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Multi-objective optimization of water scheduling in irrigation canal network using NSGA-II

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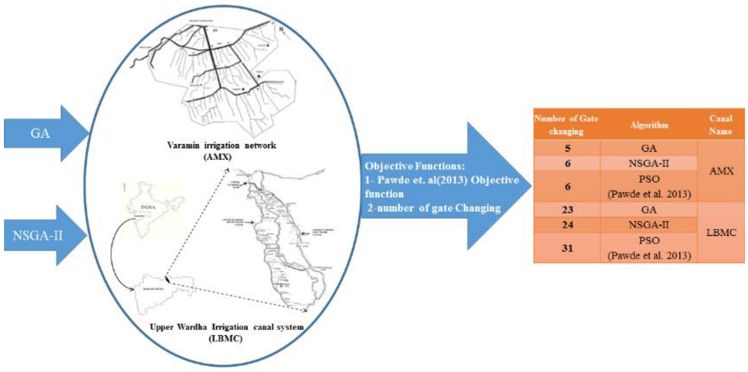
GRAPHICAL ABSTRACT



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ABSTRACT

The objective of distribution and delivery of water canal scheduling in irrigation canal networks is timely and adequate delivery of water with minimum operational stages of the head gate of supply canal in the presence of canal capacity and irrigation rotation period constraints. In this paper, two objective functions, namely, the number of gate changes and the mean discharge for two networks, were minimized by the Genetic and NSGA-II algorithms. The results showed that minimizing these two objective functions at the same time leads to fewer gate changes compared to the only mean canal discharge objective function in both algorithms. It means the mean discharge objective function cannot minimize the number of operational stages alone. Also the optimization by NSGA-II algorithm did not make a significant difference in the results in comparison with the genetic algorithm for both objective functions. However, in NSGA-II algorithm, it is not necessary to determine the weight of each of the objective functions.

1. Introduction

Increasing the yield of agricultural products and increasing water use efficiency**,** is one of the most important goals of constructing and developing irrigation canal networks. In developing countries, especially in Iran, utilization and distribution of water in agriculture is not desired and, regarding lack of water and recent droughts, it is necessary to increase the efficiency of irrigation canal networks. Inappropriate delivery and distribution of water to canals and laterals, and consequently poor distribution of water at agricultural land levels, will cause inadequate water delivery to turnouts, compared to the actual needs and can reduce hydraulic function of the network. Although low efficiency and unnecessary water use in irrigation canal networks are usually attributed to farmers and lack of facilities, network management and water delivery and distribution programs which are provided by utilization managers, are also significant. For distribution and delivery of water canal scheduling, the three main factors of water distribution and delivery, flow rate, duration and rotation of irrigation, are determined. For irrigation canal scheduling, turnouts' discharge at any time should be less than the capacity of the canal, and the irrigation time should not exceed the maximum irrigation rotation. Therefore, the problem of canal scheduling and distribution of water in irrigation canal networks, is a complex multi-objective, multivariate, and multi-constraint optimization problem, which requires a solution using optimal optimization methods (Monem and Nouri, 2010).

There are many ways to solve optimization problems that are divided into classical methods and evolutionary algorithms. Evolutionary algorithms do not have the limitations of classical methods for solving problems with non-linear and non-derivable nature. For this reason, these are widely used for solving complex optimization problems that classical methods cannot solve. Evolutionary algorithms include Genetic and NSGA II algorithms.

Given the number of decision variables, constraints and the objective function of the problem of distribution and delivery of water in

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irrigation canal networks, evolutionary algorithms have been used by various researchers to optimize it. Suryavanshi and Reddy (1986) applied linear scheduling of 0-1 to prepare the operation of irrigation canal outlet in regards to the canal scheduling problem.

Wang et al. (1995) modified a partial defect in Suryavanshi and Reddy's (1986) objective function by introducing an activation function. These models can be applied to irrigation systems of the same capacity and sub-branches. Reddy et al. (1999) introduced "time-block" concept using linear programming of 0-1 to resolve this constraint. This has led to the model ability to optimize irrigation systems in which laterals have different discharges.

Anwar and Clarke (2001) used mixed integer programming to schedule irrigation for a group of users with duration for each turnout and irrigation's time specified by the users. This model can only be used for laterals with the same flow capacity. Wardlaw and Bhaktikul (2004) employed GA method to schedule water irrigation which was aimed at optimized water resources in irrigation systems based on a rotation program. Monem and Namdarian (2005) developed "Optimal Water Distribution in Irrigation System" (OWDIS) model using simulated annealing technique. Zhao et al. (2009) presented an optimal water distribution model under inappropriate flow conditions of canals based on the dynamic penalty function and genetic algorithm. Pawde et al. (2013) considered rate of flow delivery and the starting time of the delivery points as decision variables and using PSO model, presented a delivery water program aimed at minimizing the canal capacity. The delivery program provided by them showed nearly constant inlet hydrograph to water delivery canal during the period of rotation, which implies the minimum supply canal head gate operations. Kakoei and Emadi (2013) used Ant-Colony algorithm for single-objective optimization of the optimal water delivery and distribution program. Qaderi Nasab et al. (2015) used PSO and IC algorithms for two-objective optimization of the canal scheduling problem. Literature review shows that in investigated studies objective functions of canal scheduling are converted into a scalar objective function and are optimized by different algorithms. Therefore, no multi-objective meta-heuristic algorithm has been applied to optimize network operation. In this paper, a new objective function is introduced and two objective functions are optimized by GA and NAGA-II. The results are compared with Pawed et al. (2013) for case studies.

2. Materials and methods

2.1. Introducing NSGA-II algorithm

The classical method for solving multi-objective optimization problems is by converting them into a scalar single-objective problem by assigning w_i weight to any normalized objective function $f_i'(x)$ is as Eq. (1).

$$\min f = w_1 f_1'(x) + w_2 f_2'(x) + \ldots + w_k f_k'(x) \quad (1)$$

In this Eq., $f'_i(x)$ is normalized to the objective function of $f_i(x)$ and $\sum w_i = 1$. In this method, the user needs to determine the weight of each objective function (Konak et al. 2006). One of the problems of this method is proper weighting. Given this problem, researchers have developed methods that are inherently multi-objective. One of the most well-known methods is non-dominated Sorting Genetic Algorithm (NSGA-II). In this algorithm, crowding distance is the factor used to select the best solutions for Pareto front. This parameter is defined as follows.

$$d_i^j = \left| f_j^{i+1} - f_j^{i-1} \right| / \left(f_j^{\max} - f_j^{\min} \right) \quad (2)$$

$$d_i = \sum_{j=1}^{m} d_i^j \quad (3)$$

$f_j^{\min}$ is the min value of the objective function j, d_i^j is crowding distance of the solution i in the target function j, d_i is crowding distance between the solution i in all objectives and m is the number of target functions. The stages of this algorithm are as follows.

Creating initial populations
Calculating objective functions
Sorting populations based on dominance conditions
Calculating crowding distance
Selection based on rank and crowding distance
Performing crossover and mutation for producing new offspring
Combining initial populations and populations obtained from crossover and mutation
Replacing parents' population with the best members of the combined population
All stages are repeated until stop condition is achieved (Coello Coello et al. 2007).

2.2. Objective functions

The objective function introduced by Pawde et al. (2013) for canal scheduling is as follows.

$$Minimize\ Z = \sum_{i=1}^{n} \left\{ \left[Q_{avg} - \sum_{j=1}^{m} \left(q_j \times ONOFF_{ij} \right) \right]^2 + P_i \right\} + F_j \times W \quad (4)$$

where, Q_{av} is average flow of the supply canal (l s^{-1}), q_j is capacity of lateral (l 1/s), $ONOFF_{ij}$ is 1 if lateral j operates in time step i, else it is zero, m is number of laterals, n is number of time step in rotation period, P_i is penalty function for supply canal capacity constraint. F_j is penalty function for start time constraint violation, W is penalty weighting factor.

$$Q_{avg} = \frac{1}{T} \sum_{j}^{m} \left(q_j . D_j \right) \quad (5)$$

Fj penalty function is applicable for irrigation rotation constraint.

$$F_j = \max \left(\sum_{j}^{m} \left[\left(S_j + D_j \right) - T \right], 0 \right) \quad (6)$$

where, D_j is operation duration for lateral j, S_j is starting time of lateral j, $ONOFF_{ij}$ value is determined by the start time S_j of the lateral j as follows.
$ONOFF_{ij}$ =1 if i>S_j and $ONOFF_{ij}$ =0 if i<(S_j+D_j)
The penalty function provided by Wardlaw and Bhaktikul (2004) is as follows.

$$P_i = \sum_{j=1}^{m} \max \left[\left(q_j . ONOFF_{ij} \right) - Q, 0 \right] \quad (7)$$

where, q_j and S_j are decision variables and D_j is calculated using the following equation.

$$D_j = \frac{V_j}{q_j} \quad (8)$$

If the canal capacity changes at different intervals, Pawde et al. (2013) presented the objective function as Eq. (9).

$$Minimize\ Z = \sum_{i=1}^{n} \left\{ \sum_{s=1}^{S} \left(\left[Q_{avg_s} - \sum_{j=1}^{m} \left(q_{sj} \times ONOFF_{ij} \right) \right]^2 + P_i \right) \right\} + F_j \times W \quad (9)$$

where, S is number of sections where discharge capacity changes, $Q_{avg\ s}$is average flow in supply canal just below the downstream of section s, q_{sj} is flow rate of lateral j on downstream of section s.

The objective function provided by Pawde et al. (2013) provided solutions that have a mean flow rate throughout the irrigation period in the canal. The purpose of this objective function is to reduce the number of gate changes and increase the transmission efficiency. In order to determine whether this objective function also minimizes the number of gate changes, the second objective function is defined as follows.

$$Minimize\ C = \sum_{i=1}^{n-1} G_i \quad (10)$$

where, C is total number of gate changes, G_i value is determined by Q_{i+1} and Q_i as follows.
G_i =1 if Q_{i+1}<>Q_i and otherwise G_i =0

As the canal capacity of AMX canal in Varamin is constant, the objective functions presented in equations (4) and (10) were used for it. But canal capacity is changed in Upper Wardha network, so equations (9) and (10) were used it.

2.3. Case study

In this paper, two irrigation networks' information were used to compare GA and NSGA-II algorithms. In order to test NSGA-II algorithm, AMX canal in Varamin network was chosen, for example, by Monem and Namdarian (2005). Varamin network is located in the southwest of Tehran in Iran (Fig. 1). The length of the main canal is 18 km, its capacity is 32 $m^3\ s^{-1}$ at the beginning and 12.5 $m^3\ s^{-1}$ at the end. There are three main distribution basins on the main canal. AU and

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AMX sub-canals deliver water to the first distribution basin. AMX canal with a length of 14 km and a slope of 0.00012 includes 11 turnouts of a total capacity of 14 m^3 / s and an irrigation interval of 10 days. The area covered by each turnout and AMX specification are presented in Table 1.

Table 1. Specifications of AMX canal's intakes and their coverage (Monem and Namdarian, 2005).

Turnout No.	Name of turnout	Turnout capacity (l/s)	Turnout land coverage (ha)
1	M1	570	600
2	M2	750	800
3	M3	550	550
4	M5	500	500
5	X2	1100	1100
6	X3	750	800
7	X4	300	300
8	X5	2060	2200
9	X6	780	800
10	X7	420	450
11	X8	1920	2000

The second study area is LBMC canal of Upper Wardha Irrigation Network in India, which covers 9800 hectares of agricultural land (Fig. 2). The length of the channel is 42.4 km, with initial discharge of 10.41m^3 /s and final discharge of 2.69 m^3/s, including 45 turnouts. The irrigation rotation is 24 days (Pawde et al. 2013). The information on the canal capacity at different stages and irrigation requirements are presented in Pawde et al. (2013).

3. Results and discussion

3.1. The results of varamin irrigation Network (AMX Canal)

For Varamin irrigation network, the initial population was 50, the number of replicates was 10,000, the mutation rate was 0.05, and the selection was 50 percent. The discharges and delivery duration for each turnout are presented in Table 2. Fig. 3a shows AMX canal inlet hydrograph using a genetic algorithm that includes five operational stages of the supply canal and a mean discharge rate of 968.8 liters per second. Fig. 3b shows AMX canal inlet hydrograph using NSGA-Ⅱ algorithm compared to the study results of Pawde et al. (2013) and Monem and Namdarian (2005). The results of NSGA-II algorithm include six stages of the supply canal and a mean discharge rate of 971 liters per second. Therefore, there is no big difference between the two algorithms.

Table 2. Delivery discharge and starting time for AMX canal's outlets using GA and NSGA-II.

	GA			NSGA-II		
Turnout No.	Start time (h)	Delivery discharge (l/s)	Delivery duration (h)	Start time (h)	Delivery discharge (l/s)q	Delivery duration (h)
1	143	312	45	0	58.7	240
2	0	70	240	56	91	184
3	149	145	91	180	217	60
4	0	50	240	30	57	210
5	0	105	240	142	935	26
6	144	183	96	0	73.3	240
7	0	31.5	240	0	31.5	240
8	0	210	240	0	210	240
9	89	607	31	0	79.3	240
10	0	42.5	240	0	42.5	240
11	0	196	240	0	196.7	240

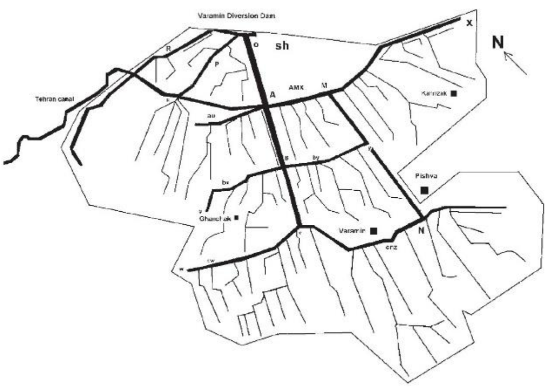

Fig. 1. Schematic of the Varamin irrigation network (Monem and Namdarian (2005)).

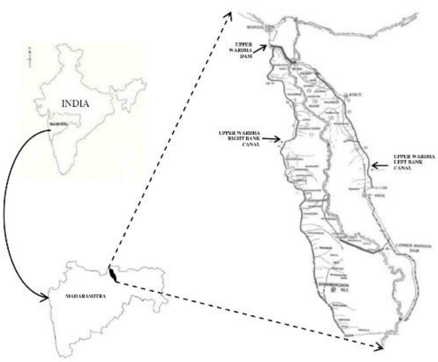

Fig. 2. Location map of Upper Wardha irrigation canal system (Pawde et al. (2013)).

3.2. The results of irrigation network of India (Upper Wardha)

For Upper Wardha irrigation network, the initial population was 200, the number of replicates was 10,000, the mutation rate was 0.05, and the selection was 50 percent. The discharges and delivery duration for each turnout are presented in Table 3. Fig. 4a shows Upper Wardha canal inlet hydrograph using genetic algorithm compared to the study results of Pawde et al. (2013). Optimization by genetic algorithm shows 23 stages of the supply canal. While the study results of Pawde et al. (2013) represent 31 stages of the supply canal. Upper Wardha canal inlet hydrograph of the optimization by NSGA-Ⅱ algorithm is presented in Fig. 4b. This hydrograph contains 24 stages of the supply canal. This number is less than the study results of Pawde et al. (2013). Although Pawde et al. stated that the objective function 1 minimizes the number of stages of the supply canal, the results of this paper showed that the objective function 2 minimizes the number of stages of the supply canal.

As it was stated in the section 2.1, in step 3 of NSGA-Ⅱ populations are sorted based on dominance conditions. The best solutions are grouped in Pareto front. For one of program run, the edge of Pareto front is shown in the space of *Z* and *C* in Fig. 5 for Upper Wardha canal. Eq. (3) is used to choose the best solution from Pareto front. The summary of results is presented in Table 4. According to the results, in AMX canal scheduling, the existence of the second objective function did not significantly improve the number of gate changes. However, in Upper Wardha canal, the number of gate changes in the presence of a second objective function was significantly reduced (compared to the results of Pawde et al. (2013), which have only applied Eq. 9 objective function for optimization). Therefore, it can be stated that the objective function introduced by these researchers alone cannot minimize the number of gate changes. The results of GA and NSGA-II algorithms do not significantly differ in the number of gate changes, but NSGA-II algorithm can be used for optimization without the need to determine the weight of objective functions.

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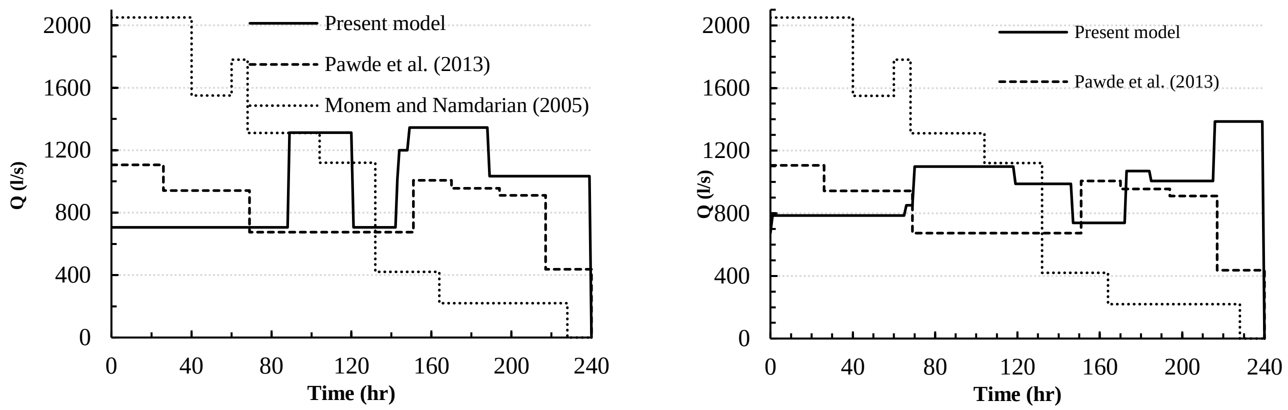

(a) (b)

Fig. 3. AMX canal hydrograph by (a) GA; (b) NSGA-II.

Table 3. Delivery discharge and starting time for Upper Wardha canal's outlets using GA and NSGA-II.

		GA			NSGA-II		
Turnout No	**Capacity (m^3/s)**	**Start time (h)**	**Delivery discharge (m^3/s)**	**Delivery duration (h)**	**Start time (h)**	**Delivery discharge (m^3/s)**	**Delivery duration (h)**
1	1.11	0	0.51	576	0	0.51	576
2	0.03	0	0.01	576	0	0.01	576
3	0.08	0	0.03	576	375	0.08	201
4	0.03	243	0.01	333	84	0.02	227
5	0.43	0	0.19	576	0	0.19	576
6	0.12	0	0.05	576	0	0.05	576
7	0.03	0	0.01	576	22	0.02	464
8	1.27	0	0.51	576	0	0.51	576
9	0.03	0	0.02	576	93	0.03	483
10	0.03	27	0.03	460	0	0.02	576
11	0.03	0	0.02	576	0	0.02	576
12	0.11	0	0.03	576	328	0.07	248
13	0.61	0	0.25	576	231	0.41	345
14	0.51	0	0.19	576	0	0.19	576
15	0.03	121	0.02	297	367	0.02	209
16	0.11	150	0.10	116	364	0.06	212
17	3.82	0	3.66	576	0	3.66	576
18	0.91	0	0.40	576	0	0.40	576
19	0.34	0	0.16	576	0	0.16	576
20	0.39	0	0.18	576	0	0.18	576
21	0.03	19	0.02	319	284	0.02	292
22	0.08	77	0.04	499	159	0.05	327
23	0.24	0	0.16	576	0	0.16	576
24	0.12	0	0.07	576	0	0.07	576
25	0.1	76	0.07	500	0	0.06	576
26	0.03	242	0.03	173	266	0.02	310
27	0.03	386	0.02	190	0	0.01	576
28	0.08	256	0.07	185	0	0.02	576
29	0.11	0	0.05	576	31	0.08	337
30	0.19	0	0.09	576	0	0.09	576
31	0.29	0	0.13	576	74	0.15	502
32	0.08	358	0.03	218	115	0.06	124
33	0.44	0	0.18	576	0	0.18	576
34	0.03	59	0.03	248	144	0.03	223
35	0.08	0	0.02	576	180	0.03	396
36	0.5	0	0.27	576	0	0.27	576
37	0.6	0	0.36	576	0	0.36	576
38	0.03	26	0.01	550	0	0.01	576
39	0.03	346	0.03	230	144	0.02	432
40	0.05	0	0.02	576	0	0.02	576
41	0.6	0	0.21	576	0	0.21	576
42	0.08	368	0.05	208	421	0.06	155
43	0.08	394	0.05	182	19	0.06	151
44	0.58	0	0.16	576	0	0.16	576
45	2.06	0	1.67	576	0	1.67	576

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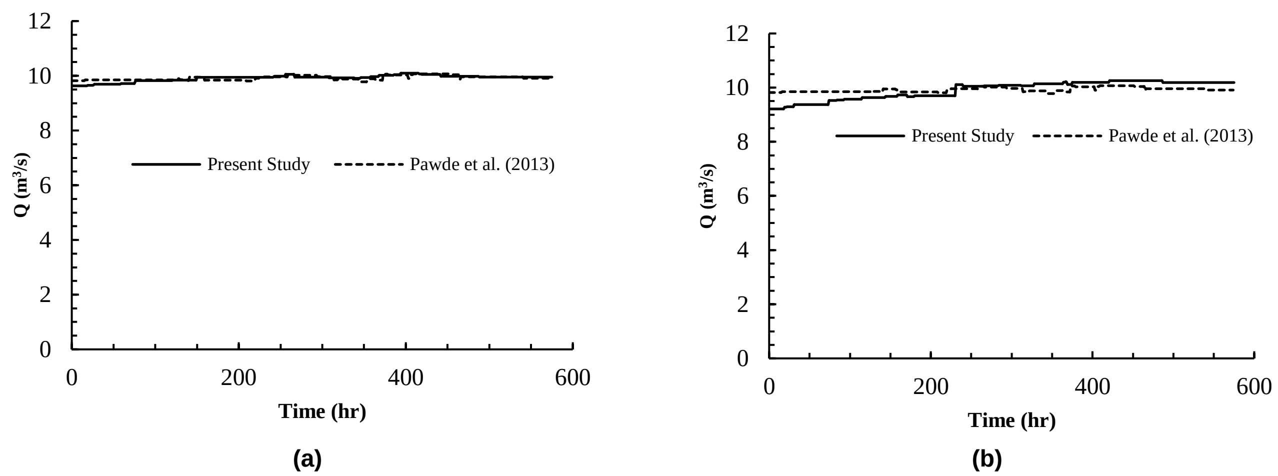

Fig. 4. Upper Wardha canal hydrograph by (a) GA; (b) NSGA-II.

4. Conclusions

In this paper, a new objective function of the number of gate changes was presented. This new objective function and the mean canal discharge objective function were minimized by GA and NSGA-Ⅱ. The existence of two objective functions in comparison to the only mean canal discharge objective function reduces the number of gate changes dramatically. Two objective functions gives 24 gate changes by NSGA-II in Upper Wardha canal while for one objective function (the mean discharge canal) it is 31 by PSO algorithm. Also, there is a small difference between GA and NSGA-II for number of gates operating in the two investigated networks. Thus, selecting the right objective function has a high impact on results rather than selecting the optimization algorithm of water scheduling in irrigation networks.

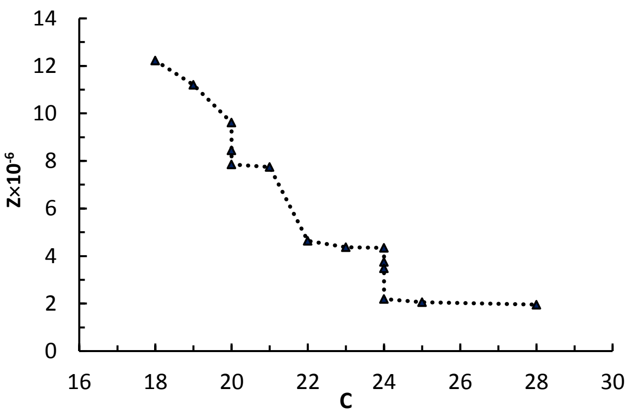

Fig. 5. Pareto front of solutions in two objective functions space.

Table 4. Summary of results for number of gate operating.

Number of gate operating	Algorithm	Canal name
5	GA	AMX
6	NSGA-II	
6	PSO (Pawde et al. 2013)	
23	GA	LBMC
24	NSGA-II	
31	PSO (Pawde et al. 2013)	

References

Anwar A.A., and Clarke D., Irrigation scheduling using mixed-integer linear programming, Journal of Irrigation and Drainage Engineering 127 (2001) 63–69.

Coello Coello C., Lamont G.B., Van Veldhuizen D.A., Evolutionary algorithms for solving multi-objective problems, 2nd ed., New York, Springer (2007).

Deb K., Pratap A., Agarwal S., Meyarivan T., A fast and elitist multiobjective genetic algorithm: NSGA-II, IEEE Transactions on Evolutionary Computation 6 (2002) 182-197.

Delaviz Y., Karami J., Shaygan M., Using NSGA-II for multi-objective optimization allocation of urban land use in order to reduce earthquake vulnerability, Journal of Geomatics Science and Technology 5 (2016) 247-264.

Goharrizi B.A., Tohidirad S., Asadi R., Using NSGA-II algorithm to solve multi-purpose location problems, Motaleate Shahri Journal 5 (2016) 15-26.

Kakouie S., and Emadi A., Optimal water delivery and distribution in AMX canal of varamin irrigation network using ACS algorithm, Iranian Water Research Journal 7 (2013) 51-58.

Konak A., Coit D.W., Smith A.E., Multi-objective optimization using genetic algorithms: A tutorial, Reliability Engineering and System Safety 91 (2006) 992–1007.

Monem M.J., and Namdarian R., Application of simulated annealing (SA) techniques for optimal water distribution in irrigation Canals, Irrigation and Drainage 54 (2005) 365–373.

Monem M.J., and Nouri M.A., Application of PSO method for optimal water delivery in irrigation networks, Iranian Journal of Irrigation and Drainage 4 (2010) 73-82.

Pawde A.W., Mathur Y.P., Kumar R., Optimal water scheduling in irrigation canal network using particle swarm optimization, Irrigation and Drainage 62 (2013) 135–144.

Qaderi Nasab F., Qaderi K., Rahnama M.B., Optimal programming for delivery and distribution of water irrigation network using evolutionary algorithms (the case study: the network irrigation at downstream of the Jiroft dam), Iranian Journal of Irrigation and Drainage 5 (2015) 830-841.

Suryavanshi A.R., and Reddy J.M., Optimal operation scheduling of irrigation distribution systems, Journal of Agricultural Water Management 11(1986) 23–30.

Wardlaw R., and Bhaktikul K., Application of gentic algorithms for irrigation water scheduling, Irrigation and Drainage 53 (2004) 397-41.

Please cite this article as: E. Darvishi, T. Kordestani, Multi-objective optimization of water scheduling in irrigation canal network using NSGA-II, Journal of Applied Research in Water and Wastewater, 6 (2), 2019, 95-99.