Evaluation of Irrigation Systems Performance Using Multicriterion Approach

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Compromise programming, Kohonen Artificial Neural Networks, Multicriterion Decision Making, Performance Evaluation, Mahi Bajaj Sagar Project

ABSTRACT
The sustainability of irrigated agriculture continues to be a priority issue in both developed and developing countries. Sustained development of irrigated agriculture is limited by shortages of suitable water supply, irrigable land and other resources. It is recognized that opportunities are available for substantial increase in agricultural output using existing water supply and project infrastructure through improvements in project management (including operations), modernization of infrastructure, better maintenance and improved on-farm agricultural practices. It has been observed that the performance of many irrigation projects is quite poor with the result that the intended benefits under the projects have not been fully realized. In this context, multicriterion decision making approaches are gaining importance due to its ability to rank the alternatives available for consideration. The selection of a suitable irrigation subsystem is examined in the multicriterion context for a case study of Mahi Bajaj Sagar Project, Rajasthan, India. The study deals with the performance evaluation of sixteen irrigation subsystems by considering seven criteria, namely, land development works, timely supply of inputs, conjunctive use of water resources, participation of farmers', economic impact, crop productivity and environmental conservation. Three phase methodology is employed for the study. Phase 1 involves formulation of payoff matrix consisting of irrigation subsystems and performance criteria. In the second phase, Kohonen Artificial Neural Networks (KANN) based classification algorithm is employed to classify the irrigation subsystems into smaller groups. In the third and final phase, Multicriterion decision making (MCDM) technique, namely, Compromise Programming (CP) is employed to rank the groups obtained from the second phase. Spearman Rank Correlation technique is employed to compute correlation coefficient values. Sensitivity analysis studies are also made on the employed techniques for various parameters to check their robustness. Based on the results, it is observed that the group consisting of Parsoliya and Bhawarwad irrigation subsystems can be made pilot irrigation subsystem to formulate guidelines for other irrigation subsystems as evident from the compromise programming analysis and extensive sensitivity analysis. The proposed methodology can serve as a model to choose the best one for formulating guide lines for improving the efficiency and performance of similar other irrigation subsystems.

1. INTRODUCTION

The sustainability of irrigated agriculture continues to be a priority issue in both developed and developing countries. Sustained development of irrigated agriculture is limited by shortages of suitable water supply, irrigable land and other resources. It is recognized that opportunities are available for substantial increase in agricultural output using existing water supply and project infrastructure through improvements in project management (including operations), modernization of infrastructure, better maintenance and improved on-farm agricultural practices. Pike (1995) stressed the role of irrigation in India in expanding crop production, reducing output instability and providing protection against periodic drought and stressed the need for increasing the productivity per unit of water. Also monitoring and evaluation of irrigation projects have received good attention in recent years. These evaluation processes provide valuable information for managers and decision makers about the long-term and short-term effectiveness of these projects (Karamouz et al. 2002). It has been observed that the performance of many irrigation projects is quite poor with the result that the intended benefits under the projects have not been fully realized (Raju and Pillai 1999). In this context, Multicriterion Decision Making is gaining importance due to its ability to rank the alternatives available for consideration (Pomerol and Romero 2000). The present study is aimed to rank the irrigation subsystem(s) which enable to formulate guidelines for other existing irrigation systems (Raju and Duckstein 2002; Vasan 2005). Three phase methodology is employed for this purpose. Phase 1 involves formulation of payoff matrix consisting of irrigation subsystems and performance criteria. In the second phase, Kohonen Artificial Neural Networks (KANN) based classification algorithm is employed to classify the irrigation subsystems into smaller groups. In the third and final phase, Multicriterion decision making (MCDM) technique, namely, Compromise Programming (CP) is employed to rank the groups obtained from the second phase. The paper is organized in the form of literature review, case studies, performance evaluation followed by summary and conclusions.

2. LITERATURE REVIEW

Biswas (1990) stressed the need for effective monitoring and evaluation of irrigation projects. He pointed out the primary requirements for effective monitoring as (1) timeliness (2) cost-effectiveness (3) maximum coverage (4) minimum measurement error (5) minimum sampling error (6) absence of bias and (7) identification of users for eliciting information. McCornick (1993) examined irrigation water management characteristics including on-farm scheduling practices of a lateral canal command in the Eastern Irrigation District, Alberta, Canada. Supply/demand ratios were used as the key indicators for the conceptual framework. A sample questionnaire was prepared to assess the water management characteristics in the command area. Bos (1997) described in detail the performance indicators, namely, water delivery, water use efficiency, maintenance, sustainability of irrigation, environmental aspects, socio-economics and management. He recommended use of these indicators in irrigation and drainage performance assessment. Walters et al. (1999) conducted response survey in eight villages located in Bais Bay Basin, Negros Island, Philippines. It is concluded that characteristics like the degree of local knowledge, security of land tenure and community cohesion affected people's participation to a great extent.

Dedrick et al. (2000) tested three phased Management Improvement Program in the Maricopa-Stanfield Irrigation and Drainage District area in central Arizona, USA. The three-phased process consists of analysis of the current performance of the agricultural system, plans for improvement by the stakeholders and collaborative implementation of the plans. The developed methodology is found to be useful and satisfactory. Javan et al. (2002) studied some of the water management problems of three different irrigation systems namely, Doroodzan project, Zayandeh Rud and Moghan project in Iran for both wet and dry seasons. Irrigation systems were evaluated on overall project water delivery efficiency and the monthly water requirement of crops. They concluded that the distribution and conveyance of water in the Doroodzan Irrigation Network was unreliable in both seasons. Water distribution equity along territories for other two projects was found to be poor. Brugere and Lingard (2003) studied the causes of irrigation deficits and farmer's vulnerability in Lower Bhavani Project in Tamil Nadu, India. They observed that lower returns from land due to insufficient water availability increased towards the tail end of the irrigation system. They concluded that irrigation deficit can be used as an indicator of farmer's vulnerability while assessing performance of an irrigation system. Fraiture and Wichelns (2010) explored several strategies for ensuring that sufficient food is produced in the future. They concluded that sufficient land and water resources are available to satisfy global food demands during the next 50 years, but only if water is managed more effectively in agriculture. Bolaños et al. (2011) assessed the performance of 22 small and medium size community-managed irrigation schemes, in different locations along the Mauritanian banks of the Lower Senegal River. It is concluded that productivity of land, irrigation water, and fuel were well below potential. Carr et al. (2011) compared farmers' perceptions to reclaimed water at a number of locations in Jordan and concluded that perceptions seem to be related to farmers' capacity to control water quality and manage agricultural challenges presented by reclaimed water.

Very few studies are reported on performance evaluation in multicriterion context. Gates et al. (1991) and Heyder et al. (1991) proposed an approach to assess the alternative strategies for an irrigation water delivery system of Alamosa river and La Jara Creek Systems in the San Luis Valley of South Central Colorado. Two MCDM methods PROMETHE-2 and Weighted Average were employed to rank 11 alternative strategies. They concluded that both methods preferred the same alternative strategy. Similar studies are reported by Raju and Pillai (1999) for the case study of Sri Ram Sagar project, India to rank five irrigation subsystems.

3. CASE STUDY

Mahi Bajaj Sagar Project (MBSP) is located in Banswara district in southern part of Rajasthan state bordering the states of Madhya Pradesh and Gujarat. The project is situated near a village Borkhera about 16 Km northeast of Banswara town. Gross storage and live storage capacities of the reservoir are 2180.39 Mm^3 and 1829.27 Mm^3. Culturable Command Area (CCA) of the project is 80,000 ha in Phase 1 and 1,23,500 ha in Phase 2. Out of these, 57,531 ha have been so far opened for irrigation. The MBSP has three main canal systems namely, Left Main Canal (LMC), Right Main Canal (RMC) and Bhungra Canal (BC). The principal crops grown in the command area in Kharif and Rabi seasons are Paddy, Cotton, Wheat, Gram and Pulses. The area is classified as semi-arid. May is the hottest month of the year, with mean daily maximum and minimum temperatures of 40.5 ^oC and 27.5 ^oC respectively. The annual range in temperature, i.e., the difference between the extreme maximum and minimum temperatures reaches about 42 ^oC. The soils of the area are categorized under black, red, brown and mixed soils (Mahi Bajaj Sagar Project Report 1978). Index map of Mahi Bajaj Sagar Project is presented in Fig. 1 whereas index map of 16 irrigation subsystems is presented in Fig. 2.

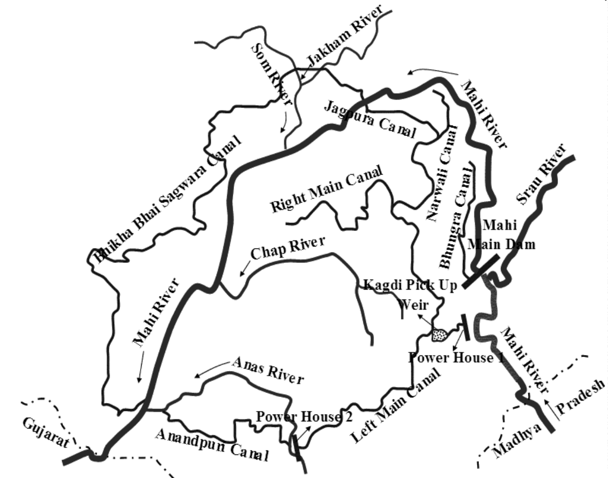

Figure 1. Index map of Mahi Bajaj Sagar Project (MBSP)

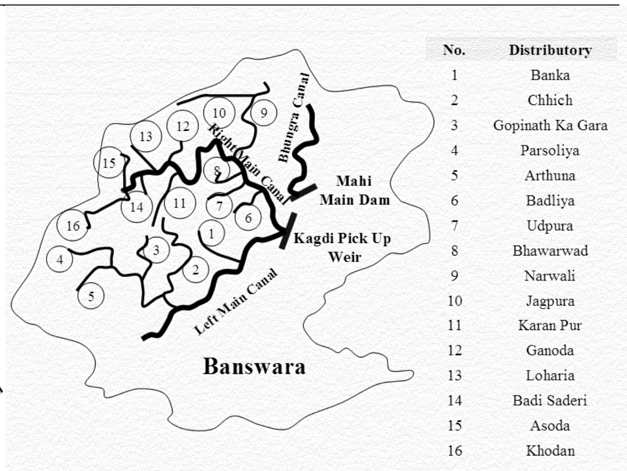

Figure 2. Index map of sixteen irrigation subsystems of Mahi Bajaj Sagar Project

4. PERFORMANCE EVALUATION

4.1 Phase 1: Formulation of Payoff Matrix

Sixteen irrigation subsystems of the Mahi Bajaj Sagar Project (these will be termed as IS1 to IS16) are evaluated in the present analysis with reference to seven criteria, namely, Land Development Works (LDW), Timely Supply of Inputs (TSI), Conjunctive Use of Water resources (CUW), Participation of Farmers' (PF), Economic Impact (EI), Crop PRoductivity (CPR) and Environmental Conservation (EC). Details about performance criteria are presented below:

Criterion 1: Land Development Works (LDW): Land Development Works includes land leveling, land shaping and consolidation of holdings.

Criterion 2: Timely Supply of Inputs (TSI): Efficient and timely use of irrigation facilities requires farmer's knowledge about the technology, developments in irrigated agriculture, timely supply of inputs.

Criterion 3: Conjunctive Use of Water resources (CUW): Conjunctive use of surface and ground water is essential to provide more reliable supply of water to crops when needed. This also reduces water logging effect, if any.

Criterion 4: Participation of Farmers' (PF): Participation of farmers' is essential for the optimum utilization of resources, which also determines the success of an irrigation project.

Criterion 5: Economic Impact (EI): The economic impact is assessed by the economic status of the individual farmer or group of farmers'.

Criterion 6: Crop PRoductivity (CPR): Crop productivity can be assessed by knowing the yield of the crop in the command area.

Criterion 7: Environmental Conservation (EC): Environmental conservation issues analyzed after introduction of irrigation facilities are ground water table and salinity level.

These are based on the responses from project officials at various levels, interactions with farmers' and interviews with them using structured questionnaire and available project reports. Two payoff matrices (of irrigation subsystems versus criterion array), namely, analyst (second author) and farmer's payoff matrix are formulated. Each criterion for the respective irrigation subsystem was assessed subjectively on a numerical scale of 0-100 [Excellent (100), Very Good (80), Good (60), Fair (40), Average (20), Unsatisfactory (0)]. Flexibility is also provided to choose any intermediate values other than those marked on the numerical scale, to minimize subjectivity while assessing the criterion values. Payoff matrix for each farmer is formulated based on the above mentioned numerical scale and their views about the irrigation subsystem to which they belong. Averaging of payoff matrix values given by farmers' and analyst is done to consider both the views in a holistic manner. Average payoff matrix presented in Table 1 is used for grouping and ranking of the irrigation subsystems.

Table 1. Average payoff matrix (before grouping)

S. No.	Irrigation Subsystem	LDW	TSI	CUW	PF	EI	CPR	EC
IS1	Banka	36	75	39	66	43	45	64
IS2	Chhich	37	52	46	54	42	53	59
IS3	Gopinath Ka Gara	22	82	26	47	57	54	69
IS4	Parsoliya	41	41	56	56	64	57	77
IS5	Arthuna	64	49	47	47	50	51	65
IS6	Badliya	46	85	33	69	49	67	55
IS7	Udpura	67	84	44	38	51	32	36
IS8	Bhawarwad	53	77	52	58	64	49	68
IS9	Narwali	45	65	47	78	54	46	46
IS10	Jagpura	37	59	36	65	58	59	69
IS11	Karan Pur	49	79	56	61	39	64	61
IS12	Ganoda	54	79	49	70	62	60	47
IS13	Loharia	49	56	27	33	48	42	71
IS14	Badi Saderi	53	66	46	27	41	50	72
IS15	Asoda	34	59	46	49	47	59	37
IS16	Khodan	27	63	31	57	51	27	48
MIN		22	41	26	27	39	27	36
MAX		67	85	56	78	64	67	77
RANGE		45	44	30	51	25	40	41

4.2 Phase 2: Classification of Irrigation Subsystems using Kohonen Artificial Neural Networks (KANN)

Kohonen Artificial Neural Networks (KANN) is a self-organizing mapping technique with only two layers, input and output. Each layer is made up of neurons. The number of neurons in input layer, *M*, is identical to the dimensionality of input vectors, while the number of neurons in the output layer, *N*, is determined by the number of groups that input data will be apportioned into. Each neuron in the output layer is interconnected with all those in the input layer by a set of weights or a weight vector, e.g., the *j* th output neuron has a weight vector connecting to all the input neurons, $w_j = \{w_{ji}\}, i = 1,2,....M$.

The function of an input neuron is to transmit input data to the next layer, whereas an output neuron calculates the Euclidean distance between its weight vector w_j and input vector X' to measure their similarity. The main objective of Kohonen network is to transform an incoming vector with arbitrary dimension into a one or two dimensional discrete map, and to perform this transformation adaptively in a topologically ordered fashion (Kohonen 1989; Liong et al. 2004). The Kohonen neural network training procedure is as follows:

1. Assign randomly small values to the initial weight vectors $w_j(0)$ of output neuron *j*, where *j* = 1, 2, . . ., *N*.
2. Draw an input vector X' randomly from the input data, and feed it into the Kohonen network.
3. Find distance D_j between input vector X' and each output neuron's weight $w_j(n)$ at time *n*.

   $D_j = \left\| X' - w_j \right\|; j = 1,2,...., N..where \ \| \ \|$ is Euclidean norm.
4. Select the winning neuron C' which has minimum D_j.

   $$C' = \arg_j \min(D_j); j = 1,2,.......N$$
5. Adjust the weight vectors of all neurons through

   $$w_j(n+1) = w_j(n) + \eta(n)[X'(n) - W_j(n)] \quad if \in A'_c$$

   $w_j(n+1) = w_n(n)$ otherwise

   $$C' = \arg_j \min(D_j); j = 1,2,.......N$$

where, $\eta(n)$ is the learning rate parameter which controls how fast the algorithm can change and update its internal parameters in response to new data or can minimize their error while learning. A'_C is the neighborhood function centered on the winning neuron C'. Repeat steps 2 to 5 until no noticeable changes are observed or when the specified number of epochs (iterations) is achieved.

In the present study, KANN is used to classify the irrigation subsystems. MATLAB-based-solution-methodology is employed. Built-in functions in MATLAB such as NEWC which is a function of NET (creates new competitive layer which includes provision of giving learning rate and conscience rate values) is used. Conscience bias learning function is used to increase the net input to neurons that have the lowest average output until each neuron responds approximately an equal percentage of the time. Learning is done using a parameter conscience rate. Default values of learning rate and conscience rate used are 0.01 and 0.001 respectively. Fig. 3 presents schematic diagram of KANN for the present planning problem.

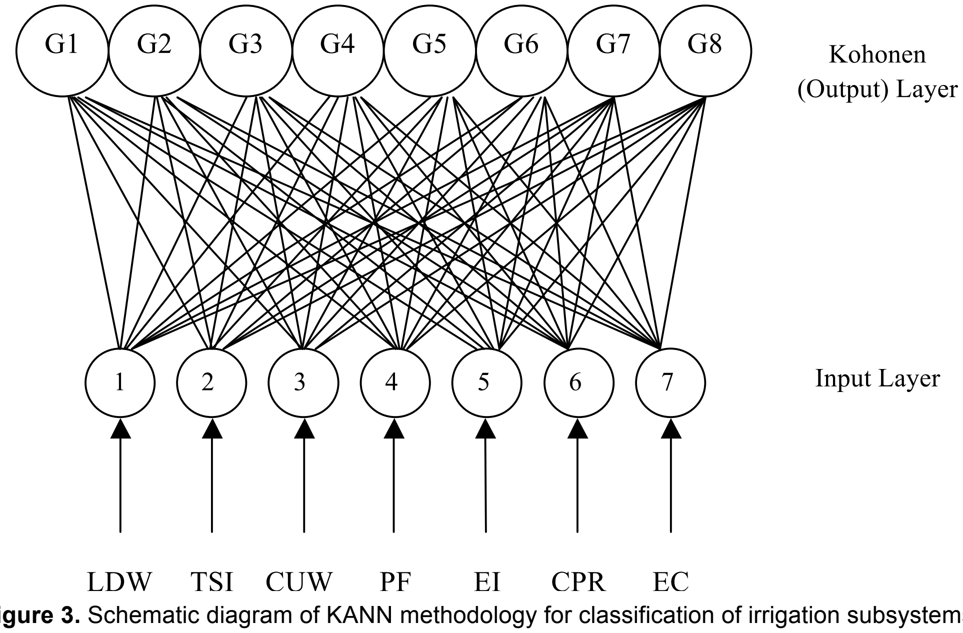

Figure 3. Schematic diagram of KANN methodology for classification of irrigation subsystems

Input layer consists of seven performance criteria (representing 1 to 7), namely, LDW, TSI, CUW, PF, EI, CPR and EC and output layer consists of a number of groups (representing with G1 to G8 as chosen after grouping, in the present planning problem). Weights of the criteria estimated by Analytic Hierarchy Process (AHP) methodology are used for further analysis. These are 0.0362, 0.0881, 0.1179, 0.1171, 0.3554, 0.1928 and 0.0925 for LDW, TSI, CUW, PF, EI, CPR and EC respectively (Vasan 2005).

For the network to operate properly, the input vector must be normalized (to make it dimensionless) to ensure that the Kohonen layer finds the correct class for the problem. In the present case, payoff matrix formulated is already a normalized matrix (as it is based on a numerical scale of 0 to 100). Weighted normalized payoff matrix is prepared (i.e., weights of the criteria obtained by AHP methodology are multiplied with payoff matrix values of concerned criteria in Table 1) to consider views of the decision maker and presented in Table 2.

Table 2. Weighted normalized payoff matrix and representative group from Kohonen classification

Irrigation subsystems	LDW	TSI	CUW	PF	EI	CPR	EC	Groups	Square Error
IS1	1.3043	6.6060	4.5977	7.7306	15.2813	8.6765	5.9187	**G8****	2.3680
IS2	1.3405	4.5802	5.4229	6.3250	14.9260	10.2189	5.4563	G8	2.3725
IS3	0.7971	7.2226	3.0651	5.5051	20.2567	10.4117	6.3811	**G3****	2.8198
IS4	1.4854	3.6113	6.6018	6.5593	22.7443	10.9902	7.1210	**G5****	3.3983
IS5	2.3187	4.3159	5.5408	5.5051	17.769	9.8333	6.0112	G2	3.0622
IS6	1.6666	7.4868	3.8904	8.0820	17.4136	12.9183	5.0864	G7	5.4513
IS7	2.4274	7.3987	5.1872	4.4509	18.1244	6.1699	3.3293	G1	3.7481
IS8	1.9202	6.7822	6.1303	6.7935	22.7443	9.4477	6.2886	G5	3.3983
IS9	1.6304	5.7252	5.5408	9.1361	19.1905	8.8693	4.2541	**G4****	4.4751
IS10	1.3405	5.1967	4.2440	7.6135	20.6120	11.3758	6.3811	G3	2.8254
IS11	1.7753	6.9583	6.6018	7.1449	13.8598	12.3398	5.6413	**G7****	5.4452
IS12	1.9564	6.9583	5.7766	8.1991	22.0336	11.5686	4.3466	G4	4.4941
IS13	1.7753	4.9325	3.1830	3.8653	17.0582	8.0980	6.5661	**G6****	3.7196
IS14	1.9202	5.8133	5.4229	3.1625	14.5706	9.6405	6.6586	G6	3.7224
IS15	1.2318	5.1967	5.4229	5.7394	16.7029	11.3758	3.4218	**G2****	3.0613
IS16	0.9782	5.5490	3.6546	6.6764	18.1244	5.2059	4.4390	**G1****	3.7439
								Total	58.1055

** Representative Irrigation subsystem for the corresponding group

The parameters used for the study are number of groups (4, 5, 6, 7, 8), different epochs (5000, 10000, 20000, 30000, 40000, 50000), various learning rates (0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0) and conscience rate (kept constant as 0.001). This results in 450 combinations (5 groups, 6 epochs and 15 learning rates). The program is run for the 450 combinations to assess their effect on square error (square of euclidean distance) values. This also enables to determine the appropriate parameters for the present problem (http://www.mathworks.com/products/neuralnet/ index.html). Here group 4 indicates that the input data are classified into 4 groups.

In the present study, learning rate of 0.01 and conscience rate of 0.001 are used as supported by literature (http://www.mathworks.com/products/neuralnet/index.html). Fig. 4 presents the variation of square error values for various groups and different epochs for a learning rate of 0.01 and conscience rate of 0.001. It is observed from Fig. 4 that square error value is decreasing from group 4 (123.8332 for 20000 and 50000 epochs, 126.3457 for 30000 epochs) to group 8 (58.1055 for 30000 epochs, 68.2792 for 40000 epochs). It is also observed that maximum and minimum square error values are reducing simultaneously with the increase in number of groups from 4 to 8 as shown in Fig. 5. It is inferred from the above analysis that learning rates and epochs are having significant effect on square error values.

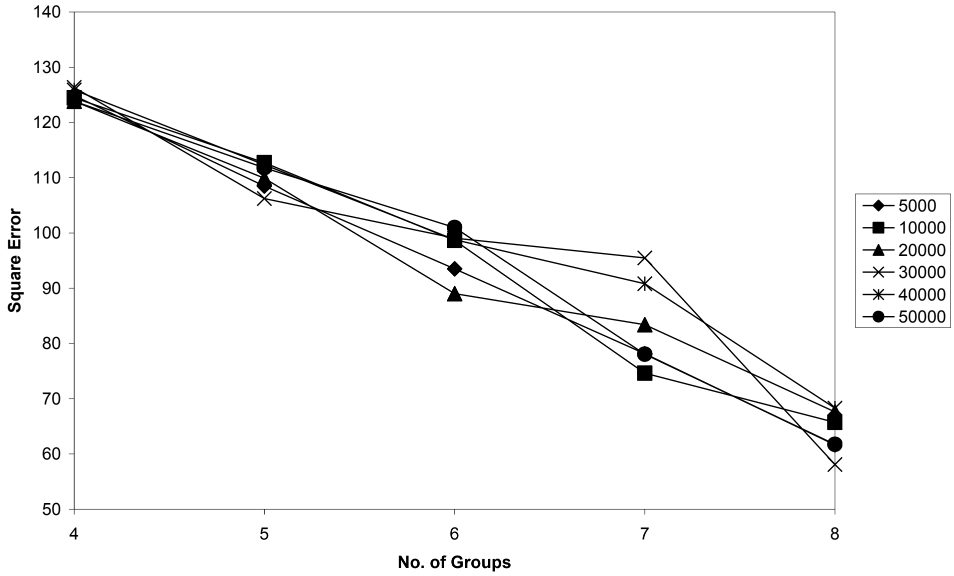

Figure 4. Variation of square error value for various groups and epochs (Learning rate = 0.01 and Conscience rate = 0.001)

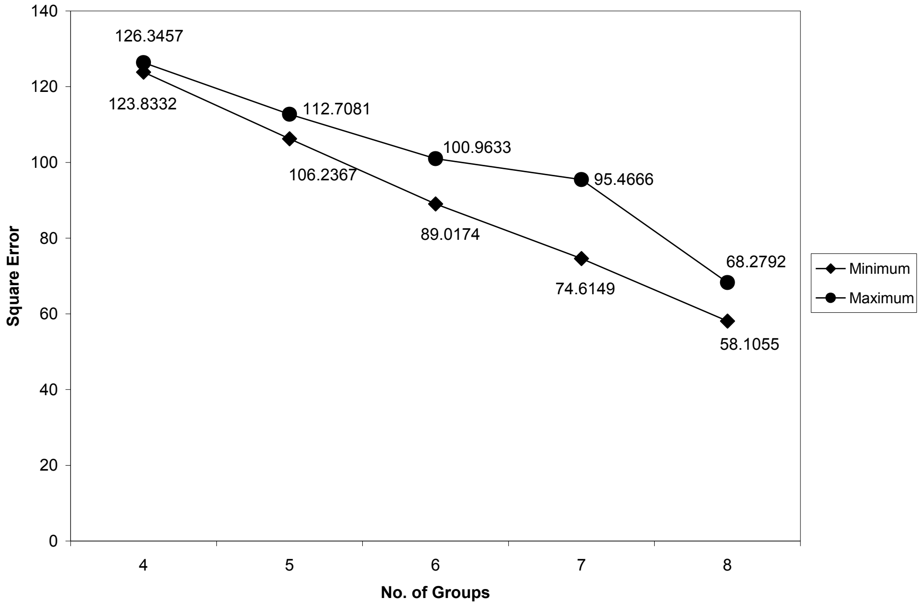

Figure 5. Variation of square error value for various groups (Learning rate = 0.01 and Conscience rate = 0.001)

The maximum number of groups is fixed as 8, as proper classification did not occur for groups more than 8 and it was not found relevant to classify beyond 8 as the number of irrigation subsystems considered is 16. Keeping the above parameters in view (learning rate 0.01, conscience rate of 0.001 and number of groups 8), the number of epochs is fixed as 30000. With this combination, the minimum square error is 58.1055 as evident from Fig 5. Table 3 presents the weights of the groups obtained by KANN methodology for the above combination. These parameters can be used further for simulating the network, if more data are available for classification.

Table 3. Weights of the groups obtained by KANN methodology for the chosen parameters (Learning rate=0.01, Conscience rate=0.001, Groups=8, Epochs=30000)

Groups	LDW	TSI	CUW	PF	EI	CPR	EC
G1	1.7026	6.4736	4.4207	5.5640	18.1244	5.6878	3.8843
G2	1.7752	4.7563	5.4818	5.6223	17.2359	10.6046	4.7164
G3	1.0687	6.2101	3.6543	6.5588	20.4343	10.8935	6.3811
G4	1.7932	6.3411	5.6586	8.6681	20.6105	10.2175	4.3003
G5	1.7028	5.1967	6.3661	6.6764	22.7443	10.219	6.7048
G6	1.8477	5.3728	4.3027	3.5140	15.8146	8.8691	6.6123
G7	1.7210	7.2225	5.2465	7.6133	15.6362	12.6290	5.3639
G8	1.3224	5.5936	5.0101	7.0281	15.1037	9.4473	5.6876

Squared error value for specific irrigation subsystem falling in a specific group is obtained by summation of square of the difference between the weight of each criterion obtained by KANN falling in that group (Table 3) and corresponding criterion values of irrigation subsystem falling in that group (Table 2). Criterion value of LDW for IS1 is 1.3043 and weight value of LDW for group 8, in which IS1 is falling, is 1.3224. Square error values for criterion LDW is $(1.3043-1.3224)^2$. Similar computations are performed for all the criteria and summation of all such values gives the square error value i.e. $[(1.3043-1.3224)^2 + (6.6060-5.5936)^2 + (4.5977-5.0101)^2 + (7.7306-7.0281)^2 + (15.2813-15.1037)^2 + (8.6765-9.4473)^2 + (5.9187-5.6876)^2] = 2.3680$. Table 2 presents the irrigation subsystems and corresponding groups after such procedure. It is observed from Table 2 that groups G1, G2, G3, G4, G5, G6, G7 and G8 consist of irrigation subsystems (IS7, IS16), (IS5, IS15), (IS3, IS10), (IS9, IS12), (IS4, IS8), (IS13, IS14), (IS6, IS11) and (IS1, IS2) respectively.

Irrigation subsystem which has the minimum square error value in that group is chosen as group representative. Thus, instead of having to consider sixteen irrigation subsystems, representative subsystem from each group are used further for effective decision making. The irrigation subsystems IS16, IS15, IS3, IS9, IS4, IS13, IS11, IS1 having minimum total squared error values of 3.7439, 3.0613, 2.8198, 4.4751, 3.3983, 3.7196, 5.4452 and 2.3680 are found to be the representative subsystems for the sixteen, due to less values of square error. The groups are represented by G1, G2, G3, G4, G5, G6, G7 and G8 for further analysis. Resulting groups which are obtained from Kohonen classification methodology and representative irrigation subsystems of each group are presented in Table 2. The normalized payoff matrix after grouping is presented in Table 4 for further analysis, such as for application of MCDM techniques.

Table 4. Normalized payoff matrix after Kohonen classification methodology

Groups	LDW	TSI	CUW	PF	EI	CPR	EC
G1	27	63	31	57	51	27	48
G2	34	59	46	49	47	59	37
G3	22	82	26	47	57	54	69
G4	45	65	47	78	54	46	46
G5	41	41	56	56	64	57	77
G6	49	56	27	33	48	42	71
G7	49	79	56	61	39	64	61
G8	36	75	39	66	43	45	64
MIN/WORST	22	41	26	33	39	27	37
MAX/BEST	49	82	56	78	64	64	77

4.3 Phase 3: Application of MCDM Technique

MCDM technique, namely, Compromise Programming (CP) is employed to rank the irrigation subsystems after grouping (in this case there are eight groups). Compromise Programming defines the 'best' solution as the one in the set of efficient solutions, whose point is at the least distance from an ideal point (Zeleny 1982). The aim is to obtain a solution that is as 'close' as possible to some 'ideal'. The distance measure used in Compromise Programming is the family of L_p - metrics and given as

$$L_p(a) = \left[\sum_{j=1}^{J} w_j'^{\,p} \left| f_j^* - f(a) \right|^p \right]^{\frac{1}{p}} \tag{1}$$

If the criteria are not expressed in commensurable terms, then a scaling function $(M_j - m_j)$ can be defined to ensure the same range for each criterion and this range corresponds to the interval (0, 1). With this transformation, Eq. 1. becomes,

$$L_p(a) = \left[\sum_{j=1}^{J} w_j'^{\,p} \left| \frac{f_j^* - f(a)}{M_j - m_j} \right|^p \right]^{\frac{1}{p}} \tag{2}$$

where $L_p(a)$ = L_p- metric for alternative *a*, $f(a)$ = Value of criterion *j* for alternative *a*, M_j = Maximum value of criterion *j* in set A', m_j = Minimum value of criterion *j* in set A, f_j^* = Ideal value of criterion *j*, w_j' = Weight of the criterion *j*, p = Parameter reflecting the attitude of the decision maker with respect to compensation between deviations. For *p*=1, all deviations from f_j^* are taken into account in direct proportion to their magnitudes meaning that there is full (weighted) compensation between deviations. For $p = \infty$, the largest deviation is the only one taken into account corresponding to zero compensation between deviations.

An interactive computer program is developed for CP in Visual Basic environment which makes use of Graphical User Interface. Fig. 6 presents a sample screen of CP in which the number of alternatives, criteria, payoff matrix and parameter *p* are given as inputs by the user. The user has the flexibility to give any number of alternatives and criteria and change the values in the payoff matrix and weights.

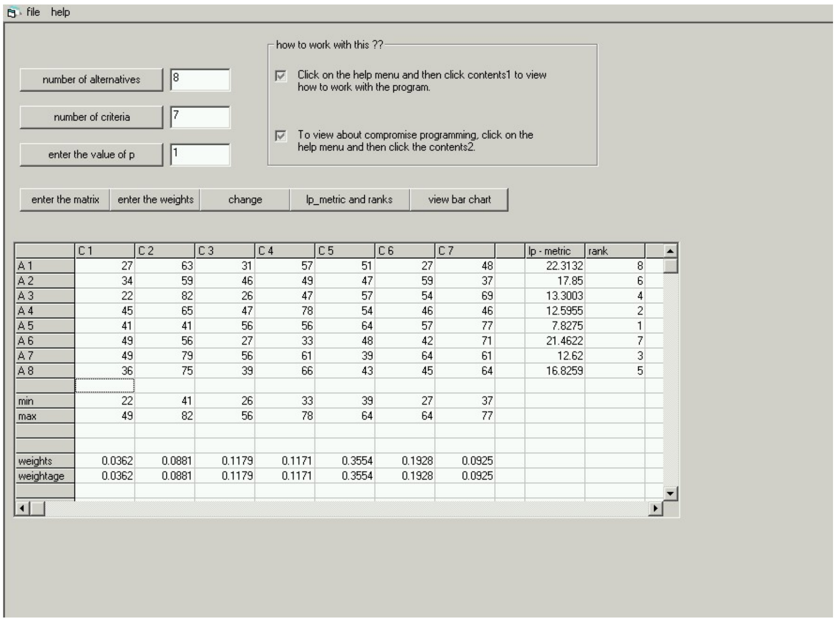

Figure 6. Sample screen of Compromise Programming methodology

The value of parameter *p* can also be modified to know the sensitivity of the ranking pattern. Maximum, minimum and ideal value for each criterion is computed by the program itself based on the given values in the payoff matrix. The L_p - metric values (with respect to *p*) and ranking pattern are computed by the program.The group having minimum L_p - metric value is taken as the best compromise solution and accordingly ranking pattern of the groups is evolved. Three compromise sets are calculated for *p*=1, 2 and ∞ (Tecle et al. 1988). Table 5 presents the L_p - metric values for *p*=1, 2 and ∞ and corresponding ranking pattern. It is observed that group G5 occupies the first position due to its low L_p - metric value of 7.8275 for *p*=1, 4.6464 for *p*=2 and 3.6242 for *p*=∞ whereas the second position is occupied by G4 due to its L_p - metric value of 12.5955 for *p*=1, 6.0239 for *p*=2 and 3.7906 for *p*=∞. Provision of graphical representation of ranking pattern in the form of a bar chart is also made in the program. Spearman Rank Correlation (SRC) technique is used to compute correlation coefficient (R) between different MCDM techniques (Vasan 2005). It is 0.7976 in case of CP (*p*=2) and CP (*p*=∞) whereas it is 0.5357 between CP (*p*=1) and CP (*p*=∞).

Table 5. L_p - metric values and final ranks by CP methodology

Groups	*p*=1		*p*=2		*P*=∞	
	L_p - metric value	Final ranks	L_p - metric value	Final ranks	L_p - metric value	Final ranks
G1	22.3132	8	9.8793	8	7.1429	6
G2	17.8500	6	8.2731	4	6.0482	5
G3	13.3003	4	6.0908	3	3.8489	3
G4	12.5955	2	6.0239	2	3.7906	2
G5	7.8275	1	4.6464	1	3.6242	1
G6	21.4622	7	9.7641	7	5.9321	5
G7	12.6200	3	9.2286	6	8.8850	8
G8	16.8259	5	8.7841	5	7.4640	7

4.4 Sensitivity Analysis

The maximum and minimum value for each criterion from Table 1 is included in the denominator as per Eq. 2. L_p - metric and ranking pattern for p=1, 2, ∞ are calculated and are presented in Table 6. It is observed that group G5 occupies the first position due to its low L_p - metric value for all p=1, 2, ∞. Spearman rank correlation coefficient between p=1 and p=2 is 0.6428 whereas it is 0.5238 between p=1 and p=∞. High correlation coefficient value of 0.9285 is observed between p=2 and p=∞.

Table 6. L_p - metric values and final ranks by CP methodology

Groups	p=1	p=2	p=∞
G1	8	5	4
G2	5	4	6
G3	3	2	2
G4	2	3	3
G5	1	1	1
G6	7	6	5
G7	4	8	8
G8	6	7	7

5. SUMMARY AND CONCLUSIONS

The present paper dealt with performance evaluation of sixteen irrigation subsystems of MBSP, envisaging first application involving KANN methodology for the performance evaluation studies. Seven performance criteria namely, land development works, timely supply of inputs, conjunctive use of water resources, participation of farmers', economic impact, crop productivity and environmental conservation are considered in evaluating the irrigation subsystems. Three phase methodology, consisting of formulating payoff matrix, grouping by KANN methodology and ranking by Compromise Programming, was employed. Spearman Rank Correlation coefficient values are computed between the ranks obtained by various scenarios. The following conclusions are drawn from the study:

1. Three phase methodology employed in the present study is found to be useful.
2. It is observed that G5 (consisting of Parsoliya and Bhawarwad irrigation subsystems) can be made pilot irrigation subsystem to formulate guidelines for other irrigation subsystems as evident from the compromise programming analysis and extensive sensitivity analysis.
3. Potentiality of KANN methodology is explored to group the irrigation subsystems for performance evaluation studies and can be extended to similar situations.
4. It is observed from KANN methodology that square error value is decreasing from group 4 to group 8.
5. It is inferred from the above analysis that learning rates and epochs are having significant effect on square error values.

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