4.

# 4 FARMERS'S RESPONSE SURVEY

Farmers' response survey is conducted during 1994-95 to understand the irrigation management characteristics and to identify performance indicators. Questions were asked regarding canal gate opening details, timing, adequacy and distribution pattern (such as equitable etc.) of water supply, status of supplementing canal supplies with ground water, usage of high yield variety seeds, knowledge of critical periods of crops, cost of canal water, participation in operation and management works, relationship with co-farmers and authorities, role of farmers association for effective participatory irrigation management. Questions were also asked on constraints which may reduce yield such as poor drainage, land development work, availability of marketing facilities and fertilisers, water and corresponding effect on economic and social scenarios. Suggestions from farmers are also requested that can be useful for further improvements of the project. The main conclusions emanated from the response survey is (1) all farmers have expressed their satisfaction with the performance of the project and agreed that they benefited from the project (2) They also agreed that participatory approach in the developmental aspects of the project yielded very good results in terms of increasing co-ordination among them selves (3)Formation of farmers association helps to organise them selves to utilise the resources such as water, fertilisers, seeds effectively. Response survey also helped the authors to get acquainted with the project and formulation of performance criteria (indicators).

# 5 FORMULATION OF INDICATORS AND PAYOFF MATRIX

In the present study, contrary to a single indicator of how the input (water) is used other indicators on agricultural, economic and social environment are also considered. Six performance criteria (indicators), namely, environmental impact ($C_1$), conjunctive use of surface and ground water resources ($C_2$), participation of farmers ($C_3$), social impact ($C_4$), productivity ($C_5$), economic impact ($C_6$), are formulated and evaluated for selecting the best irrigation subsystem. Out of the six, three criteria, namely, environmental impact, conjunctive use of surface and ground water resources and social impact are related to sustainability. Even though productivity and economic impact are interdependent to some extent, these are assumed to be independent to assess their effect on the overall planning scenario. Brief details of the criteria are as below.

- Environmental impact issues analysed after introduction of irrigation facilities are raise in ground water table and salinity level;

- Conjunctive use of surface and ground water is essential to provide more reliable supply of water to crops when needed as well as to reduce water logging effect;

- Participation of farmers: Farmers participation/knowledge of technology and new developments are essential for optimum utilization of resources. It is the way in which farmers use irrigation water, determines the success of an irrigation project;

- Social impact includes labour employment, which is measured in terms of man days employed per hectare for each crop grown;

- Productivity of various crops for various seasons for various land holdings are to be determined;

- Economic impact includes farmer's income and revenue collected due to supply of irrigation water;

Information on above criteria has been obtained from primary sources such as marketing societies, irrigation, ground water and agricultural departments. Additional information on criteria is obtained from secondary sources such as interviews conducted with farmers, discussion with officials of the project, economic and statistics reports etc. Criteria C1, C2, C3 are qualitative and remaining criteria C4, C5, C6 are quantitative type. However these criteria are also assumed to be qualitative due to the following reason: converting productivity (yield) values of six crops to a base equivalent for 2 seasons under surface and well irrigation for different land holdings becomes complex. Similar difficulties are faced for the other two criteria (Raju, 1995). The above criteria are evaluated against each irrigation subsystem (termed as payoff matrix or systems versus criteria array) on a fuzzy rating basis. Three experts who are monitoring the project are requested to fill up the payoff matrix with the following evaluations (1 for excellent and 0 for unsatisfactory). Experts are having the flexibility to choose any intermediate evaluations for eg. between excellent and unsatisfactory. Table 1 presents payoff matrix corresponding to four irrigation subsystems and six performance indicators on a fuzzy rating basis for the three experts. Based on the evaluations given by all the three experts for each criterion for each alternative (i.e., 3 values) lowest and highest values are considered for the interval for that scenario. For example, for alternative 1 and criterion 2, three experts have given their fuzzy rating as 0.4, 0.2 and 0.2. Accordingly interval was given as [0.2, 0.4]. If all the experts have given same rating such as 0.2, 0.2 and 0.2 then the interval was given as [0.2, 0.2]. Table 2 presents payoff matrix in the interval form. The approach presented here is indirectly considering group decision making by taking the opinions of all experts with out averaging the evaluations to arrive at a single value.

# 6 RESULTS AND DISCUSSION

In the present study fuzzy logic based Multicriterion decision making methodology is employed. The methodology is developed in the form of Decision Support System and is named as *Decisive*. Fig 1 presents the sample screen of *Decisive*. In this number of alternatives, criteria, payoff matrix (alternatives versus criteria array) and weights of criteria are to be given as inputs by the user. Provisions for changing the values in the payoff matrix and weights are also incorporated. Reference alternative for each criterion is to be given by the user.

Table 1. Alternatives versus criteria array (payoff matrix) given by individual experts

| Irrigation sub system | Expert | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ |
|---|---|---|---|---|---|---|---|
| I1 | 1 | 0.2 | 0.4 | 1.0 | 1.0 | 1.0 | 1.0 |
| | 2 | 0.2 | 0.2 | 1.0 | 0.8 | 0.8 | 0.8 |
| | 3 | 0.2 | 0.2 | 0.8 | 1.0 | 0.8 | 1.0 |
| I2 | 1 | 0.4 | 0.2 | 0.8 | 0.8 | 0.8 | 0.6 |
| | 2 | 0.6 | 0.0 | 0.6 | 0.8 | 0.8 | 0.4 |
| | 3 | 0.4 | 0.2 | 0.6 | 0.6 | 1.0 | 0.6 |
| I3 | 1 | 0.4 | 0.2 | 0.4 | 0.8 | 0.6 | 0.8 |
| | 2 | 0.4 | 0.0 | 0.0 | 0.6 | 1.0 | 1.0 |
| | 3 | 0.4 | 0.0 | 0.6 | 0.6 | 0.6 | 0.8 |
| I4 | 1 | 0.4 | 0.6 | 0.6 | 0.8 | 0.6 | 0.8 |
| | 2 | 0.6 | 0.4 | 0.4 | 0.8 | 0.6 | 0.8 |
| | 3 | 0.4 | 0.2 | 0.4 | 0.6 | 0.4 | 0.6 |

Table 2. Alternatives versus criteria array (payoff matrix) in the interval form

| Irrigation sub system | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ | Degree of similarity and rank |
|---|---|---|---|---|---|---|---|
| I1 | [0.2, 0.2] | [0.2, 0.4] | [0.8, 1.0] | [0.8, 1.0] | [0.8, 1.0] | [0.8, 1.0] | 0.6833 (1) |
| I2 | [0.4, 0.6] | [0.0, 0.2] | [0.6, 0.8] | [0.6, 0.8] | [0.8, 1.0] | [0.4, 0.6] | 0.5666 (2) |
| I3 | [0.4, 0.4] | [0.0, 0.2] | [0.0, 0.6] | [0.6, 0.8] | [0.6, 1.0] | [0.8, 1.0] | 0.5333 (4) |
| I4 | [0.4, 0.6] | [0.2, 0.6] | [0.4, 0.6] | [0.6, 0.8] | [0.4, 0.6] | [0.6, 0.8] | 0.5500 (3) |

*Decisive* computes the degree of similarity between given alternative and reference alternative (as per equation 4). Higher degree of similarity of an alternative with respect to reference alternative is considered as the best. *Decisive* has the flexibility to change any parameter for the purpose of sensitivity analysis. Provision of graphical representation of ranking pattern in the form of bar chart is also made and presented in Fig 2.

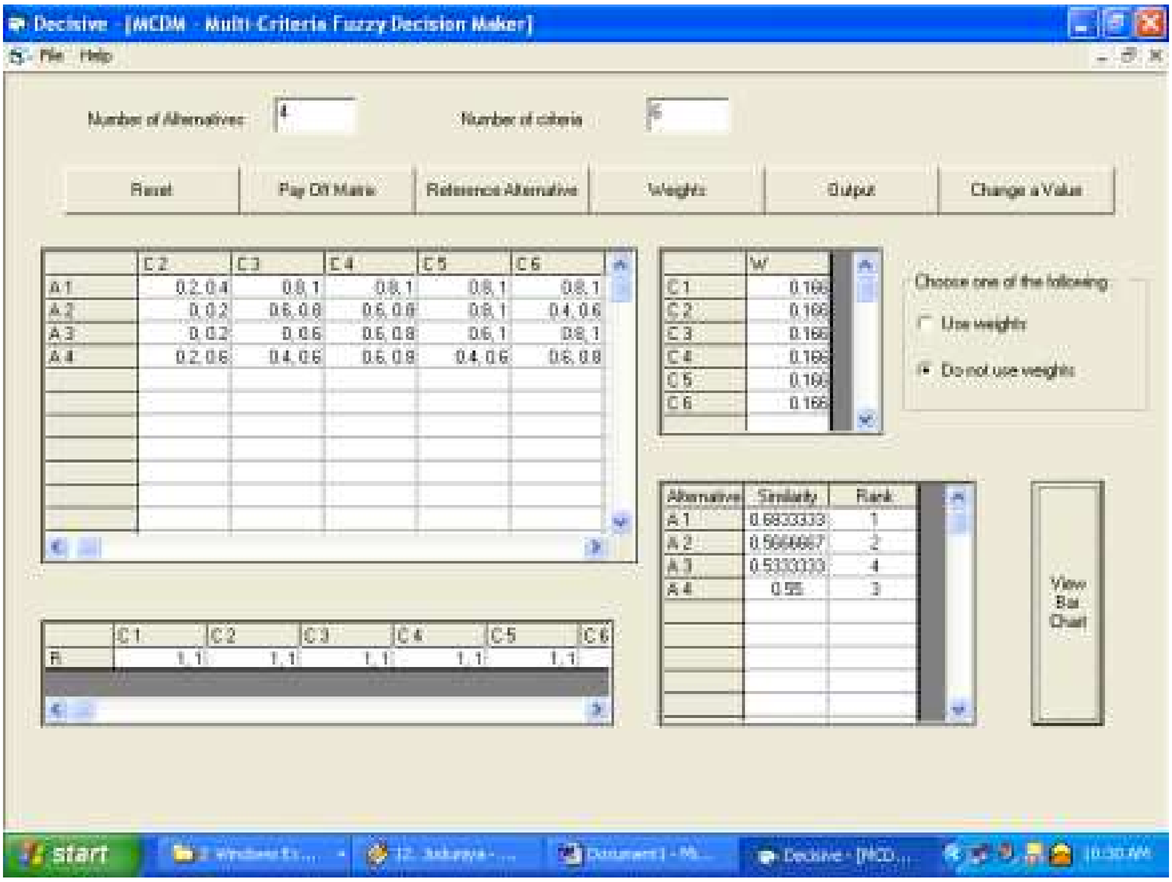


Fig 1. Sample screen of *Decisive*

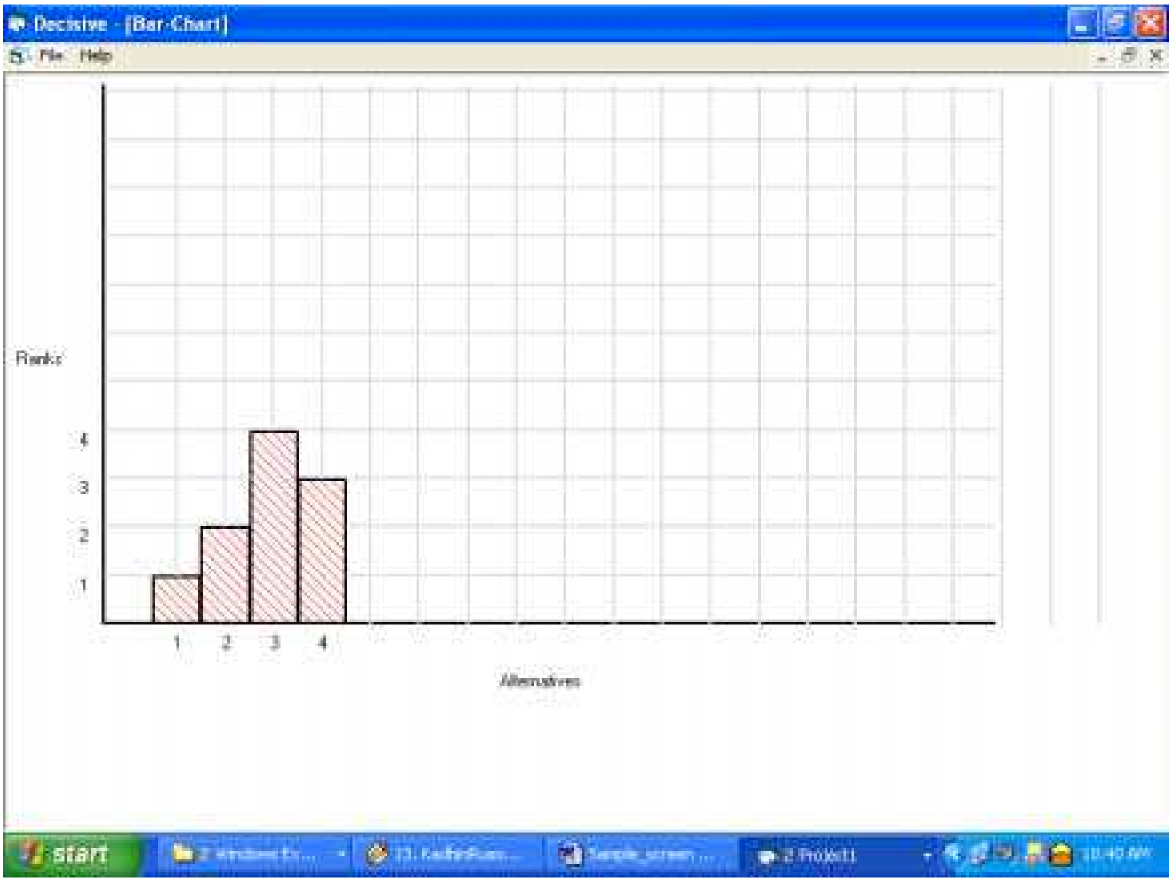


Fig 2. Sample screen of bar chart

In the present study weights of the criteria are assumed to be equal (0.166 each). Reference alternative for all criteria is taken as (1,1). Similarity measure for irrigation sub systems I1 to I4 are computed as per equation 4 and found to be 0.6833, 0.5666, 0.5333, and 0.55 indicating that I1 is the best. Table 2 presents degree of similarity measure and corresponding ranking pattern of four irrigation sub systems. Effect of changing the weights of criteria on the ranking pattern is also studied. Weights of the criteria are fixed based on a numerical scale of 1-10. Table 3 presents the selected weight scenarios and corresponding ranking pattern in the order of alternatives. It is observed from Table 3 that effect of weights is considerable. However, top position remains unchanged. It is observed from above analysis that integration of fuzzy logic with real world irrigation planning problem is very much effective particularly with multiple experts and subjective data environment.

Table 3. Effect of weights on the ranking pattern

| Weight Scenarios | Weights for Criterion | | | | | | Rank for Alternative | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | C1 | C2 | C3 | C4 | C5 | C6 | I1 | I2 | I3 | I4 |
| S1 | 2 | 3 | 3 | 6 | 7 | 8 | 1 | 3 | 2 | 4 |
| S2 | 2 | 3 | 3 | 8 | 6 | 7 | 1 | 3 | 2 | 4 |
| S3 | 1 | 1 | 1 | 7 | 7 | 7 | 1 | 3 | 2 | 4 |
| S4 | 2 | 2 | 10 | 7 | 8 | 10 | 1 | 2 | 3 | 4 |
| S5 | 7 | 8 | 9 | 8 | 9 | 10 | 1 | 2 | 4 | 3 |
| S6 | 10 | 10 | 10 | 6 | 6 | 6 | 1 | 2 | 4 | 3 |
| S7 | 7 | 7 | 7 | 9 | 9 | 9 | 1 | 2 | 3 | 4 |
| S8 | 8 | 8 | 8 | 9 | 9 | 9 | 1 | 2 | 4 | 3 |

# 7 CONCLUSIONS

1. Irrigation sub system I1 is found to be the best as evident from higher degree of similarity.

2. Weights of the criterion do not have any effect on the ranking pattern as far as first position (irrigation sub system I1) is concerned which is evident from sensitivity analysis.

3. *Decisive* is found to be useful due to its flexibility in the approach and graphical features.

4. It is observed that integration of fuzzy logic with real world irrigation planning problem is very much effective particularly with multiple experts and subjective data environment.

# 8 REFERENCES

Chen, S.M, “A new method for handling multicriteria fuzzy decision making problems”, Cybernetics and Systems, Vol. 25, 1994, pp.409-420.

Groenfeldt, David, “Transferring Irrigation Systems from the State to Users: Questions of Management, Authority, and Ownership”, 1997, Economic Development Institute. The World Bank.

Raju, K.S., “Studies on multicriterion decision making methods and management of irrigation systems”, unpublished Doctoral Dissertation, 1995, Indian Institute of Technology, Kharagpur, India.

Raju, K.S. and D. Nagesh Kumar, “Multicriterion decision making in irrigation development strategies”, J. Agricultural Systems, Vol. 62, No. 2, November 1999, pp. 117-129.

Raju, K.S. and D. Nagesh Kumar, “Performance evaluation of an irrigation system by Analytic Hierarchy Process: A case study”, Xth World Water Congress, Melbourne, Australia, 12-17 March 2000, published in CD-ROM.

Groenfeldt, David, 1997. Transferring Irrigation Systems from the State to Users: Questions of Management, Authority, and Ownership. Economic Development Institute. The World Bank.