Optimum design of sewer networks with pump station using Genetic Algorithms

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Abstract. The main aim of the current study is to develop a new model for the minimum cost of optimum design for a sewer network with pumping stations. The difficulty and relatively large number of nonlinear and discrete constraints in a sewer network with pump station design problems make their handling of extreme importance. For this purpose, an adaptive genetic algorithm (GA) model is proposed for the effective and efficient optimal design with a fixed layout so that each chromosome, consists of diameters, slopes of the pipes and pump indicators. In the present model, the pump locations are decided preliminary, then for each GA chromosome, the network characteristics including the diameters of pipes and slope for those pipes are determined. MATLAB code was used to perform the optimization model. Then a sewer network from previous literature was used to be designed as a benchmark example for the proposed method. It’s concluded that the proposed model has reached the optimal solution at the lowest cost and the fewest number of generations compared with previous methods in the literature.

1. Introduction
Sewer networks are the basic urban infrastructure that greatly and directly affects public health. Therefore, creating a new sewer system is a very difficult and expensive task, especially in densely populated cities. This problem has interested researchers and engineers to exploit and develop optimization methods for finding cost-effective designs [1-5]. Generally, The importance of this field, attracting the attention of many researchers, very few researchers have dealt with the problem of optimal design of sewer network with pump due to it is higher complication compared to network with gravity. Merritt and Bogan [6] used a method for adding a pump station in the sewage system when the gravitational flow result violates the maximum permissible depth of the soil. Froise and Burges [7] design method approach in which pumping station or deciduous constructions are selected when the solution violates the limitations of the depth of soil cover downstream. Li and Matthew [8] used a discrete differential dynamic programming (DDDP) model to optimize the sewer network with pump station. Pan and Kao [9] hybridized the Genetic Algorithm (GA) with Quadratic Programming (QP) to the optimum design of sewer network and created pumped and gravity alternatives for the fixed layout of a sewer network with a suitable computational time. Haghighi and Bakhshipour [10] proposed an adaptive AGA method for the optimum design of pumped and gravity networks of the sewer. Rohani and Afshar [11] developed a Model hybridized of the GAs with cellular automata (CA), as a more effective and efficient model for the optimal design of a sewer network with a pump station for a fixed network layout. Mostly, the research on optimisation of sewer networks has been limited to gravity networks without pump stations whereas, in real life states, pumping becomes imperative from, both cost and engineering
considerations. The need for a pumping station in the sewer system lies in two cases: As for the traditional method, which is the need for the station when the constraint of a maximum depth is exceeded, or by comparing the cost with the presence or absence of the pump station, which is better [12-16]. Genetic algorithms (GAs) a technique that performs well for a global search. It is suitable to solve combinatorial optimization problems with large spaces of solution [17-20]. Originally, the GAs was conceived by Holland (1975) [21] and It has since been advanced before De Jong (1975) [22], Goldberg [23] and consequently by others researcher [24]. The use of genetic algorithms for effective and efficient research of the optimal layout solution for sewer network is governed by several factors such as coding type, fitness function, size of the population, three main operators (choice, mating and mutation), penalty method, number of generation and finally, the most important is the search space size [25-28].

In the current study, developing an adaptive method to increase the efficiency of genetic algorithm formulation to reduce the search space. One of the most essential features of genetic algorithm adaptation is that it makes the search space much smaller than it was in the case that the GA was used alone, and this has a great impact in achieving better results. How to do this will be explained later after the methodology details are presented.

2. Adaptive genetic algorithms

Genetic algorithms are considered one of the most important methods used to solve and search optimization problem, with a random or adaptive search structure. It deals with a population of individuals, where each individual – in this study a sewer network– represents a potential solution to a specific problem. It's based on Darwin's principle of survival of the fittest. Popular genetic algorithms (GAs) are unconstrained technologies, so the search space is vast. To reduce this problem by Adapts a genetic algorithm to increase its efficiency and effectiveness. In this paper, an adaptive approach is developed by decoding the chromosomes as integer representation, this reduces unfeasible solutions. As well as using a selection method (TOS) that keeps the genetic algorithm in a feasible space of the search area and improves the optimization performance in terms of speed.

3. Formulation of optimization

3.1. Objective Function

The following equation estimates the cost of constructing a sewer network with a pumping station, and it is considered the objective function of optimisation in this work:

$$\text{Min } C = \sum_{i=1}^{N_p} L_i K_p (D_i Z_i^1 Z_i^2) + \sum_{i=1}^{N_p+1} K_m h m_i \sum_{i=1}^{N_m} K_{pp} Q_i$$ (1)

Where;

- $C$ = Total cost of the sewer network,
- $N_p$ = Number of network pipes,
- $N_m$ = Number of network nodes,
- $L_i$ = Length of $i^{th}$ pipes,
- $D_i$ = Diameter of $i^{th}$ pipes,
- $Z_i, Z_i'$ = Upstream and downstream depth of excavation of $i^{th}$ pipe,
- $K_p$ = Unit construction cost for each pipe, defined as a function of pipe’s diameter ($D_i$ ), upstream and downstream depth of pipe excavation ($Z_i, Z_i'$ ),
- $h m_i$ = depth of manhole.
- $K_m$ = unit construction cost of $i^{th}$ manhole.
- $Q_i$ = Pumping discharge,
- $K_{pp}$ = Cost coefficient for installing the pump at the $i^{th}$node.
Basically, genetic algorithms are designed to solve unconstrained optimization problems. To solve a constrained optimization problem, such as a sewer network, it is necessary to include the constraints in the objective function and use the penalty cost as an additional cost over the total cost.

### 3.2. Constraints

An optimal design is defined as a set of diameters of pipes, slopes, and pump locations that satisfies all constraints for a fixed layout. The following are the constraints in the model:

- The flow velocity does not exceed the minimum and maximum limit respectively, for the ability to self-clean and to prevent scouring and sedimentation.
  
  \[ V_{\text{min}} \leq V_l \leq V_{\text{max}} \quad l = 1, \ldots, NP \]  

  (2)

- Provided a minimum burial depth to avoid damage from loads of traffic and other surface factors.
- Taking into consideration the minimum and maximum permissible slope of each pipe in the network pipes.
- In each pipe, the downstream crown elevation equal to or lower than this upstream crown elevation. Except in the pipes where there is a pump station.
- Assigning the outlet diameter of the pipe \((D_{l'})\) equal to or larger than the upstream pipe’s inlets \((D_l)\), for each manhole.
- The pipe diameters selected should be included in the list of commercial pipes.

### 4. Formulation of the model

Each decision variable in this algorithm is considered as a gene and the set of decision variables is preserved as a chromosome. Then, the evolution mechanism begins in the proposed algorithm in the form of stages: selection, crossing and mutation, the inappropriate chromosomes are eliminated according to the fitness function and the other chromosomes remain functional to continue to the next generation and this mechanism is returned until an acceptable solution is obtained. The following steps show how the model works to get the optimal design of a sewer network with a pump station:

1. **Chromosomes (Encoding the Design Variables):** Each chromosome contains the diameters of the sewer network and the location of the pump, and is considered a feasible design. The chromosomes are created by binary coding and then decoding into a possible design. The length of the chromosome is equal to the number of pipes. A set of profitable (commercial) pipes was approved and represented as an integer coding.

2. **Population:** The GAs begin optimizing the problem with an initial set of chromosomes called population (here sewer networks) that are generation randomly at the beginning and evolve through the sequential iteration of generations in the algorithm [29].

3. **For each chromosome:**
   a) Computed the optimum slope: In this step, the slope of the ground and the minimum and maximum slope of each pipe in the network are calculated and the optimum slope is chosen through a logical algorithm.
   b) Computed the hydraulic properties of the network: In this step, the velocity is calculated and the constraints of the velocity and relative flow depth are applied. Wholly these properties are calculated by considering the steady flow.
   c) Computed the penalty costs: In the GA, a penalty cost is imposed on every network (chromosome) in the event that the proposed solution doesn’t fulfil one or more constraint.
d) Computed the total costs of networks: It’s calculated by the sum of the pipe’s installation, manhole, pump construction and penalty costs.

4. Fitness account: the fitness value for each individual in the population is calculated by applying the inversely of the objective function cost value for each network. So that the higher the cost value the less fitness and thus the least chance of selecting [30].

5. Generated a new population: the new population is generated by repeating the following operators until to get a new population, which can be generated many times.

a) Selection operator: two individuals are chosen according to the fitness from the initial population (the best fitness is the highest chance to chosen) and in this model, the Tournament Selection Method (TOS) was used [31]. It is the best method from the other methods [32].

b) Crossover operator: after the individuals’ selection process, the individuals get crossover to have offspring (new children). Better children are produced than individuals (parents) by applying the cross factor to the mating pool. Here, considered Single-point crossover where Pc = 1.

c) Mutation operator: the purpose of mutation in genetic algorithms is to introduce diversity into a sample population. Mutation factors are used in an attempt to avoid local minimums by avoiding the chromosomes in the population from becoming very similar to one another, therefore slow or even stop the convergence to the global optimal level. In this work, a gene (pipe) in one of the chromosomes will be randomly changed and in a certain proportion (Pm).

6. Replace the current population with a new generation: after applying the operators on the initial population and create the new population that needs to be decoded and evaluated, the process continues until the preferred convergence is reached as shown in Fig. 1.

5. Results and discussion

To evaluate the performance of the present model, a benchmark example will be designed from the previous literature. Originally, this example was used by Li and Matthew (1990) [33]. A sewer network of 79 pipes and 80 manholes was designed to collect wastewater from a residential area of 260 hectares. Fig. 2. Table (1) shows the name, length, flow rate, and ground elevations for each pipe in the sewer network for a benchmark example. Manning’s coefficient (0.014) was used. As well as Table (2) shows the problem constraints for the benchmark example. Then the design problem of the network concerning the specific construction costs given in Table (3) is improved, whereas, this table is adapted to determine the objective cost function (eq. 1) of the problem. There are 24 commercial diameters size that will be adopted in this problem: (0.2, 0.25, 0.30, 0.35, 0.38, 0.40, 0.45, 0.50, 0.53, 0.60, 0.70, 0.80, 0.90, 1.00, 1.05, 1.20, 1.35, 1.40, 1.50, 1.60, 1.80, 2.00, 2.20, and 2.40) m.
Figure 1. Present model Flow chart.
Figure 2. Layout of the benchmark example [20].
### Table 1. Specifications for the benchmark example of sewer network [8].

| Link ID | Ground Elevation (m) | Length (m) | Q design (l/s) |
|---------|----------------------|------------|----------------|
|         | Upstream             | Downstream |                |
| 1       | 2.5                  | 2.3        | 360            | 5.87           |
| 2       | 2.2                  | 2.3        | 350            | 7.69           |
| 3       | 2.3                  | 2.5        | 290            | 19.07          |
| 4       | 2.5                  | 2.4        | 270            | 9.92           |
| 5       | 2.6                  | 2.5        | 260            | 31.57          |
| 6       | 2.5                  | 2.9        | 220            | 50.09          |
| 7       | 2.9                  | 2.5        | 240            | 95.97          |
| 8       | 2.85                 | 2.9        | 275            | 48.59          |
| 9       | 2.8                  | 2.7        | 240            | 5.87           |
| 10      | 2.7                  | 2.6        | 300            | 9.72           |
| 11      | 2.5                  | 2.6        | 490            | 4.86           |
| 12      | 2.6                  | 2.7        | 250            | 17.52          |
| 13      | 2.7                  | 2.6        | 300            | 25.63          |
| 14      | 2.7                  | 2.85       | 310            | 2.23           |
| 15      | 2.7                  | 2.6        | 240            | 13.03          |
| 16      | 2.6                  | 2.8        | 230            | 20.08          |
| 17      | 2.8                  | 2.6        | 200            | 7.69           |
| 18      | 2.8                  | 2.8        | 190            | 8.91           |
| 19      | 2.8                  | 2.85       | 380            | 38.52          |
| 20      | 2.85                 | 2.6        | 250            | 3.24           |
| 21      | 2.6                  | 2.45       | 200            | 5.87           |
| 22      | 2.25                 | 2.2        | 300            | 6.07           |
| 23      | 2.1                  | 2.1        | 280            | 11.72          |
| 24      | 2.2                  | 2.1        | 360            | 6.07           |
| 25      | 2.2                  | 2.4        | 350            | 12.1           |
| 26      | 2.4                  | 2.4        | 230            | 18.56          |
| 27      | 2.1                  | 2           | 230            | 15.04          |
| 28      | 2                    | 2           | 250            | 2.63           |
| 29      | 2.4                  | 2           | 260            | 142.18         |
| 30      | 2.4                  | 2.4        | 310            | 135.41         |
| 31      | 2.5                  | 2.4        | 300            | 108.32         |
| 32      | 2.5                  | 2.5        | 180            | 100.23         |
| 33      | 2.4                  | 2           | 190            | 9.92           |
| 34      | 2.4                  | 2.5        | 260            | 7.08           |
| 35      | 2.5                  | 2.45       | 320            | 10.52          |
| 36      | 2.3                  | 2.35       | 290            | 4.45           |
| 37      | 2.4                  | 2.35       | 325            | 5.67           |
| Link ID | Ground Elevation (m) | Length (m) | Q design (l/s) |
|---------|----------------------|-------------|---------------|
|         | Upstream            | Downstream  |               |
| 38      | 2.6                 | 2.4         | 200           | 11.33         |
| 39      | 2.4                 | 2.2         | 210           | 44.16         |
| 40      | 2.45                | 2.4         | 370           | 29.8          |
| 41      | 2.25                | 2.45        | 260           | 2.63          |
| 42      | 2.25                | 1.95        | 230           | 4.66          |
| 43      | 1.95                | 2           | 225           | 2.02          |
| 44      | 1.95                | 2           | 350           | 10.73         |
| 45      | 2.05                | 2           | 180           | 3.64          |
| 46      | 2.2                 | 2           | 230           | 53.21         |
| 47      | 2                   | 1.95        | 320           | 68.5          |
| 48      | 2.35                | 1.95        | 440           | 28.69         |
| 49      | 1.95                | 2           | 290           | 106.98        |
| 50      | 1.9                 | 1.95        | 310           | 18.56         |
| 51      | 2.3                 | 1.9         | 440           | 10.23         |
| 52      | 1.9                 | 2           | 350           | 5.06          |
| 53      | 2                   | 2.1         | 310           | 4.05          |
| 54      | 2.1                 | 2.1         | 260           | 7.89          |
| 55      | 2.1                 | 2.2         | 300           | 15.22         |
| 56      | 2.2                 | 2.25        | 350           | 208.37        |
| 57      | 2.1                 | 2.25        | 230           | 140.62        |
| 58      | 2.25                | 2.2         | 280           | 328.16        |
| 59      | 2.2                 | 2.2         | 500           | 337.77        |
| 60      | 2.2                 | 2.2         | 180           | 12.85         |
| 61      | 2.2                 | 2.2         | 230           | 9.72          |
| 62      | 2.2                 | 2.2         | 230           | 4.66          |
| 63      | 2.2                 | 2.1         | 270           | 1.42          |
| 64      | 2                   | 2.1         | 250           | 154.43        |
| 65      | 2                   | 2.1         | 260           | 6.48          |
| 66      | 2                   | 2           | 140           | 13.59         |
| 67      | 2                   | 2.1         | 270           | 18.04         |
| 68      | 2.1                 | 2.1         | 280           | 172.55        |
| 69      | 2.1                 | 2.2         | 280           | 180.36        |
| 70      | 2.2                 | 2.2         | 650           | 203.94        |
| 71      | 2.2                 | 2.2         | 270           | 192.34        |
| 72      | 2.1                 | 2.2         | 230           | 7.49          |
| 73      | 2.1                 | 2.2         | 300           | 8.91          |
| 74      | 2.1                 | 2.1         | 320           | 3.24          |
| 75      | 2.05                | 2.1         | 150           | 3.04          |
| 76      | 2.1                 | 2.1         | 300           | 10.73         |
| 77      | 2.1                 | 2           | 290           | 21.72         |
| 78      | 2                   | 2.1         | 280           | 135.65        |
| 79      | 2                   | 2           | 310           | 13.03         |
Table 2. Design Standards for the benchmark example [8].

| Item name                      | Item value                          |
|-------------------------------|-------------------------------------|
| Maximum velocity $v_{\text{max}}$ | 5.0 m/s                             |
| Minimum velocity $v_{\text{min}}$ (if $D \leq 500$ mm, $Q > 15$ l/s) | 0.7 m/s                             |
| Minimum velocity $v_{\text{min}}$ (if $D > 500$ mm, $Q > 15$ l/s) | 0.8 m/s                             |
| Minimum slope $S_{\text{min}}$ (if $Q \leq 15$ l/s) | 0.003                               |
| Maximum proportional water depth $(h/D)_{\text{max}}$ (if $D \leq 300$ mm) | 0.6                                 |
| Minimum cover depth $C_{\text{min}}$ | 1 m                                 |

Table 3. Cost components of construction for the benchmark example in Yuan [8]

For pipes, $k_p$

| Expression | $D \leq 1$ m, $h \leq 3$ m |
|------------|-----------------------------|
| $(4.27 + 93.59D^2 + 2.86D \times h + 2.39h^2) \times L$ | $D \leq 1$ m, $h > 3$ m |
| $(36.47 + 88.96D^2 + 8.70D \times h + 1.78h^2) \times L$ | $D > 1$ m, $h \leq 4$ m |
| $(20.50 + 149.27D^2 - 58.96D \times h + 17.75h^2) \times L$ | $D > 1$ m, $h > 4$ m |
| $(78.44 + 29.25D^2 + 31.80D \times h - 2.32h^2) \times L$ |

For manholes, $CM$

| Expression | $D \leq 1$ m, $h \leq 3$ m |
|------------|-----------------------------|
| $136.67 + 166.19D^2 + 3.50D \times h + 16.22h^2$ | $D \leq 1$ m, $h > 3$ m |
| $132.67 + 790.94D^2 - 280.23D \times h + 34.97h^2$ | $D > 1$ m, $h \leq 4$ m |
| $209.04 + 57.53D^2 + 10.93D \times h + 19.88h^2$ | $D > 1$ m, $h > 4$ m |
| $210.66 - 113.04D^2 + 126.43D \times h - 0.60h^2$ |

For pump stations, $k_{pp}$

| Expression | $Q$ (l/s) |
|------------|-----------|
| $270.021 + 316.42Q - 0.1663Q^2$ |

Where, $K_p$, $K_m$ and $K_{pp}$ are the cost of construction for pipe, manhole and pump in (Yuan), $D$ is the pipe’s diameter in (m), $h$ is the depth of buried in (m), $L$ is the length of pipes in (m), and $Q$ is the discharge of pump in (l/s).

Li and Matthew used the DDDP method to get the optimum design for this example. The results obtained the optimal solution when a pump station is at point 9. After that, Pan and Kao suggested a hybrid method (GA-QP) to solve the example using the optimum layout of Li and Matthew, which led to many alternatives, with or without a station of a pump. The problem was later solved by Rohani and Afshar [11] proposed a hybrid model between the genetic algorithm and cellular automata, which to design an efficient and effective sewer network with a pumping station. The best design of the sewer network with pump station at Node 9 was obtained by the GA-GHCA1 model. In this paper, the optimal design solution was obtained with the lowest cost compared to other methods shown in table 5. Moreover, the number of generations was very small. It's concluded from the results that the model is efficient in terms of cost, time and computational effort. Table 4 shows the characteristics of optimal design by the present model.
Table 4. Characteristics of optimal design for example by the proposed model

| Link ID | Excavation Depth (m) | US  | DS  | D(m) | V(m/s) |
|---------|----------------------|-----|-----|------|--------|
| 1       | 1.20                 | 2.88| 0.20| 0.72 |
| 2       | 1.20                 | 3.12| 0.20| 0.7  |
| 3       | 3.15                 | 4.50| 0.25| 0.72 |
| 4       | 1.20                 | 2.51| 0.20| 0.7  |
| 5       | 1.30                 | 1.99| 0.30| 0.74 |
| 6       | 1.35                 | 2.29| 0.35| 0.76 |
| 7       | 2.45                 | 2.44| 0.45| 0.81 |
| 8       | 1.35                 | 2.08| 0.35| 0.76 |
| 9       | 1.20                 | 2.35| 0.20| 0.72 |
| 10      | 2.40                 | 3.82| 0.20| 0.73 |
| 11      | 1.20                 | 3.85| 0.20| 0.72 |
| 12      | 3.90                 | 4.97| 0.25| 0.7  |
| 13      | 4.97                 | 6.30| 0.25| 0.83 |
| 14      | 1.20                 | 2.97| 0.20| 0.7  |
| 15      | 1.20                 | 2.35| 0.20| 0.72 |
| 16      | 2.40                 | 3.49| 0.25| 0.72 |
| 17      | 1.20                 | 3.56| 0.20| 0.7  |
| 18      | 1.20                 | 2.19| 0.20| 0.7  |
| 19      | 3.54                 | 5.14| 0.30| 0.86 |
| 20      | 1.20                 | 2.25| 0.20| 0.7  |
| 21      | 2.25                 | 3.70| 0.20| 0.7  |
| 22      | 1.20                 | 2.71| 0.20| 0.7  |
| 23      | 1.20                 | 2.66| 0.20| 0.7  |
| 24      | 1.20                 | 2.98| 0.20| 0.7  |
| 25      | 2.71                 | 4.74| 0.20| 0.71 |
| 26      | 2.56                 | 3.44| 0.25| 0.71 |
| 27      | 2.66                 | 3.80| 0.20| 0.76 |
| 28      | 1.20                 | 2.50| 0.20| 0.7  |
| 29      | 1.45                 | 2.12| 0.45| 1.19 |
| 30      | 4.99                 | 6.14| 0.45| 1.13 |
| 31      | 1.40                 | 2.64| 0.80| 1.15 |
| 32      | 2.44                 | 2.81| 0.45| 0.84 |
| 33      | 1.20                 | 1.79| 0.20| 0.7  |
| 34      | 1.20                 | 2.66| 0.20| 0.7  |
| 35      | 1.20                 | 2.82| 0.20| 0.7  |
| 36      | 1.20                 | 2.76| 0.20| 0.7  |
| 37      | 1.20                 | 2.84| 0.20| 0.7  |
| 38      | 2.04                 | 2.88| 0.20| 0.7  |
| 39      | 3.03                 | 3.35| 0.35| 0.74 |
| 40      | 3.24                 | 4.32| 0.30| 0.73 |
| 41      | 1.20                 | 2.76| 0.20| 0.7  |
| 42      | 1.20                 | 2.10| 0.20| 0.7  |
| 43      | 1.20                 | 2.42| 0.20| 0.7  |
| 44      | 2.10                 | 3.97| 0.20| 0.71 |
| 45      | 1.20                 | 2.09| 0.20| 0.71 |
| 46      | 3.38                 | 3.69| 0.38| 0.74 |
Figure (3) shows the convergence curve for the optimal cost solution in relation to the number of generations during the process of evolution. As the results indicated that the best-estimated cost (1.464 E5 Yuan) was obtained through the TOS method of selecting and the method of one-point crossovering with 166 generations. When comparing the results with previous work in the literature, it was found that the algorithm adaptation method showed more successful results in improving the design of the sewer network with pumps problem, as well as easier to implement, as shown in Table 5.

| Link ID | Excavation Depth (m) | D(m) | V(m/s) |
|---------|----------------------|------|--------|
|         | US                   | DS   |        |
| 47      | 4.17                 | 4.79 | 0.40   | 0.77   |
| 48      | 2.94                 | 3.88 | 0.30   | 0.72   |
| 49      | 4.84                 | 5.56 | 0.45   | 0.89   |
| 50      | 1.25                 | 2.50 | 0.25   | 0.71   |
| 51      | 1.20                 | 3.09 | 0.20   | 0.7    |
| 52      | 1.20                 | 3.12 | 0.20   | 0.7    |
| 53      | 1.20                 | 2.92 | 0.20   | 0.7    |
| 54      | 1.20                 | 2.56 | 0.20   | 0.7    |
| 55      | 2.92                 | 4.68 | 0.20   | 0.77   |
| 56      | 1.53                 | 2.67 | 0.53   | 1.17   |
| 57      | 1.45                 | 2.53 | 0.45   | 1.18   |
| 58      | 2.67                 | 4.78 | 0.53   | 1.84   |
| 59      | 5.08                 | 7.19 | 0.60   | 1.48   |
| 60      | 1.20                 | 2.14 | 0.20   | 0.72   |
| 61      | 1.20                 | 2.40 | 0.20   | 0.7    |
| 62      | 1.20                 | 2.40 | 0.20   | 0.7    |
| 63      | 1.20                 | 2.51 | 0.20   | 0.7    |
| 64      | 4.13                 | 4.70 | 0.53   | 0.9    |
| 65      | 1.20                 | 2.66 | 0.20   | 0.7    |
| 66      | 2.42                 | 3.15 | 0.20   | 0.73   |
| 67      | 3.19                 | 4.34 | 0.25   | 0.7    |
| 68      | 4.69                 | 5.29 | 0.53   | 0.97   |
| 69      | 5.29                 | 6.05 | 0.53   | 1.01   |
| 70      | 2.47                 | 4.41 | 0.53   | 1.14   |
| 71      | 6.05                 | 6.76 | 0.53   | 1.08   |
| 72      | 1.20                 | 2.49 | 0.20   | 0.7    |
| 73      | 2.66                 | 4.32 | 0.20   | 0.71   |
| 74      | 1.20                 | 2.87 | 0.20   | 0.7    |
| 75      | 1.20                 | 2.03 | 0.20   | 0.7    |
| 76      | 1.20                 | 2.76 | 0.20   | 0.7    |
| 77      | 2.92                 | 3.94 | 0.25   | 0.73   |
| 78      | 5.56                 | 6.71 | 0.45   | 1.14   |
| 79      | 3.12                 | 4.74 | 0.20   | 0.72   |
Figure 3. The optimal cost solution of generation by the present method.

Table 5. Optimal sewer network costs with pump station obtained by different methods

| Model                        | Cost (yuan) | Pump Location |
|------------------------------|-------------|---------------|
| Li and Matthew (1990) [20]   | $1.67 \times 10^6$ | Node 9        |
| Pan & Kao (2009) [9]          | GA-QP1      | $1.740 \times 10^6$ | Node 19 |
|                              | GA-QP2      | $1.85 \times 10^6$ | Node 39 |
| Rohani and Afshar (2014) [11]| GA-GHCA1    | $1.471 \times 10^6$ | Node 9  |
|                              | GA-GHCA2    | $1.521 \times 10^6$ | Node 9  |
| Proposed model               |             | $1.464 \times 10^6$ | Node 8  |

6. Conclusions
This research presents an adaptive genetic algorithm to improve sewer network systems with a pump station. A highly effective algorithm is adopted for determining the optimum. The GA was accountable for determining the optimal location for the pump stations and for determining the composition of the sewer network, that is pipe diameters and slopes. The proposed method for solving a benchmark example has been used in the literature and the results are presented and compared to the current results as shown in Table 5. The results specified the applicability, pliability and efficiency of the proposed model for the optimum design of pumped and lower generation sewage networks than required by other methods.

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