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Model for Waste Load Allocation in Rivers: A Cooperative Approach

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Abstract: In this paper, a new methodology for efficient river water quality management known as Cooperative Water Quality Management Approach is introduced. Based on optimization model with a new developed simulation technique and genetic algorithm, the waste load capacity of a river system was enhanced and the cost of waste load discharge is minimized. In a new approach, the cooperation among some single waste dischargers as a primary treatment process and also the discharge of the shared waste load into the river system in an appropriate location along the river was identified. In order to define the exact problem, possible cooperation scenarios among various dischargers with and without any cooperation among the dischargers which may lead to the targeted objectives and the individual discharge with stated conditions were compared with the application of the defined model. Considering the new determined waste capacity of the river system, initial waste treatment levels for both shared and single dischargers which correspond to the treatment costs were calculated. The possibility of cooperation among two or more dischargers are intimately related to financial issues, land availability and its topographic condition, effluent standards and also technical factors. The practical application of the proposed methodology was demonstrated through an actual case study of Zarjub River System located in northern part of Iran.

Key words: Water Quality Management · Waste Capacity · Waste Dischargers · Cooperative Approach · Effluent Standards · Zarjub River System

INTRODUCTION

Water is the most essential but scarce resource in the world. Degradation of water quality in most of water bodies is now a common challenge in many countries. After the rapid economic growth during the 1960's, which was accomplished by a spread and intensification of water pollution problems, some policies to manage water quality of rivers were proposed. The origin of polluted water sources are discussed and emphasized as crucial economical issues. To manage water quality in the river systems, many different approaches have been proposed. Water quality management approaches should consider the important factor such as efficiency; the economic use of water resources with respect to costs minimization and benefit maximization may be concerned [1]. Waste load allocation approaches in water quality modeling typically consider the efficiency and determine the required removal fraction or treatment level at a set of point sources.

The goal of water quality management is not only to maintain the standard quality, but also to search for the optimal values. In contrary, the minimization of the treatment cost and the magnitude or frequency of water quality violations are the major concerns [2]. Traditional waste load allocation models have been developed to minimize the total effluent treatment cost, while satisfying water quality standards throughout the system [2-5]. Great efforts have been implied by many research scientists for the development of waste load allocation models and the water quality in river systems [6-14].

Effluent trading in a river system was first proposed by Crocker and Dales [15, 16]. Water quality trading allows one pollution source to meet its regulatory obligations with the aim of pollutant reductions, created by other source that has lowered the treatment costs [17].

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In this methodology, water quality management (WQM) was carried out in two main steps. Based on a network representation of a river system: (1) regarding to both quality standards and efficiency principles, the initial amounts of waste released in each single discharger and the initial treatment percentages of them is allocated; and (2) based on the results of previous step; various possible cooperation scenarios among some dischargers and respecting the mentioned principles of WQM, amount and location of waste releases of shared dischargers is modeled. The possibility of the cooperation scenarios among two or more dischargers is intimately depended on financial issues, land availability and its topographic condition, effluent standards and also other technical factors. Regardless of the above stated technical and non-technical factors, it is assumed that the cooperation is only possible for those dischargers who are located in the same side of the river bank.

According to the above mentioned framework, the Cooperative Water Quality Management Approach (CWQMA) was developed. The objectives of the present research paper was to introduce CWQMA and also apply the methodology in a complex water quality problem in Zarjub River System which is located in northern part of Iran. In order to demonstrate how the CWQMA can utilize, to assist the managers for the achievement of a more reliable and steady condition of WQM in the river system.

MATERIALS AND METHODS

In this paper the main objective was to propose a new methodology to assess the possibility of an increasing in waste capacity of a river system when the initial waste treatment percentages and/or effluent releases into the river are pre-fixed. Also the aim was to review the feasibility of a decreasing in the initial treatment level and its related costs when the quality condition in the river system kept in its previous status. In this field, none of past studies addressed the cooperative potentials in WQM. Hence, motivation by the fact that some possible cooperation scenarios among the dischargers can lead to a more efficient quality control of the river. These scenarios and their impact on WQM were evaluated by the CWQMA. To demonstrate this task, a mathematical simulation process embedded to a Genetic Algorithm (GA) optimization model was developed. The model is able to simulate the quality condition of the river under various single and shared waste discharging scenarios, using modified Streeter and Phelps quality simulation relations [19]. The overall flowchart of the methodology is shown in Figure 1.

Optimization Model: In a general river system, there are a set of dischargers releasing their waste load into the river after a primary partial treatment. In this step, an optimization model is formulated to minimize the total

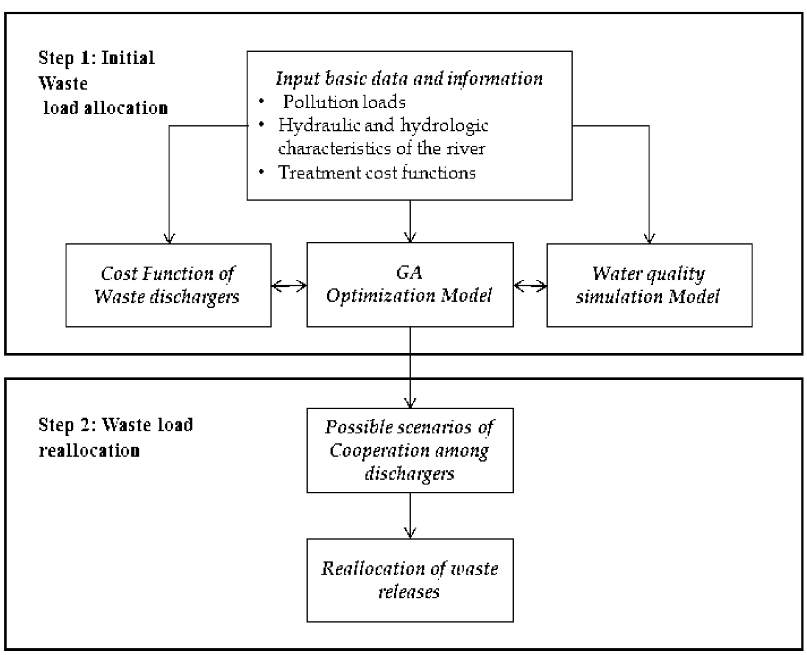

Fig. 1: Flowchart for the proposed methodology

costs of primary fractional treatment of the waste dischargers, while the water quality standards were maintained at satisfaction level. Water quality condition of a river is assessed at some checkpoints by monitoring water quality indicator levels such as dissolved oxygen (DO) concentration. In a water quality management model, the concentration level of the water quality indicator is declared as a function of the fractional removal levels for the pollutants released by dischargers [18]. The total treatment costs (c) of primary fractional treatment of effluent dischargers can be expressed as:

$$c = \sum_{i=1}^{n} f_i(x_i) \qquad (1)$$

Where:

$f_i(x_i)$: Treatment cost function of each single or shared discharger i,

x_i: Factional removal level

n: The number of dischargers in the river system in each scenario.

For such problem, the optimization process was conducted using Genetic Algorithm (GA). Genetic algorithms are global optimisation procedures that are commonly used in water quality modeling in order to find approximate solutions for search problems through application of the principles of evolutionary biology [20].

Genetic algorithms use biologically inspired techniques such as genetic inheritance, natural selection, mutation and sexual reproduction (recombination, or crossover). To solve the problem, members of a space of candidate solutions, called individuals are represented using abstract representations called chromosomes. The GA consists of an iterative process that evolves a working set of individuals called a population toward an objective function, or fitness function. The evolutionary process of a GA is a highly simplified and fashionable simulation of the biological version. It starts from a population of individuals randomly generated according to some probability distribution, usually uniform and updates this population in steps called generations. Each generation, multiple individuals are randomly selected from the current population based upon certain application of fitness, bred using crossover and modified through mutation to form a new population [20]. As GA is the only applicable to solve maximization problems, here the objective function is expressed as follows:

$$c' = \frac{1}{c} = \frac{1}{\sum_{i=1}^{n} f_i(x_i)} \qquad (2)$$

Subject to:

$$c_{al} \le c_a \quad \forall a, l$$

Where $c_{\alpha l}$ is concentration of water quality indicator α (such as DO) at checkpoint l (mg/L); and c_α is the minimum acceptable concentration for water quality indicator α (such as DO; mg/L).

Simulation Model: In a standard status of river water quality, the amount of waste load discharged into the river system must be equal or less than the final waste capacity of the system. To identify the quality condition of a river, the capacity should be modeled by a simulation process regarding all effective parameters. In addition to the initial quality condition of a river, the quality and quantity of each waste load and the discharging location of the river system, have formulated solid roles which depend on ultimate quality condition of the river. In this paper, water quality simulation is carried out through a well-known equation developed by Streeter and Phelps in 1925 to predict the amount of DO in the rivers. The model simulates water quality of the river using five hundred Monte Carlo (MC) analyses. Regarding the minimum amount of DO equal to 4 mg/l as the least acceptable standard for water quality of the river, the MC analyses are utilized considering the main random variables in the water quality simulation model including upstream river flow and water temperature, BOD concentration, quantity and quality of discharged wastewaters, the location of each single or shared waste discharged along the river, the decay coefficient rate of BOD (k) and the reaeration coefficient (k_2).

MC generates discrete parameter sets according to probability or possibility distribution and running a simulation for each set. Alternatively, the parameter set samples and associated with probability masses were derived in the course of calibration; while avoiding the required assumptions regarding the form of distribution. The application of multiple simulations resulted in a close approximation to analytical form of the probability density function (PDF) using frequency analysis. The model can easily be included in such a framework with minimal input.

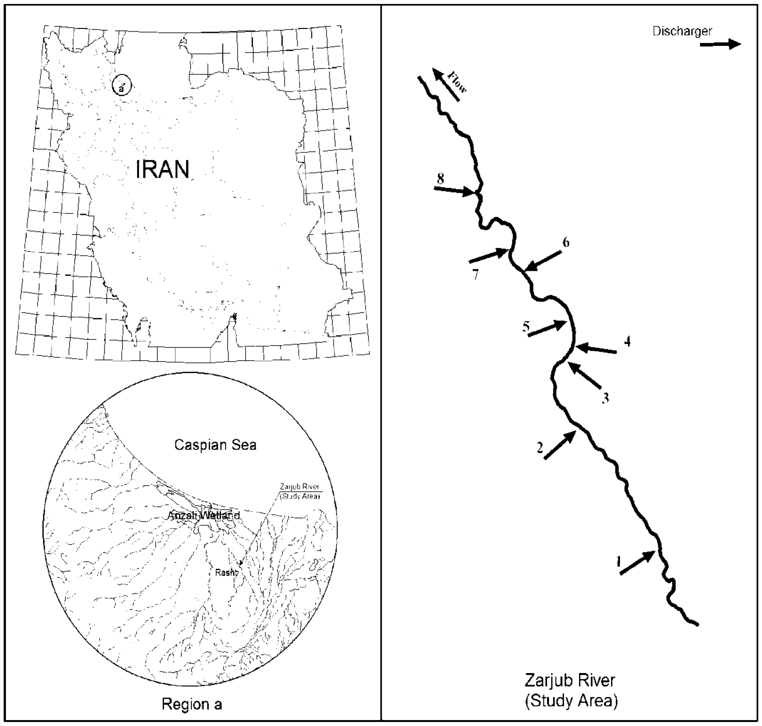

Fig. 2: Schematic map of Zarjub river system and location of waste disposal of dischargers in the study area

Table 1: The main characteristics of Zarjub River and dischargers in the study area (IDOE, 2005)

	Flow (m3/s)		Temperature		DO (mg/L)		BOD (mg/L)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Upstream	0.178	0.0177	24	2.4	6	0.6	5	0.5
Discharger	0.07	0.007	24	2.4	8	0.80	5	0.5
Discharger	0.08	0.008	24	2.4	8.2	0.82	40	4
Discharger	0.02	0.002	24	2.4	8	0.8	7.32	0.73
Discharger	0.01	0.001	25	2.5	0.1	0.01	120	12
Discharger	0.01	0.001	24	2.4	0.1	0.01	180	18
Discharger	0.01	0.001	23	2.3	0.1	0.01	110	11
Discharger	0.1	0.01	23	2.3	0.1	0.01	90	9
Discharger	0.02	0.002	23	2.3	0.1	0.01	180	18

Case Study: The proposed model was applied to Zarjub river system, which is located in Gilan province in northern part of Iran. The river is originated from Talesh Mountains and ends to natural lagoon port of Anzali (Bandar-e Anzali), the natural wetland in southern coast of Caspian Sea. The annual discharge to the river is about 59 million cubic meters and most of the discharged waste load is domestic wastewater. The river supplies water demand for 54,000 ha of cultivated agricultural lands. The study area is restricted to a 24 km along the river, which passes through Rasht City and its suburb with a population of half of million. The study area includes eight major pollution sources, which dispose their waste load into the river. The river reach in the study area which is divided in to eight zones counted as 1 to 8 from upstream to downstream. Figure 2 shows the schematic map of Zarjub river system and location of waste discharging points in the study area. Iran Department of Environment (IDOE) as the official responsible of surface and groundwater quality management monitored the river water quality in the study area in 2005 [21]. Table 1 presents the main characteristic of the river system as well as the waste load released as dischargers. In the next sections, the proposed methodology is applied for the WQM in Zarjub River.

RESULTS AND DISCUSSION

Currently, the waste loads of the study area are discharged into the river without any essential treatment. Mesbah has estimated the treatment cost function for dischargers. The aerated lagoon system for treating pollution loads was considered [22]. It was assumed that the total treatment cost was almost related to the construction and operational costs of the system. Based on the above principles, the operational cost of an aerated lagoon was considered to be 13 percent of its construction cost and treatment cost functions were developed for all dischargers [18, 22]. The cost functions for the treatment systems are expressed by the general form of the following equation:

$$f_i(r_i) = a_i r_i^2$$

Where, f_i is the abatement cost function of discharger i for duration of 15-year planning (million \$), r_i is the treatment level of discharger $I(0 \leq r_i \leq 1)$ and α_i is a dimensionless coefficient for discharger i.

The values of α_i for each one of dischargers and the distance of discharge point from the starting point of the study area (upstream of first discharging point indicated in Figure 2) are presented in Table 2 [18, 22]. In this case study, α_i varies between zero to 2.

Besides modeling the problem, it was assumed that the values of α_i in the state of cooperation among some dischargers are equal to the average values of the cooperated dischargers of each state.

Step 1: Allocation of Initial Waste Treatment Levels for Each One of Single Dischargers in the Status of Single Waste Disposal: In this step, the CWQMA calculates the initial treatment levels (fractional removal percentages) for each of the dischargers in the status of single waste discharging. Table 3 presents the allocated initial waste treatment levels for each one of single discharger and also corresponding treatment cost for each of them in the status of single discharging, which are called initial fractional waste removal levels and initial treatment costs.

Step 2: Reallocation of Initial Waste Treatment Levels for Each One of the Single or Cooperated Dischargers in the Status of Shared (Cooperated) Waste Disposal: Regarding to pre-mentioned assumptions and the existing site constraints, the cooperation among the dischargers possibly categorized in three main classes including the conditions when 1, 2 or 3 partnerships among the dischargers can be practiced, respectively. Those possible partnerships include just one cooperation among the dischargers are assessed in first class. Table 4 presents the six different possible cooperation states of

Table 2: Coefficients of the treatment cost functions (dimensionless) for single dischargers and the distance of location from the starting point of the study area

Discharger	1	2	3	4	5	6	7	8
Coefficients of the treatment cost functions (dimensionless)	1.011	1.157	0.29	0.145	0.144	0.144	1.417	0.283
Length of each stream (m)	6934	9915	10816	12958	17877	18718	28396	28396
Total distance from start point of study area (m)	6934	9915	10816	12958	17877	18718	28396	28396

Table 3: The initial fractional waste removal levels for each of the dischargers in the status of single waste treatment and its related costs

Discharger	1	2	3	4	5	6	7	8
Initial fractional waste removal levels (%)	9.37	56.25	4.69	100	100	100	79.69	93.75
Initial waste treatment costs ($)	937	22,500	4,221	160,000	250,000	360,000	390,481	600,000
Total treatment cost of the system ($)	1,788,139							

Table 4: The initial treatment levels (fractional removal percentages) for each of the dischargers in the first cooperation class and the related costs

Cooperation states	Cooperated dischargers	Coefficients of the treatment cost functions (dimensionless)	fractional removal percentage (%)	Initial waste treatment costs of each cooperation($)	Distance of waste discharge place from start point of the river(m)	Total Treatment cost in the river system ($)
State 1	2 & 5	0.1505	67.19	67,943	15815	1,583,582
State 2	5 & 7	0.7805	82	524,808	23477	1,672,466
State 3	7 & 8	0.85	77.34	508,425	27896	1,306,083
State 4	2 & 5 & 7	0.859	71.87	443,699	21245	1,568,857
State 5	5 & 7 & 8	0.922	100	922,000	17877-28396*	1,469,658
State 6	4 & 6	0.1445	100	144,500	12958-18718*	1,412,639

*Discharge point in these cases can be located anywhere between the cited ranges.

Table 5: The optimum initial treatment levels (fractional removal percentages) for each of the dischargers in the second cooperation class and its related costs

Cooperation states	Cooperated dischargers	Coefficients of the treatment cost functions (dimensionless)	fractional removal percentage (%)	Initial waste treatment costs of each cooperation($)	Distance of waste discharge place from start point of the river(m)	Total Treatment cost in the river system ($)
State 1	2 & 5 & 7	0.859	74.22	473,189	20815	1,598,347
	4 & 6	0.1445	82.81	99,091	19858	1,367,230
State 2	2 & 5	0.1505	34.53	17,944	10315	1,533,583
	4 & 6	0.1445	98.43	139,998	13358	1,408,137
State 3	5 & 7	0.7805	100	780,500	17877-23396*	1,928,158
	4 & 6	0.1445	100	144,500	12958-18718*	1,412,639
State 4	2 & 5	0.1505	89.84	121,472	13515	1,637,111
	8 & 7	0.85	82.81	582,887	27996	1,380,545
State 5	5 & 7 & 8	0.922	100	922,000	17877-28396*	1,469,658
4 & 6	0.1445	100	144,500	12958-18718*	1,412,639	
State 6	7 & 8	0.85	100	850,000	27996	1,647,658
	4 & 6	0.1445	100	144,500	12958-18718*	1,412,639

*Discharge point in these cases can be located anywhere between the cited ranges.

Table 6: The optimum initial treatment levels (fractional removal percentages) for each of the dischargers in the third cooperation class and its related costs

Cooperation states	Cooperated dischargers	Coefficients of the treatment cost functions (dimensionless)	fractional removal percentage (%)	Initial waste treatment costs of each cooperation($)	Distance of waste discharge place from start point of the river(m)	Total Treatment cost in the river system ($)
State 1	2 & 5	0.1505	89.84	121,472	13815	1,637,111
State 2	4 & 6	0.1445	100	144,500	13058	1,412,639
State 3	7 & 8	0.85	82.81	582,887	27996	1,380,545

first class, coefficients of the treatment cost functions of dischargers, the initial treatment levels (fractional removal percentages), initial waste treatment costs and the distance of removal place of effluent from starting point of the study area.

Finally, in the second and third cooperation classes, the problem is assessed when there are two and three different cooperation states among the dischargers. Different possible cooperation states of second and third classes, coefficients of the treatment cost functions of dischargers, the initial treatment levels (fractional removal percentages), initial waste treatment costs and the distance of removal place of effluent from the starting point of the study area, are summarized in the Tables 5 and 6.

Results of the CWQMA model showed that 20 states from all 21 possible cooperation states have lower total treatment costs than the single waste discharging state of the system. The third cooperation state presented in Table 2 have the lowest total treatment cost among all possible cooperation states. In this state, the cooperation between discharger 7 and 8 jointly have a shared treatment system and discharge to the common waste in an appropriate location along the river, which is located in a 4500 meters distance from the downstream of the primary waste discharging point of discharger 7. The shared treatment system, can decrease the total treatment cost of the system from U.S. $ 1,788,139 to a reduced value of U.S. $1,306,083. This action can gain a total saving of U.S. $ 482,056 for the dischargers.

CONCLUSION

In this paper, a new methodology called CWQMA was developed. This method has provided an efficient treatment waste allocation among the effluent dischargers in a river system. The proposed methodology includes several models such as river water quality simulation model, optimization model based on genetic algorithms and Monte Carlo analysis. The river water quality simulation model is embedded in GA to find the best scenarios of cooperation among the waste dischargers of the system, which can lead to a noticeable saving in initial waste treatment (fractional waste disposal), or to increase the waste load capacity of the river system. The methodology was applied to Zarjub river system in northern part of Iran. The obtained results from the proposed methodology showed that this method can be used as an efficient and practical planning utility in the study area.

Finally, it should be mentioned that cooperation among some waste dischargers into the river system to dispose the waste in a shared treatment system as well as selecting an appropriate discharging point along the river. The developed methodology can be practically used in water quality management and planning of rivers, especially those which are involved with intensive waste loads and restricted waste load capacity.

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REFERENCES

1. Wang, L., L. Fang and K.W. Hipel, 2008. Basin-wide cooperative water resources allocation. European J. Operational Res., 190(3): 798-817.
2. Kerachian, R. and M. Karamouz, 2005. Waste Load Allocation Model for Seasonal River Water Quality Management: Application of Sequential Dynamic Genetic Algorithms. J. Scientia Iranica, 12(2): 117-130.
3. Liebman, J.C. and W.R. Lynn, 1996. The optimal allocation of stream dissolved oxygen. J. Water Resources Res., 2(3): 581-591.
4. Loucks, D.P., C.S. Revelle and W.R. Lynn, 1967. Linear programming models water pollution control. Management Sci., 14(4): B166-B181.
5. Revelle, C., D.P. Loucks and W.R. Lynn, 1968. Linear programming applied to stream dissolved oxygen. Water Resources Res., 4(1): 1-9.
6. Herbay, J.P., Y. Smeers and D. Tyteca, 1983. Water quality management with time varying river flow and discharger control. Water Resources Res., 19(6): 1481-1487.
7. Ferrara, R.A. and M.A. Dimino, 1985. A case study analysis for seasonal nitrification: Economic efficiency and water quality preservation. Journal of the Water Pollution Control Federation, 57(7): 763-769.
8. Ellis, J.H., 1987. Stochastic water quality optimization using imbedded chance constraint. Water Resources Res., 23(12): 2227-2338.
9. Fujiwara, O., W. Puanmaha and K. Hanaki, 1988. River basin water management in stochastic environment. J. Environmental Engineering, ASCE, 114(4): 869-877.
10. Burn, D.H., 1989. Water quality management through combined simulation-optimization. Journal of Environmental Engineering. ASCE, 115(5): 1011-1024.
11. Cardwell, H. and H. Ellis, 1993. Stochastic dynamic programming models for water qulity management. Water Resources Res., 29(4): 803-813.
12. Sasikumar, K. and P.P. Mujmadar, 1998. Fuzzy optimization model for water quality management. Journal of Water resources Planning and Management, ASCES, 124(2): 79-84.
13. Burn, D.H. and S. Yulianti, 2001. Waste-load allocation using genetic algorithms. J. Water Resources Planning and Management, ASCE, 127(2): 121-129.
14. Karamouz, M., R. Kerachian and M. Mahmoodian, 2003. Seasonal waste-load allocation model for river water quality management. Proceedings of 2003 World Water and Environment Resource Congress, Philadelphia, USA,
15. Crocker, T.D., 1966. The structuring of atmospheric pollution control systems. In H. Wolozin (Ed.) the Economics of Air. Poll., pp: 61-68.
16. Dales, J.H., 1968. Land, water and ownership. The Canadian J. Economics, 1(4): 791-804.
17. Niksokhan, M.H., R. Kerachian and M. Karamouz, 2009. A Game Theoretic Approach for Trading Discharge Permits in Rivers. J. Water Science Technol., 60(3): 793-804.
18. Niksokhan, M.H., R. Kerachian and P. Amin, 2009. A stochastic conflict resolution model for trading pollutant discharge permits in river systems. Environmental Monitoring and Assessment, Springer, Doi: 10.1007/s10661-008-0390-7.
19. Streeter, H.W. and E.B. Phelps, 1925. A study of the pollution and natural purification of the Ohio River. III. Factors concerning the phenomena of oxidation and reaeration. Public Health Bulletin No. 146, Public Health Service, Washington, DC.
20. Holland, J.H., 1975. Adaption in Natural and Artificial Systems, Ann Arbor, MI: University of Michigan Press.
21. Iran Department of Environment (IDOE), 2005. Calculating Total Maximum Daily Load (TMDL) for Zarjub River, Iran. Technical report (Persian).
22. Mesbah, M., 2006. Developing a Fuzzy-based Model for Water Quality Trading in River Systems. M.Sc. Thesis, University of Tehran (Persian, with English abstract).