

A Fuzzy-GAs Model for Determining Varied Irrigation Efficiency

¹Anongrit Kangrang and ²Chavalit Chaleeraktragoon

¹Faculty of Engineering, Mahasarakham University, Mahasarakham, Thailand

²Department of Civil Engineering, Faculty of Engineering
Thammasat University, Klong Luang, Pathumthani, 12120, Thailand

Abstract : Irrigation efficiency is necessary information in water resource management. We proposed fuzzy sets approach for estimating varied irrigation efficiency. Genetic algorithms technique was applied to calibrate membership function of fuzzy model. The fuzzy sets technique considered the uncertainty of the available water resource and required area as the input variables. The approach model was applied to determine the fluctuated irrigation efficiency of the Nong Wei Irrigation Project (in the Northeast region of Thailand). Results found that the fuzzy-GAs model can be used to obtain the irrigation efficiencies, given the total available water resources and requested irrigation-area. The GAs calibration provided the optimal condition of the proposed model. Moreover, the proposed approach can be given the irrigation efficiencies which are close to the actual irrigation efficiency. Further, the results indicate that the varied irrigation efficiency is more precise than the constant irrigation efficiency.

Keywords : Fuzzy set, Genetic algorithms, Irrigation efficiency, Crop water-requirement

INTRODUCTION

Irrigation efficiency is important information in the planning of water resource management. 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^[1-4]. However, it is likely that the efficiencies tend to vary due to the uncertainty of the water resources^[5]. Therefore, they may use the erroneous irrigation efficiency which unsuitable for the seasonal available water.

A Fuzzy set is mathematical theory for describing the interested variables from uncertain factors or variables like seasonal inflows. 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^[6-10]. Often, the calibration processes of the fuzzy model were performed by manual adjusting (trial and error) the membership functions and rule bases. However, depending on the result of the adjustment, it does not guarantee to yield the optimal solution.

Genetic algorithms are search and optimization techniques based on the principles of natural selection and genetics. GAs 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^[11-14]. The best part of GA is that they can handle any type of objective function.

Often, at the starting of each irrigation season, the imploring areas for cultivation are required from a farmer, while the seasonal inflow is given from the reservoir administration which release for serving the scenario. However, this study guessed the factual irrigation efficiency should vary with available inflow that dependant on uncertainty of natural inflow and requested irrigation-area which change with the time.

This paper thus proposes the fuzzy set model for finding the varied irrigation efficiency which corresponding seasonal inflow and requested irrigation-area. The genetic algorithms technique is applied to calibrate the membership of the fuzzy model.

Model Formulation: In order to account for any uncertainty on seasonal inflow and requested irrigation-area, the fuzzy sets theory and its rule-based system are applied for estimating irrigation efficiency. System inputs include the seasonal inflow and the seasonal

Corresponding Author: Anongrit Kangrang, Lecturer, Faculty of Engineering, Mahasarakham University, Khamriang, Campus, Kantharawichai, Mahasarakham, 44150, Thailand

requested area. Output is the seasonal irrigation efficiency. There are four steps in developing fuzzy model as the following.

The first step of creating a fuzzy model is to transform the crisp inputs into fuzzy variable through the membership function, called Fuzzification process. The number and type of membership functions are constructed based on statistical data and experience of engineers, generally upon the considering problem^[15, 16]. Because the seasonal irrigation efficiency and requested irrigation-area variables are high uncertainty, these trapezoidal, bell and sigmoid membership functions are unsuitable for describing them. Fuzzy sets with triangular and Gaussian membership functions are used to describe the uncertain parameters because of their flexibility and easy computation.

The second step, the fuzzy rule bases are created using seasonal historical data and fuzzy operator. The historical data of irrigation efficiency will be presented in the next section. These fuzzy operators AND and OR are applied to combine the input variables.

Next step is to apply the input membership functions and the rule bases to obtain the output membership functions. This step is 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 are jointed to one output fuzzy set, called aggregation process.

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

The adequacy of the fuzzy model is evaluated by considering the coefficient of determination (R^2) which defined based on the irrigation efficiency estimation errors as:

$$R^2 = \frac{(\sum \phi_j \hat{\phi}_j - m \bar{\phi}_j \bar{\hat{\phi}}_j)^2}{(\sum \phi_j^2 - m \bar{\phi}_j^2)(\sum \hat{\phi}_j^2 - m \bar{\hat{\phi}}_j^2)} \quad (1)$$

where ϕ_j is the estimated irrigation efficiency of the scenario during season j which calculated using fuzzy model, $\hat{\phi}_j$ is the actual irrigation efficiency of the scenario during season j which calculated from irrigated area, $\bar{\phi}_j$ and $\bar{\hat{\phi}}_j$ are respectively the average of above mentions and m is the number of yearly data. The

fuzzy model is calibrated by adjusting the membership functions and rule bases using the genetic algorithms technique, these performances will be stopped when the results obtained the highest coefficient of determination (closed to 1.0).

The calibration processes using GAs are described as follows. GAs requires encoding schemes that transform the decision variables into chromosome. Then, the genetic operations (reproduction, crossover, and mutation) are performed. These genetic operations will generate new sets of chromosomes. In this study, each decision variable represents a parameter of membership function. The objective function of the search is to maximize the coefficient of determination (R^2). This study used population size = 80, crossover probability = 0.9, and mutation probability = 0.01.

Generally, an irrigation efficiency is the overall system efficiency which affecting by conveyance, distribution and field application^[1-4, 17]. The irrigation efficiency of the system can be computed for each scenario by the following equation:

$$\hat{\phi} = 100 \left(\frac{Vr}{Vd} \right) \quad (2)$$

where Vr is the net volume of crop water requirement, and Vd is 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:

$$Vr = \sum_{k=1}^K (EP_k \times KC_k) X_k \quad (3)$$

where EP_k is potential evaporation, KC_k is crop coefficient, and X_k is cultivated area of crop k .

Illustrative Application: Three sequences of 26-year (1978 - 2003) seasonal flow, irrigated area and crop water-requirement records; and related evaporation, and effective rainfall data (the Nong Wei Irrigation Project in the Northeast region of Thailand) during dry season were considered for illustrating the application of the proposed approach. Figure 1 presents the location of the Nong Wei Irrigation Project.

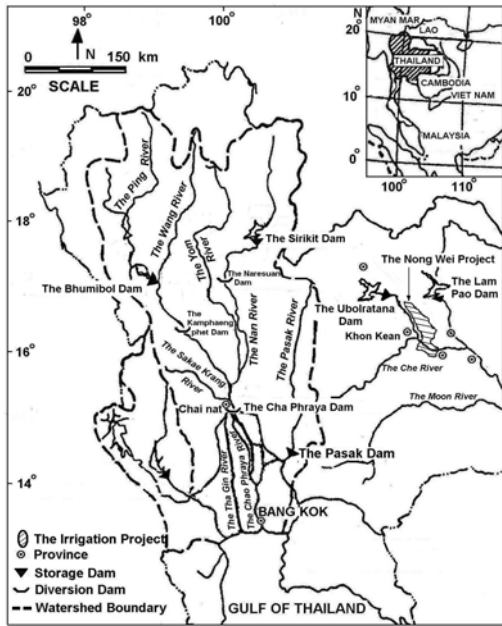
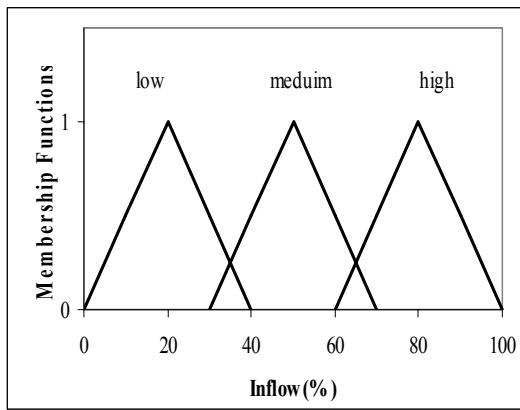
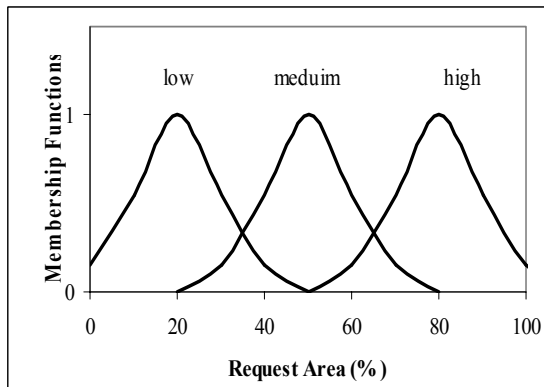


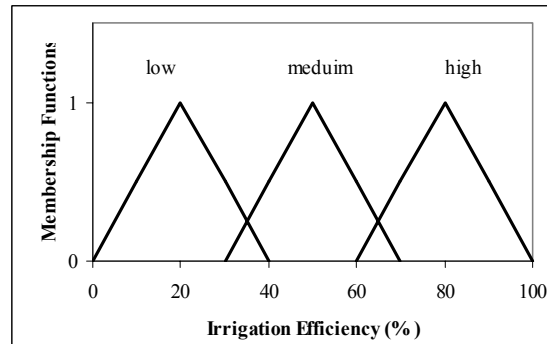
Fig. 1: Locations of the Nong Wei Irrigation Project



(a)



(b)



(c)

Fig. 2: Typical membership functions of input and output variables using triangular and Gaussian types

Table 1 gives the available inflow, requested irrigation-area and the irrigation efficiency during dry season for 26 years. The results 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 m²). Note that, the seasonal irrigation efficiency in 1983, 1988, 1996, and 1997 are greater than 100 %, so the data of these years are not accepted to compute. Table 2 shows an example of fuzzy rule bases using AND and OR operators. The numbers of membership function of each variable are 2, 3 and 4 that cover the preliminary cluster of the historical data. Figure 2 shows the typical membership functions of the input and output variables using triangular and Gaussian type.

RESULTS AND DISCUSSIONS

Tables 3 and 4 show the coefficient of determination for several membership functions using the manual adjustment and the GAs calibration. The results shown that the coefficients of determination of GAs calibration are higher than those of manual adjustment, the highest values are 0.9887 and 0.9925 using number 4-4-3 of triangular and Gaussian respectively. These results found that the suitable number and shape of membership functions give the highest coefficient of determination; the GAs calibration provided the optimal condition of membership function. The function was further validated using the actual irrigation efficiencies which were not considered (1979, 1986, 1987, 1998, and 2001) for constructing model.

Table 1: Historical data of an available inflow, requested irrigation-area and the irrigation efficiency

Year	Inflow (MCM)	Requested irrigation-area (Rai)	Irrigated area (Rai)				Irrigation efficiency (%)
			Rice	Corn	Vegetable	Total	
1978	51	10,100	6,294	1,767	963	9,024	29.19
1979*	63	25,900	16,746	2,066	1,551	20,363	34.64
1980	177	22,000	20,726	1,207	1,122	23,055	23.39
1981	120	33,500	28,260	2,227	2,173	32,660	48.31
1982	185	14,210	14,762	96	284	15,142	15.20
1983	70	70,100	64,691	662	1,557	66,910	176.72**
1984	226	64,120	54,931	1,376	1,886	58,193	47.14
1985	226	27,110	25,788	869	1,116	27,773	22.40
1986*	112	58,500	48,169	4,867	3,478	56,514	51.96
1987*	241	33,440	25,917	5,729	3,142	34,788	35.00
1988	188	120,620	98,747	11,428	4,606	114,781	110.04**
1989	441	172,800	154,450	13,726	2,407	170,583	70.73
1990	500	212,020	181,820	28,175	1,268	211,263	75.89
1991	521	221,150	186,950	17,658	1,886	206,494	72.18
1992	496	230,100	209,066	12,694	1,660	223,420	83.21
1993	479	151,230	117,430	20,085	1,313	138,828	52.15
1994	377	43,290	27,900	15,012	1,200	44,112	19.83
1995	350	110,540	57,250	30,834	2,600	90,684	44.25
1996	118	101,120	68,315	28,083	1,968	98,366	147.83**
1997	275	150,080	125,355	21,180	1,509	148,044	100.13**
1998*	381	105,300	78,972	16,572	1,917	97,461	57.47
1999	218	112,250	89,318	13,925	2,883	106,126	91.01
2000	452	151,552	150,567	3,354	1,893	155,814	66.49
2001*	486	172,624	176,205	2,080	1,379	179,664	71.63
2002	488	165,000	152,772	4,591	2,493	159,856	63.06
2003	467	204,400	198,172	2,502	2,637	203,311	83.71

Table 2: Example of fuzzy rule bases for estimating irrigation efficiency

IF Inflow	AND Requested irrigation-area	THEN Irrigation efficiency
less	less medium high	medium medium high
medium	less medium high	less medium medium
high	less medium high	less less medium

Tables 5 and 6 show the deviations between the estimated irrigation efficiency and the actual efficiency, as well as the deviations between the estimated irrigation efficiency and the constant efficiency of

Triangular and Gaussian membership function respectively. The results show that the former deviations are less than those of the second. In addition, the estimated irrigation efficiencies are close to the actual efficiency. Moreover, the averaged deviations between the fuzzy and actual efficiencies of triangular and Gaussian membership functions are 2.98 % and 2.44 % respectively. The deviations are quite small, as compared with those of the constant efficiency. It indicates that the varied irrigation efficiency is more precise than the constant irrigation efficiency. For this reason, the calibrated Gaussian membership function of 4-4-3 is accepted to find the varying irrigation efficiency. Figure 3 shows the calibrated Gaussian membership functions of the input and output variables for the number 4-4-3 using GAs technique.

Table 3: Membership function numbers of requested irrigation-area, inflow, and irrigation efficiency with R² for Triangular membership function

Number of membership function					R ²	Number of membership function					R ²
Request area	Inflow	Irrigation efficiency	GAs calibration	Manual adjustment		Request area	Inflow	Irrigation efficiency	GAs calibration	Manual adjustment	
4	4	4	0.9712	0.9094		3	3	2	0.7775	0.7057	
4	4	3	0.9887*	0.9167		3	2	4	0.8726	0.8006	
4	4	2	0.8452	0.6855		3	2	3	0.6979	0.6259	
4	3	4	0.8859	0.8239		3	2	2	0.6994	0.6274	
4	3	3	0.9136	0.8516		2	4	4	0.8741	0.8021	
4	3	2	0.8674	0.8054		2	4	3	0.863	0.7910	
4	2	4	0.8002	0.7382		2	4	2	0.6834	0.6124	
4	2	3	0.6934	0.6314		2	3	4	0.823	0.7511	
4	2	2	0.8123	0.6395		2	3	3	0.8248	0.7528	
3	4	4	0.8645	0.8025		2	3	2	0.8013	0.7293	
3	4	3	0.9094	0.8474		2	2	4	0.7015	0.6293	
3	4	2	0.8214	0.7591		2	2	3	0.6932	0.6213	
3	3	4	0.8543	0.7933		2	2	2	0.7341	0.6621	
3	3	3	0.8019	0.7142							

Table 4: Membership function numbers of requested irrigation-area, inflow, and irrigation efficiency with R² for Gaussian membership function

Number of membership function					R ²	Number of membership function					R ²
Request area	Inflow	Irrigation efficiency	GAs calibration	Manual adjustment		Request area	Inflow	Irrigation efficiency	GAs calibration	Manual adjustment	
4	4	4	0.9818	0.9098		3	3	2	0.7671	0.6951	
4	4	3	0.9925*	0.9205		3	2	4	0.7721	0.7001	
4	4	2	0.7767	0.7047		3	2	3	0.7538	0.6818	
4	3	4	0.8794	0.8074		3	2	2	0.7269	0.6549	
4	3	3	0.966	0.8940		2	4	4	0.8766	0.8046	
4	3	2	0.9067	0.8347		2	4	3	0.8477	0.7757	
4	2	4	0.7943	0.7223		2	4	2	0.7556	0.6836	
4	2	3	0.7215	0.6495		2	3	4	0.813	0.7410	
4	2	2	0.7424	0.6704		2	3	3	0.7988	0.7268	
3	4	4	0.8838	0.8118		2	3	2	0.7833	0.7113	
3	4	3	0.9338	0.8618		2	2	4	0.7509	0.6789	
3	4	2	0.8124	0.7380		2	2	3	0.8124	0.6267	
3	3	4	0.8717	0.7997		2	2	2	0.7066	0.6346	
3	3	3	0.8023	0.7303							

Table 5: Deviation between the estimated irrigation efficiency and the actual efficiency, as well as the deviation between the estimated irrigation efficiency and the constant efficiency (Triangular, 4-3-3)

Year	Inflow (MCM)	Requested irrigation-area (Rai)	Irrigation efficiency (%)		$ \hat{\phi}_j - \phi_j $	$ \hat{\phi}_j - \phi $
			$\hat{\phi}_j$ (Actual)	ϕ_j (Estimated)		
1979	63.445	25,900	34.64	29.68	4.96	22.06
1986	112.334	58,500	51.96	48.65	3.31	4.74
1987	241.435	33,440	35.00	36.08	1.08	21.70
1998	381.324	105,300	57.47	54.54	2.93	0.77
2001	486.020	172,624	71.63	74.23	2.60	14.93

Table 6: Deviation between the estimated irrigation efficiency and the actual efficiency, as well as the deviation between the estimated irrigation efficiency and the constant efficiency (Gaussian, 4-3-3)

Year	Inflow (MCM)	Requested irrigation-area (Rai)	Irrigation efficiency (%)		$ \hat{\phi}_j - \phi_j $	$ \hat{\phi}_j - \phi $
			$\hat{\phi}_j$ (Actual)	ϕ_j (Estimated)		
1979	63.445	25,900	34.64	31.14	3.50	22.06
1986	112.334	58,500	51.96	48.78	3.18	4.74
1987	241.435	33,440	35.00	34.69	0.31	21.70
1998	381.324	105,300	57.47	54.72	2.75	0.77
2001	486.020	172,624	71.63	74.10	2.47	14.93

Figure 4 presents the relationship between the input variables (seasonal inflow and requested area) and the output variable (irrigation efficiency) for the number 4-4-3 of Gaussian membership functions. It shows that at the low inflow with low requested area provides the less irrigation efficiency, while at the high inflow with the high requested area gives the high irrigation efficiency. Also, it indicates that available water on the high inflow situation is enough for the project and the farmer can be cultivated fully land area, so the irrigation efficiency is increased.

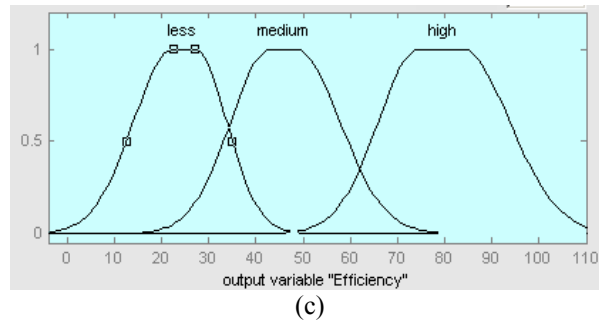
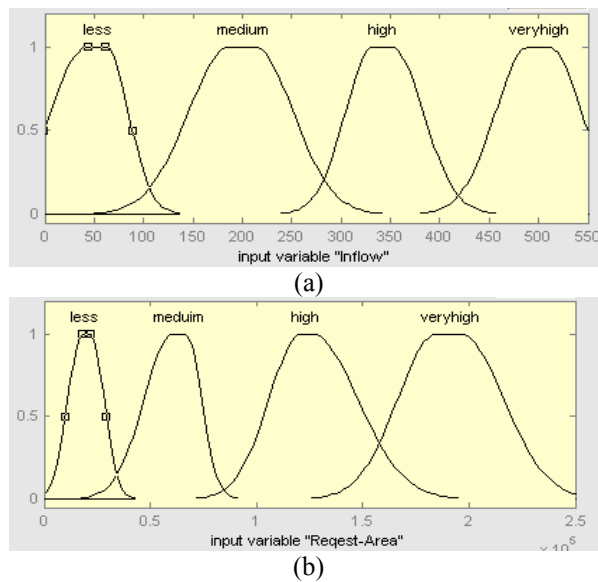


Fig. 3: The calibrated Gaussian membership functions of the input and output variables for the number 4-4-3

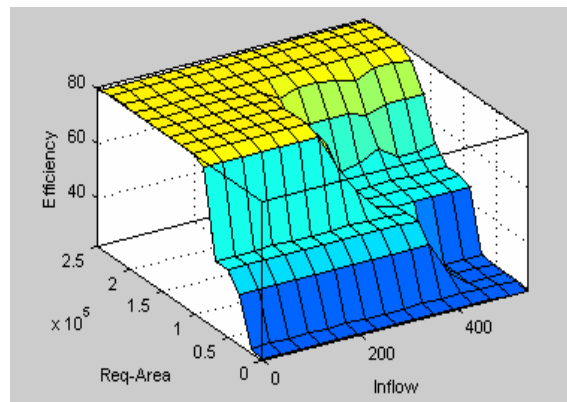


Fig 4: Relationship between the input variables and the output variable of Gaussian membership function number 4-4-3

CONCLUSIONS

This paper developed a fuzzy set for finding the varied irrigation efficiency. The calibration process of the fuzzy model used Genetic algorithms technique. Results show that the fuzzy sets theory which used in this study can be used to estimate the varied irrigation efficiencies, given the total available water resources and requested irrigation-areas which are uncertain variables. The Genetic algorithms calibration of the model provided the optimal condition of membership function. The deviations between the estimated irrigation efficiency and the actual efficiency are quite small, as compared with the deviations between the estimated irrigation efficiency and the constant efficiency. In addition, the estimated irrigation efficiencies are close to the actual efficiency. It indicates that the varied irrigation efficiency is more precise than the constant irrigation efficiency.

ACKNOWLEDGE

The authors would like to express their appreciation to Faculty of Engineering, Maharakham University for financial support.

REFERENCES

1. Brown, D., 1999. Water-use efficiency on irrigation systems: a review of research carried out under DFID's engineering research program. *Agricultural Water Management*, 40, 139-147.
2. Ali, M. H., Shui, L. T., Yan, K. C., Eloubaidy, A. F. and Foong, K. C., 2000. Modeling water balance components and irrigation efficiencies in relation to water requirements for double-cropping systems. *Agricultural Water Management*, 46, 167-182.
3. Yoshida, K., Tanji, H., Somura, H., Toda, O. And Higuchi K., 2004. Evaluation of irrigation efficiency at KM6 Project site, LAOS. *Proceedings of 2nd Asia Pacific Association of Hydrology and Water Resources Conference*, 5-8 July, 2004 Singapore, volume I, 652-659.
4. Royal Irrigation Department, RID, 2004. The plain for allocating water in dry season 2004/2005 of the Nong Wei Irrigation Project, Royal Irrigation Department, Report. (in Thai)
5. Burke, S. Mulligan, M. and Thornes, J. B., 1999. Optimal irrigation efficiency for maximum plant productivity and minimum water loss. *Agricultural Water Management*, 40, 377-391.
6. Ross, T. J., 1995. *Fuzzy logic with engineering application*. McGraw-Hill Inc., USA.
7. Shrestha, B.P., Duckstein, L. and Stakhiv, E.Z., 1996. Fuzzy rule based modeling of reservoir operation. *Journal of Water Resources Planning and Management*, 122(4), 262-269.
8. Jairaj, P. G. and Vedula, S., 2000. Multireservoir system optimization using fuzzy mathematical programming. *Water Resources Management*, 14(6), 457-472
9. Panigrahi, D. P. and Mujumda, P. P., 2000. Research operation modeling with fuzzy logic. *Water Resources Management*, 14, 89-109.
10. Umamahesh, N. V. and Chandramouli, S., 2004. Fuzzy dynamic programming model for optimal operation of a multipurpose reservoir. *Proceedings of 2nd Asia Pacific Association of Hydrology and Water Resources Conference*, 5-8 July, 2004 Singapore, volume I, 164-171.
11. Wardlaw, R. and Sharif, M., 1999. Evaluation of Genetic Algorithms for Optimal Reservoir System Operation. *Journal of Water Resources Planning and Management*, ASCE, 124(1): 25-33.
12. Goldberg, D.E., 1989. *Genetic Algorithms in Search, Optimization, and Machine Learning*, Addison-Wesley Publishing Company Inc., London. 412 p.
13. Chang, F. J., Lai, J. S. and Kao, L. S., 2003. Optimization of operation rule curves and flushing schedule in a reservoir. *Hydrological Processes*, 17: 1623-1640.
14. Kangrang, A. and Chaleeraktragoon, C., 2007. Genetic Algorithms Connected Simulation with Smoothing Function for Searching Rule Curves. *American Journal of Applied Sciences*, 4(2): 73-79.
15. Jang, S. R., Sun, C. T. and Mizutani, E., 1997. *Neuro-Fuzzy and soft computing*. Prentice-Hall Inc., USA.
16. Saruwatari, N. and Yomota, A., 1995. Forecasting system of irrigation water on paddy field by fuzzy theory. *Agricultural Water Management*, 28, 163-167.
17. Ali, M. H. and Shui, L. T., 2001. Optimal allocation of monthly water withdrawals in reservoir systems. *Water Resources Management*, 15, 323-341.