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An Estimation of Irrigation Efficiency of Limited Water Resource Area

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Abstract: This study proposes a fuzzy sets approach for estimating irrigation efficiency of limited water resource area. Genetic algorithm technique was applied to calibrate membership function condition of fuzzy sets model. The proposed model considered the total available water resource and the farmer participation of water resource management as the input variables. The approach model was applied to determine the irrigation efficiency of the Nong Wei Irrigation Project (in the Northeast region of Thailand). Results showed that the fuzzy sets model can be used to estimate the irrigation efficiencies, given the total available water resources and the farmer participation. Furthermore, the results indicated that the farmer participation in water resource management can be calculated via the proportion of seasonal required-area and the overall land area of the irrigation project.

Key words: Fuzzy set, genetic algorithms, irrigation efficiency, water resource management participation

INTRODUCTION

Irrigation efficiency is important information in the planning of water resource management in limited water resource area. Generally, the irrigation efficiency is the multiplication of conveyance, distribution and field application efficiencies. Often, most previous planning considered the irrigation efficiency as a constant value for all seasons (Brown, 1999; Ali *et al*., 2000; RID, 2004). However, it is likely that the efficiencies tend to vary due to the uncertainty of the water resources (Burke *et al*., 1999). Therefore, they may use the erroneous irrigation efficiency which unsuitable for the seasonal available water. Moreover, the participation of stakeholder in water resource management is the main effect of irrigation efficiency (Yoshida *et al*., 2004). Hence, farmer participation of water resource management is important factor for estimating irrigation efficiency.

A Fuzzy set is mathematical theory for describing the interested variables from uncertain factors or variables like seasonal inflows and the participation of stakeholder in water resource management. The relationship between input and output variables is defined from fuzzy rule, according to human processes in thinking and decision. In addition, fuzzy rules are relatively easy to explain and understand. Recently, the fuzzy model was accepted to describe the relationship of the uncertain variables (Ross, 1995; Shrestha *et al*., 1996; Jairaj and Vedula, 2000; Panigrahi and Mujumda, 2000; Umamahesh and Chandramouli, 2004). Often, the calibration processes of the fuzzy model were performed by manual adjusting (trial and error) the membership functions and rule bases. Therefore, depending on the result of the human adjustment, it does not guarantee to yield the optimal solution.

A Genetic Algorithm (GA) is search and optimization techniques based on the principles of national selection and genetics. GA is a robust method for searching for the optimum solution of a complex problem. It can provide the near global optimal solution. The GA was applied to solve the optimal solution of water resource problems (Goldberg, 1989; Wardlaw and Sharif, 1999; Chang *et al*., 2003; Kangrang and Chaleeraktrakoon, 2007). The best part of GA is that they can handle any type of objective function describing decision variables.

This study thus proposes the fuzzy set model for finding the irrigation efficiency which corresponding seasonal inflow and farmer participation in water resource management. The genetic algorithm technique is applied to calibrate the membership of the fuzzy model. The farmer participation will be calculated via the relationship between seasonal required-area and the whole area of irrigation project.

MODEL FORMULATION

In order to account for any uncertainty on seasonal inflow and farmer participation, the fuzzy sets theory and its rule-based system were applied for estimating irrigation efficiency. System inputs include the seasonal inflow and the farmer participation in water resource management (F). Output is seasonal irrigation efficiency. The total seasonal required-area is the summation of each farmer's area. It varies with the farmer decision of each season. Hence, the

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farmer participation is substituted by the proportion of seasonal required-area and the overall area of irrigation project. The participation in water resource management of each season can be calculated by Eq. 1.

$$F = 100\left(\frac{X_j}{T}\right) \quad (1)$$

where:

X_j = The total required-area during season j (j = 1, 2, 3,..., m).

T = The whole area of irrigation project and m is the number of yearly historic data.

There are four steps in developing fuzzy model as the following. First step of creating a fuzzy inference system is to transform the crisp inputs into fuzzy variable through the membership function. The number and type of membership functions were constructed based on statistical data and experience of engineers, generally upon the considering problem (Jang *et al*., 1997; Saruwatari and Yomota, 1995). These types of membership function; trapezoidal, generalized bell, sigmoid, triangular and Gaussian were used to describe the input and output valuables. The optimal conditions of membership function for each type will be searched in the next section. Because there are many types of membership function, the high efficiency of optimization technique was required to search their optimal condition.

Then the fuzzy rule bases were created using the characteristic of seasonal historical data and fuzzy operator. The actual historical data of irrigation efficiency will be presented in the next section. These fuzzy operators; AND and OR were applied to combine the input variables.

Next step was to apply the input membership functions and the constructed rule bases to obtain the output membership functions. This step was done by the implication method which obtaining a fuzzy set of output when given a single number of each inputs. Then the output membership functions of each rule were jointed to one output fuzzy set.

Finally, the fuzzy set of output was converted into a single crisp value. The most common method was the centroid evaluation, which returns the center of area under the curve.

The adequacy of the fuzzy model was evaluated by considering the coefficient of determination (R^2) which defined based on the actual irrigation efficiency and the estimated irrigation efficiency as:

$$R^2 = \frac{\left(\sum \phi_j \hat{\phi}_j - m\overline{\phi}_j \overline{\hat{\phi}}_j\right)^2}{\left(\sum \phi_j^2 - m\overline{\phi}_j^2\right)\left(\sum \hat{\phi}_j^2 - m\overline{\hat{\phi}}_j^2\right)} \quad (2)$$

where:

ϕ_j = The estimated irrigation efficiency of the scenario during season j (j = 1, 2, 3,...,m) which determined by fuzzy model

$\hat{\phi}_j$ = The actual irrigation efficiency of the scenario during season j which calculated from cultivated area.

$\overline{\phi}_j$ and $\overline{\hat{\phi}}_j$ = The average irrigation efficiency of above mentions and m is the number of yearly historic data.

The fuzzy model was calibrated by adjusting the membership functions and rule bases using the genetic algorithm technique. These five types of membership function; including trapezoidal, generalized bell, sigmoid, triangular and Gaussian were used to describe the input and output valuables for finding the suitable type. For each type of membership function, the optimal conditions were searched by the genetic algorithm technique; these performances will be stopped when obtained the highest coefficient of determination (closed to 1.0).

The calibration processes using the genetic algorithm were described as follows. The genetic algorithm requires encoding schemes that transform the decision variables into chromosome. This study, the decision variables were the typical membership function of each type. Figure 1 and Eq. 3 show the typical membership function of triangular type. They present that the decision variables of each membership function for 1 group are a, b and c. These variables were transferred into the chromosome for searching in the process of genetic algorithm.

$$\mu_r(a,b,c) = \begin{cases} 0, & r \le a \\ \frac{r-a}{b-a}, & a \le r \le b; \\ \frac{c-r}{c-b}, & b \le r \le c; \\ 0, & c \le r \end{cases} \quad (3)$$

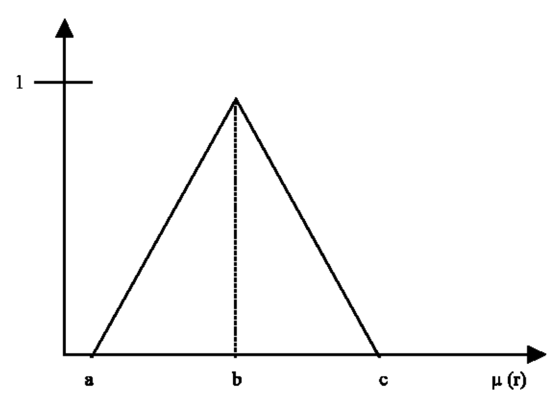

Fig. 1: Typical membership function of triangular type

where:

μ_r = Membership function of value r for input or output variable (i.e., seasonal inflow, farmer participation and irrigation efficiency).

μ = Membership value of the variable, r is the value of input or output variable.

Then, the genetic operations (reproduction, crossover and mutation) were performed. These genetic operations generated new sets of chromosomes. The objective function of the search was to maximize the coefficient of determination (R^2). This study used population size = 80, crossover probability = 0.9, mutation probability = 0.01 (Goldberg, 1989). The search will be stopped when obtained the highest coefficient of determination, hence the optimal value of a, b and c was met.

Generally, an irrigation efficiency is the overall system efficiency which affecting by conveyance, distribution and field application (Brown, 1999; Ali *et al.*, 2000; Yoshida *et al.*, 2004; RID, 2004; Ali and Shui, 2001). The actual irrigation efficiency ($\hat{\phi}$) of the system can be computed for each scenario by the following equation:

$$\hat{\phi} = 100\left(\frac{Vr}{Vd}\right) \quad (4)$$

where:

Vr = The net volume of crop water requirement.

Vd = The amount of water diverted from the source to the conveyance system.

The net volume of crop water requirement is computed by the method developed as:

$$Vr = \sum_{k=1}^{K}(EP_k \times KC_k)X_k \quad (5)$$

where:

EP_k = Potential evaporation.

KC_k = Crop coefficient

Xk = Cropped area of crop k.

ILLUSTRATIVE APPLICATION

Three sequences of 26-year (1978 - 2003) seasonal flow and crop water-requirement records and related evaporation and effective rainfall data (the Nong Wei

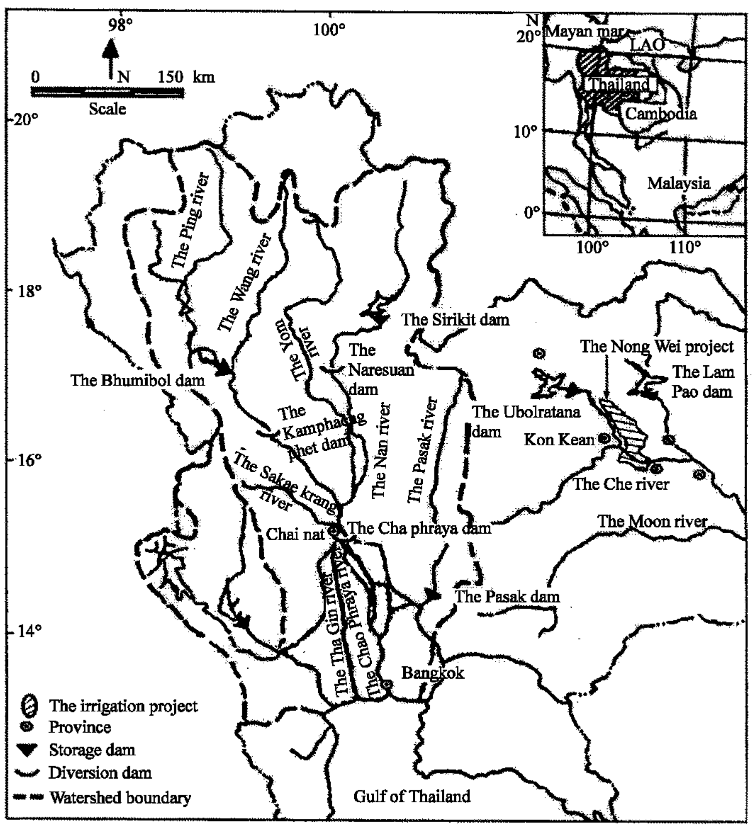

Fig. 2: Locations of the Nong Wei irrigation project

Irrigation Project in the Northeast region of Thailand) during dry season were considered for illustrating the application of the proposed approach. Figure 2 presents the location of the Nong Wei Irrigation Project. It indicates that the Ubolratana Dam released the water to the project directly. However, in the dry season the available water is insufficient for cultivating the entire area of the irrigation project. Therefore, irrigation efficiency is important factor in this irrigation project. The overall area of irrigation project is 259,400 Rai (1 Rai = 1,600 m^2).

Table 1 shows the available inflow, requested irrigation-area, farmer participation in water resource management and the irrigation efficiency during dry season for 26 years. The farmer participation were calculated via the relationship between the requested irrigation-area and the overall area of irrigation project. They indicate that the maximum and the minimum seasonal inflow are 521 MCM and 51 MCM, respectively. The seasonal requested irrigation-areas are varying during 10,100 and 230,100 Rai (1 Rai = 1,600 m^2). The least and the highest farmer participation are 3.89 and 88.70%, respectively. The actual seasonal irrigation efficiency in 1983, 1988, 1996 and 1997 are greater than 100%, so the data of these years are not accepted for computing.

Table 1: Historical data of an available inflow, requested irrigation-area, farmer participation in water resource management and actual irrigation efficiency

Year	Inflow (MCM)	Total requested irrigation-area (Rai)	Farmer participation in water resource management (%)	Actual irrigation efficiency (%)
1978	51	10,100	3.89	29.19
1979*	63	25,900	9.98	34.64
1980	177	22,000	8.48	23.39
1981	120	33,500	12.91	48.31
1982	185	14,210	5.48	15.20
1983	70	70,100	27.02	176.72**
1984	226	64,120	24.72	47.14
1985	226	27,110	10.45	22.40
1986*	112	58,500	22.55	51.96
1987*	241	33,440	12.89	35.00
1988	188	120,620	46.50	110.04**
1989	441	172,800	66.62	70.73
1990	500	212,020	81.73	75.89
1991	521	221,150	85.25	72.18
1992	496	230,100	88.70	83.21
1993	479	151,230	58.30	52.15
1994	377	43,290	16.69	19.83
1995	350	110,540	42.61	44.25
1996	118	101,120	38.98	147.83**
1997	275	150,080	57.86	100.13**
1998*	381	105,300	40.59	57.47
1999	218	112,250	43.27	91.01
2000	452	151,552	58.42	66.49
2001*	486	172,624	66.55	71.63
2002	488	165,000	63.61	63.06
2003	467	204,400	78.80	83.71

Note: The overall area of irrigation project = 259,400 Rai (1 Rai = 1,600 m^2), * = Yearly data for validation, ** = Irrigation efficiency exceeds 100%

Table 2 shows an example of fuzzy rule bases using AND and OR operators. The numbers of membership function of each variable is 3 groups (less, medium and high). However, the numbers of membership function will be searched from 1 to 5 groups that cover the preliminary cluster of the historical data. Further more, the 5 types of membership function were used to search for finding the optimal condition providing the highest coefficient of determination.

Table 2: Example of fuzzy rule bases for estimating irrigation efficiency (the numbers of membership function = 3 groups)

IF inflow	AND farmer participation	THEN irrigation efficiencyless
Less	less	medium
	medium	medium
	high	high
Medium	less	less
	medium	medium
	high	medium
High	less	less
	medium	less
	high	medium

RESULTS AND DISCUSSION

The optimal condition of all types of membership functions using the genetic algorithm for calibration that provides the highest coefficient of determination as shown in Table 3. Coefficients of determination of Gaussian type with the number 4-4-3 is the highest values 0.9948. The least value of coefficients of determination is 0.8859 of the sigmoid type. These results present that the optimal conditions of all types provide the high coefficient of determination. Therefore, these types are suitable for estimating irrigation efficiency given the optimal condition of calibration. The functions were further validated using actual irrigation efficiencies which were not considered (1979, 1986, 1987, 1998 and 2001) for constructing model.

Table 4 shows the estimated irrigation efficiency of each type of membership function and their average

Table 3: Optimal condition of membership function with the highest R^2 for all types of membership function

Membership function type	The No. of membership function Inf.	Far.	Irr.	R^2
Gaussian	4	4	3	0.9948
Triangular	4	4	3	0.9857
Sigmoid	4	4	2	0.9452
Trapezoidal	3	3	4	0.8859
Generalized bell	4	3	3	0.9636

Note: Inf. = Inflow, Far. = Farmer participation and Irr. = Irrigation efficiency

Table 4: Estimated irrigation efficiencies of each type of membership function and the average error of each type

Year	Inflow (MCM)	Farmer participation (%)	Actual irrigation efficiency (%)	Estimated irrigation efficiency (%)				
				Gaussian	Triangular	Sigmoid	Trapezoidal	Generalized bell
1979	63.445	9.98	34.64	31.14	29.68	31.25	36.78	30.26
1986	112.334	22.55	51.96	48.78	48.65	47.55	55.12	47.68
1987	241.435	12.89	35.00	34.69	36.08	37.12	38.75	36.30
1998	381.324	40.59	57.47	54.72	54.54	56.34	52.45	55.20
2001	486.020	66.55	71.63	74.10	74.23	68.24	76.98	75.10
The average error (%)				4.22	4.39	5.17	6.53	5.56

errors. The results show that the average error of Gaussian type is quite small (4.22%), as compared with those of the other types whereas; the average error of trapezoidal type is the highest of 6.53%. However, these values are not significantly different. They indicate that the optimal conditions of fuzzy model give the estimated irrigation efficiency close to the actual irrigation efficiency for all types of membership function. Moreover, it concludes that the farmer participation in water resource management can be calculated via the proportion of seasonal required-area and the overall land area of the irrigation project.

CONCLUSIONS

This paper developed the fuzzy sets model for finding the irrigation efficiency of limited water resource area. The calibration process of the fuzzy model was used the genetic algorithm technique to search the optimal condition of membership function. The developed model was applied to determine the irrigation efficiency of the Nong Wei Irrigation Project (in the Northeast region of Thailand). Results showed that the fuzzy model which used in this study can be used to estimate the irrigation efficiencies, given the total available water resources and the farmer participation in water resource management. The optimal conditions of these types; trapezoidal, generalized bell, sigmoid, triangular and Gaussian membership function provided the estimated irrigation efficiency close to the actual irrigation efficiency similarly. Furthermore, the results indicated that the farmer participation in water resource management can be calculated via the proportion of seasonal required-area and the whole area of the irrigation project.

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