



Site Selection for Wastewater Treatment Plants in Rural Areas Using the Analytical Hierarchy Process and Geographical Information System

Samaneh Taghilou^a | Mazyar Peyda^{a*} | Younes Khosravi^b | Mohammad Reza Mehrasbi^a

^a Department of Environmental Health Engineering, School of Public Health, Zanjan University of Medical Sciences, Zanjan, Iran.

^b Department of Environmental Science, School of Science, University of Zanjan, Iran.

*Corresponding author: Mazyar Peyda

Department of Environmental Health Engineering, School of Public Health, Zanjan University of Medical Sciences, Zanjan, Iran. Postal code: 4515786349.

E-mail address: mazyarpeyda@zums.ac.ir

ARTICLE INFO

Article type:
Original article

Article history:
Received 28 May 2019
Revised 22 June 2019
Accepted 18 August 2019

DOI: [10.29252/jhehp.5.3.8](https://doi.org/10.29252/jhehp.5.3.8)

Keywords:
Site selection
Wastewater treatment plant
Optimization
AHP
GIS

ABSTRACT

Background: Population growth and industrial and agricultural activities have increased the consumption of water, leading to clean water scarcity. Wastewater treatment is an important concern as determining proper sites for wastewater treatment plants (WWTP) largely influences proper operation. The present study aimed to determine an optimized site for WWTP in the rural complexes of Zanjanrood catchment in Zanjan province, Iran.

Methods: The site priority map was generated using the geographical information system (GIS) and analytical hierarchy process (AHP). Locating of the plants was based on various parameters. After map preparation, the weight of each parameter was determined using the AHP approach, and the conversion of the layers was performed using the GIS. The site priority map for each sub-catchment was determined and optimized.

Results: In the criteria pairwise comparison matrix, the distance from the city had the highest value (16%), while the distance from the oil and gas transmission pipelines had the lowest value (1%). The site was located at the lowest elevation compared to the villages in each complex.

Conclusion: According to the results, the AHP followed by the optimization method could pinpoint the optimal sites for the environmental protection of treatment plant construction in rural areas.

1. Introduction

To date, more than 1.8 billion people have no access to clean water across the world. According to the United States Environmental Protection Agency (USEPA), half of the world's population will be living in water-stressed areas by 2025 [1]. Today, large populations are faced with water scarcity (especially in arid and semi-arid areas) due to population growth, as well as droughts and advancement of industrial and agricultural activities. Proper management of water and wastewater improves hygienic and economic conditions, and wastewater treatment is considered to be a

cost-effective strategy for pollution control and reuse [2].

An important concern regarding wastewater treatment is the determination of the treatment plant sites [2]. Many countries and scientific organizations have issued their standards or guidelines for the site selection of wastewater treatment plants. Many parameters must be considered in site selection studies, and systematic approaches are required to combine the data obtained from a wide range of disciplines [3]. The geographical information system (GIS) integrates spatial data (e.g., maps, aerial photographs, and satellite images) with quantitative, qualitative, and descriptive information databases.

How to cite: Taghilou S, Peyda M, Khosravi Y, Mehrasbi MR. Site Selection for Wastewater Treatment Plants in Rural Areas Using the Analytical Hierarchy Process and Geographical Information System. *J Hum Environ Health Promot.* 2019; 5(3): 137-44.

These factors render the GIS an appropriate tool for site selection studies [4].

The analytical hierarchy process (AHP) and GIS tools have successfully been used for site selection. In addition, proper sites have been selected for olive mill wastewater disposal [5], domestic wastewater treatment plants [6], and decentralized treatment plants using the AHP and GIS [7]. To select the optimal sites from among the prioritized sites that are obtained using the AHP, fuzzy logic and other techniques are considered essential to the use of optimization methods. Researchers have also optimized site selection using various mathematical methods, algorithms, and expert opinions [8-15]. The fuzzy AHP has been employed for drought management [16], and a risk assessment study has also been performed regarding a water supply network using the GIS [17].

In the present study, the site priority map of the wastewater treatment plant for each sub-catchment in Zanjanrood catchment, Iran was prepared using the AHP and GIS, and an optimized site for each rural complex was also selected using the proposed algorithm.

2. Materials and Methods

2.1. Study Area

The study area was located in the rural regions of Zanjanrood catchment, Iran. The catchment is divided into 25 sub-catchments, where 35 rural complexes were determined, with each comprising of two or more villages based on the location in the same sub-catchment and length of the wastewater transmission line. To determine the conventional length of the transmission line, the locations of Hamadan, Ardebil, East Azarbaijan, and Zanjan provinces were selected due to their similar climate and neighboring state to Zanjan province. The population of the cities in these provinces was correlated with the length of the transmission lines, and the obtained correlation was employed to calculate the conventional length of transmission line (3 kilometers). Figure 1 depicts the length of the transmission line.

In each sub-catchment, proper sites were selected using the AHP and GIS. Figure 2 shows the location of Zanjanrood catchment.

2.2. Analytical Tools

The AHP is a multi-criteria decision analysis (MCDA) technique [18]. The MCDA involves a set of processes that evaluate the weight of the alternatives to a specific aim [3]. The AHP divides decision problems into understandable steps, each of which is analyzed separately and integrated into a logical procedure [19]. On the other hand, a major problem in decision-making is deriving the relative weights of the criteria.

The AHP is a popular weight evaluation technique [20], in which a matrix and the criteria weights are reached as a result of pairwise comparisons and these calculations, respectively. One of the factors that is gained most in pairwise comparison is the consistency ratio (CR) of decisions. Furthermore, it is possible to determine the CR of decisions in pairwise comparisons. The CR reveals the random probability of the values that are obtained in a

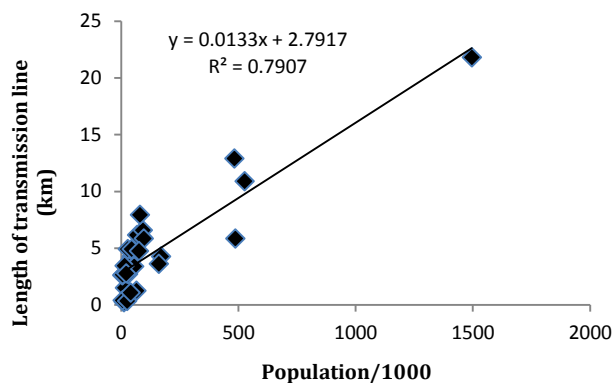


Figure1: Population and Length of Transmission Lines in Neighboring Provinces of Zanjan Province

pairwise comparison matrix [21]. Overall, the AHP process involves the following steps [22]:

Step1: Development of a Pairwise Comparison Decision Matrix (A):

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

In this step, a_{ij} indicates the significance of the i th objective in terms of the j th objective while making a proper material handling/equipment selection decision. As for i and j , it is essential that $a_{ii}=1$ and $a_{ij}=1/a_{ji}$ [21]. In this method, comparison is performed in accordance with the scales presented in Table 1 [5, 19, 23].

Step 2: At this stage, each value in column j must be divided by the total of the values in column j , and the total of the values in each column of the new A_w matrix must be equal to one. Eventually, a normalized pairwise comparison matrix is developed.

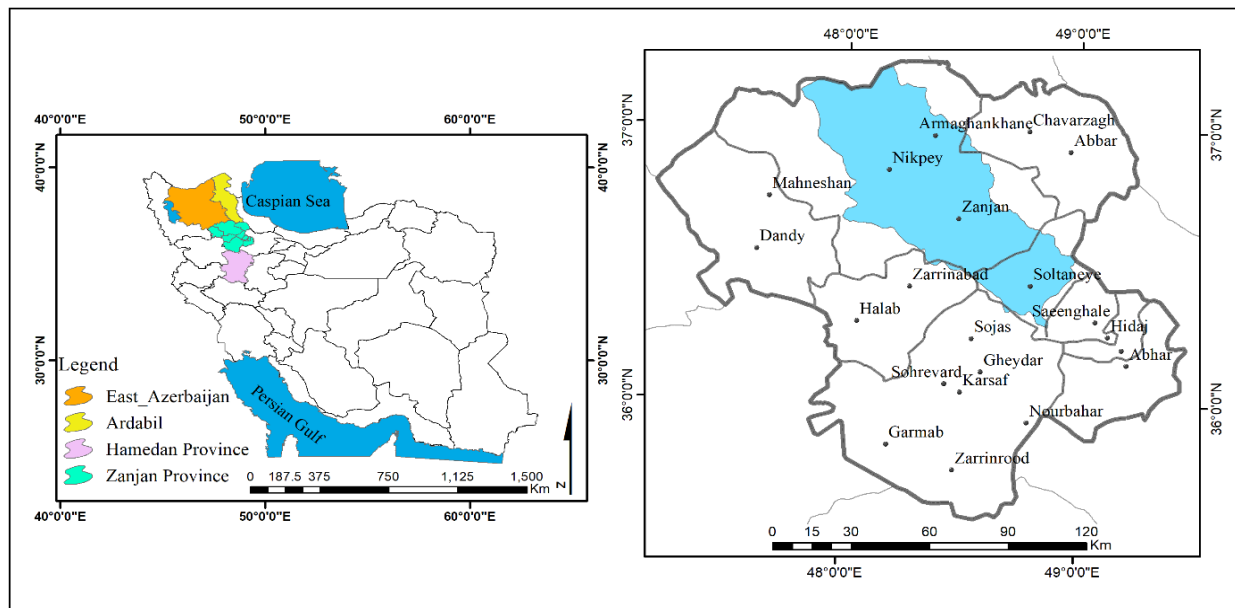
$$A_w = \begin{bmatrix} \frac{a_{11}}{\sum a_{i1}} & \frac{a_{12}}{\sum a_{i2}} & \dots & \frac{a_{1n}}{\sum a_{in}} \\ \dots & \dots & \dots & \dots \\ \frac{a_{n1}}{\sum a_{i1}} & \frac{a_{n2}}{\sum a_{i2}} & \dots & \frac{a_{nn}}{\sum a_{in}} \end{bmatrix}$$

Step 3: In the AHP, c_i is obtained by finding the principal eigenvector of the A matrix. In the current research, a simplified method was applied to calculate c_i as presented below, and the c_i value shows the relative degree of significance (weight) of the i th objective.

$$C = \begin{bmatrix} C_1 \\ C_2 \\ \vdots \\ C_n \end{bmatrix} = \begin{bmatrix} \frac{a_{11}}{\sum a_{i1}} + \frac{a_{12}}{n} + \dots + \frac{a_{1n}}{n} \\ \dots \\ \frac{a_{n1}}{\sum a_{i1}} + \frac{a_{n2}}{n} + \dots + \frac{a_{nn}}{n} \end{bmatrix}$$

Step 4: At this stage, the consistency of the weight values is controlled (c_i). To determine the consistency, the following procedure must be adopted:

- 1) Calculation of the $A \times C$ matrix (consistency vector);



a. Zanjan, Hamadan, Ardabil, East Azerbaijan province

b. Zanjanrood catchment

Figure 2: Study Area in Zanjanrood Catchment in Zanjan Province, Iran

Table 1: Comparison Scale in AHP

Intensity of important	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Medium importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored, and its dominance is demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between adjacent judgments the two	When compromise is needed

$$A \times C = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \times \begin{bmatrix} C_1 \\ C_2 \\ \cdot \\ \cdot \\ C_n \end{bmatrix} = \begin{bmatrix} X_1 \\ X_2 \\ \cdot \\ \cdot \\ X_n \end{bmatrix}$$

2) Calculation of xi by multiplying AxC using the following formula, by which λ_{max} is estimated:

$$\lambda_{max} = -\frac{1}{n} \sum_{i=1}^n \frac{x_i}{c_i}$$

In the formula above, λ_{max} is the eigenvalue of the pairwise comparison matrix.

In the next step, the consistency index (CI) must be calculated, as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

CR is the last calculated ratio; in general, if the CR is less than 0.1, the judgments are consistent, and the derived weights could be used [24]. The formulation of CR is as follows:

$$CR = \frac{CI}{RI}$$

In the formula above, RI is the random consistency index. If $CR \leq 0.10$, the degree of consistency is satisfactory, and if $CR > 0.10$, there are staid inconsistencies [25].

In the present study, the following parameters were considered in order to determine the proper sites for wastewater treatment plants:

- a. Distance from the city and villages;
- b. Distance from water wells;
- c. Land use;
- d. Distance from protected areas;
- e. Slope;
- f. Distance from main roads;
- g. Geology units and soil permeability;
- h. Distance from receiving waters (rivers);
- i. Distance from faults and industrial sites;
- j. Distance from power, water, oil, and natural gas transmission lines

2.3. Classification of Lands

Initially, the main criteria of proper site selection were determined based on the national guidelines [26], some related articles [2, 3, 6] and the data obtained from the questioners distributed among the experts. The criteria

were ranked based on expert opinions. Other information were also obtained from the governor of Zanjan province, including the layers of the catchment area, digital elevation model (DEM), geology, protected areas, land use, rivers, main roads, soil features, slope, villages, city, water transmission lines, electricity and gasoline, faults, industrial sites, and water wells. Finally, the layers were converted into raster and a reclassified format.

As mentioned earlier, the AHP weights were calculated using the pairwise comparison matrix. Following that, these parameters were used to label the rows and columns of the pairwise matrix, and the intersections in-between were filled with a numerical preference value. The principal eigenvector of the matrix was also calculated, and the sum of their criteria was normalized by calculating the relative preference for the parameters [27].

The AHP model was executed using the model boiler of the ArcMap10.3 and weighed over the layer, followed by addition to the main layer (sub-catchment). Afterwards, the final weight was placed in an influence section, and the final AHP map was prepared in the GIS software environment. The prioritized sites were presented using various colors on the AHP map.

2.4. Decision-making Algorithm

The AHP method was applied to identify the sites with the same priority in each sub-catchment. In each sub-catchment, it was possible to use the priority sites in the adjacent sub-catchments. The optimization process to select the optimal site based on the adjacent sub-catchment was performed using the algorithm shown in Figure 3. The optimization was carried out considering the transition line of less than three kilometers and lower DEM based on the villages in each complex.

3. Result and Discussion

3.1. Complexes and Population

In total, there were 35 complexes and 85 villages with the total population of 31,000 in the studied area. Complex 12 had the minimum population (n=128), and complex six had the maximum population (n = 4,401).

3.2. Reclassification of the Criteria

Reclassification of the quantitative site selection criteria is presented in Table 2. The AHP method was used to reclassify each parameter into five classes, with class one indicating the worst condition, and class nine indicating the optimal condition.

The possible ranges of each parameter were divided into qualitative classes.

Treatment plants should not be constructed within the city and village limits since they could potentially cause adverse environmental effects on the population, land value, and future development [5]. On the other hand, treatment plants should not be far from cities or villages since distant treatment plants may impose higher costs for wastewater transmission. In addition, they will have difficult accessibility to major arteries, such as water, power, gas, and main roads [26]. Therefore, the distances range of 1,000-1,500 meters was classified as optimal (class 9), while the distance of more than 6,000 meters was defined as the worst (class 1). In the other studies regarding wastewater treatment plant site selection, the buffer zone for urban and rural areas has been considered to be 1,000 and 300 meters, respectively [3]. In the present study, a uniform buffer zone was selected for urban and rural areas.

Wastewater treatment plants should not be in the proximity of water wells due to the risk of sewage leakage [28]. The safe boundary of water wells has been determined to be 20 and 30 meters on each side for drinking water and farming, respectively [29]. In such case, sealing will impose significant costs for construction. In the current research, the distance of less than 30 meters was considered as the worst condition, and the distance of more than 30 meters was considered as the optimal condition. In the other studies in this regard, the buffer of groundwater well distance has been considered to be 300 meters [3] or 50 meters for landfill siting [30]. In the present study, we selected the national constraint.

Wastewater treatment plants should not be located near protected areas (e.g., national parks), so that the risk of contamination would reduce [2, 5]. As such, the distances of 0-100 and more than 10,000 meters were defined as the worst and optimal classes, respectively. In another study regarding a disposal site, buffer zone of 3,000 meters (5) and 500 meters were used to locate a wastewater treatment plant [2].

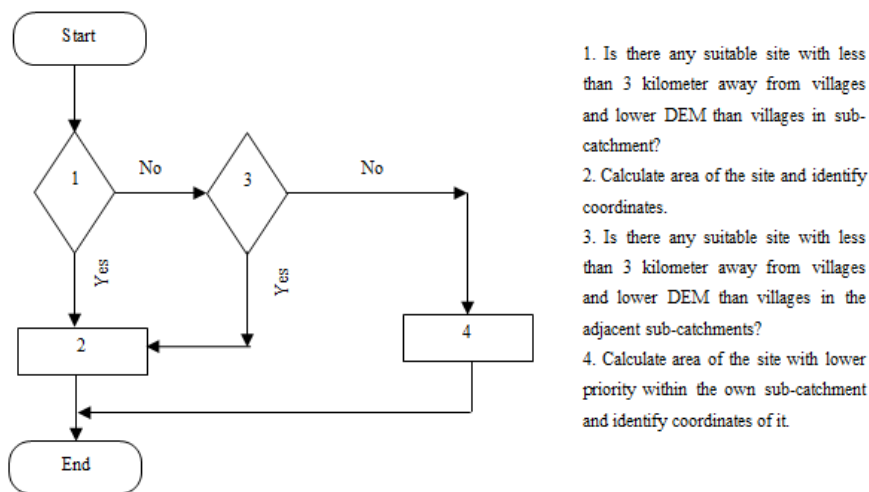


Figure 3: Decision-making Algorithm

1. Is there any suitable site with less than 3 kilometer away from villages and lower DEM than villages in sub-catchment?
2. Calculate area of the site and identify coordinates.
3. Is there any suitable site with less than 3 kilometer away from villages and lower DEM than villages in the adjacent sub-catchments?
4. Calculate area of the site with lower priority within the own sub-catchment and identify coordinates of it.

Table 2: Reclassification of Wastewater Treatment Plant Construction Criteria

Parameter	Class1	Class3	Class5	Class7	Class9
Distance from city and villages (m)	> 6000	0-1000	3000-6000	1500-3000	1000-1500
Distance from wells (m)	< 30	-	-	-	> 30
Distance from protected areas (m)	0-100	100-1000	1000-3000	3000-10000	> 10000
Slope (%)	< 0.3 , > 10	-	-	-	0.3-10
Distance from main roads (m)	0-500	> 10000	5000-10000	3000-5000	500-3000
Distance from power transmission line (m)	< 60	-	-	-	> 60
Distance from receiving waters (rivers) (m)	0-500	> 3000	2000-3000	1000-2000	500-1000
Distance from faults (m)	< 1000	-	-	-	> 1000
Distance from industrial sites (m)	> 6000	0-1000	3000-6000	1500-3000	1000-1500
Distance from water transmission line (m)	< 5	-	-	-	> 5
Distance from oil transmission line (m)	< 25	-	-	-	> 25
Distance from Natural gas transmission line (m)	< 250	-	-	-	> 250

Class 1: worst condition; class 9: optimal condition; (-): no class

Plant transmission pipes should not be passed through flat terrains as it increases the lifting height in treatment plants [26]. Moreover, steep trains require more excavation to construct plants and increase the capital costs [3]. Consequently, slopes of 0.3-10% and more than 10% were classified as the optimal and the worst classes, respectively. In the other studies regarding landfill sites, slops less than 10% [5] and less than 12% [30] have been used, while a proper slope for the site of wastewater treatment plants has been assumed to be 0-2% [3].

Wastewater treatment plants should not be far from or in the proximity of the main roads [26]. Locating the plants far from roads increases the construction and maintenance costs. On the other hand, the presence of wastewater treatment plants in the proximity of roads adversely affects the landscape, climate, and public health [3]. In the current research, the distances of 0-500 and 500-3,000 meters were considered as the worst and optimal classes, respectively. In another study, category one with the distance of 0-500 meters and category four with the distance of 1,500-2,000 meters from the buffer zone were applied [3].

Wastewater treatment plants should not be located inside the safety boundaries of power transmission lines [2]. Based on the regulations in this regard, the safety boundary for high-voltage transmission lines (750 kW) is 60 meters on each side [31]. Based on this data, the distances of less than 60 meters and beyond were considered as the worst and optimal classes, respectively. Since we could not find any other studies regarding power transmission lines as a constraint in the locating of treatment plants, we used the national regulations.

Wastewater treatment plants should have access to the receiving waters, while protecting natural resources [26, 32]. Considering the possibility of flooding, the range of 0-500 meters was considered as the worst class in the present study. On the other hand, distances of more than 1,000 meters are not appropriate in this regard due to the lack of accessibility to receiving waters. In a similar study, distances of 500-3,000 meters have been used for this criterion [32], while this value was assumed to be within the range of 500-1,000 meters as the optimal class in the current research.

Wastewater treatment plants should not be in the proximity of faults [2], and the distance range of 0-2,000 meters has been considered as the danger zone of faults [33]. In the current research, the distance of less than 1,000 meters was considered as the worst class, while the distance of more than 1,000 meters was defined as

theoptimal class. In another study, this value has been estimated at 100-300 meters [3].

Wastewater treatment plants should not be located in industrial areas [26]. In the present study, the distance of less than 500 meters was considered for this criterion as the worst class, while the distance of more than 500 meters was defined as the optimal class. In a similar research regarding landfills, the distance of 500 meters of the buffer zone was applied for industrial areas [34].

Wastewater treatment plants should not be located within the safety boundaries of water, oil, and natural gas transmission lines. In the current research, the safety boundaries of the main water supply pipes (800-1,200 m) [35], oil [36], and natural gas [37] were considered to be five, 25, and 250 meters on each side, respectively. Since the other studies in this regard have not been focused on power transmission lines, we used the national regulations.

In the present study, the land was reclassified based on its use. The urban areas and combination of gardens and trees were also reclassified as class one, while the worn salty lands were defined as class nine. Wastewater treatment plants should not be constructed in valuable lands, such as urban and rural areas, gardens, and surface reservoirs [26, 38]. On the other hand, the worn salty lands that do not have agricultural capability are optimal for the construction of wastewater treatment plants.

In the current research, soil and geological units were reclassified based on their permeability. Due to the high risk of ground water and water well pollution, the geological units and soil with high permeability were deemed improper (worst class), while the geological units and soil with lower permeability were considered proper for the location sites (optimal class) [2]. Table 3 shows the criteria of the pairwise comparison matrix.

In the first row and column of the matrix, the order of the parameters is based on priority, and the priority of the parameters declines in the rows from left to right and in the column from top to bottom. The main diagonal of the matrix is filled with one, and the rows above the main diagonal is valued in a descending manner from right to left, while it is valued reversely underneath. In this matrix, the final weight (percentage) of each parameter is available. According to the information in Table 3, the distance from the city has the highest value (16%), while the distance from the oil and gas transmission pipelines has the lowest value (1%). Table 4 shows the location coordinates of the optimal site of the plants in each complex.

Table 3: Criteria of Pairwise Comparison Matrix of Wastewater Treatment Plant Site

Parameter	distance from city	distance from villages	distance from wells	types of land use	distance from protected areas	slope	distance from major roads	distance from power transmission line	geology permeability	oil permeability	distance from receiving water	distance from faults	distance from industrial areas	distance from water transmission line	distance from oil transmission line	distance from natural gas transmission line	Normalized final weight (%)
City	1	1	2	2	2	3	3	4	5	5	6	7	8	9	9	9	16
Villages	1	1	1	2	2	2	3	3	4	5	5	6	7	8	9	9	14
Wells	1/2	1	1	1	2	2	2	3	3	4	5	5	6	7	8	9	12
Land use	1/2	1/2	1	1	1	2	2	2	3	3	4	5	5	6	7	8	10
Protected areas	1/2	1/2	1/2	1	1	1	2	2	2	3	3	4	5	5	6	7	9
Slope	1/3	1/2	1/2	1/2	1	1	1	2	2	2	3	3	4	5	5	6	8
Major Roads	1/3	1/3	1/2	1/2	1/2	1	1	1	2	2	2	3	3	4	5	5	6
Power	1/4	1/3	1/3	1/2	1/2	1/2	1	1	1	2	2	2	3	3	4	5	5
Geology	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1	1	1	2	2	2	3	3	4	4
Soil	1/5	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1	1	1	2	2	2	3	3	4
Receiving Water	1/6	1/5	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1	1	1	2	2	2	3	3
Faults	1/7	1/6	1/5	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1	1	1	2	2	2	2
Industrial Areas	1/8	1/7	1/6	1/5	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1	1	1	2	2	2
Water	1/9	1/8	1/7	1/6	1/5	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1	1	1	2	2
Oil	1/9	1/9	1/8	1/7	1/6	1/5	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1	1	1	1
Natural Gas	1/9	1/9	1/9	1/8	1/7	1/6	1/5	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1	1	1

Table 4: Location Coordinates of Optimal Wastewater Treatment Plant Site in Each Rural Complex

Number of Sub-Catchment	Number of Complex	Villages in Complex	Location Coordinates (m)		Area of site (m ²)
			X	Y	
1	1	Rajeein, Govalan	219432	4113780	41000
2	8	Qelaychi, Qeytoor	244674	4106834	16781245
2	9	Dash bulaq, Ahmad ababd, Aqje qal'e	251619	4110565	9175901
2	10	Lahargin, Qeble bulaqi	257771	4110565	13923038
3	11	Qarluq, Bahrambeik	254873	4104810	23246248
4	12	Buluq, Arabche, Kordeqeshlaq	251182	4095865	23848295
4	13	Qashqa tape, Orachi, Galje	258128	4098579	8126028
5	14	Baq, jalil abad, Dusraran	258922	4096119	2967058
6	5	Ali abad, Nezam abad, Vala rood (bari)	262890	4068179	4068179
6	15	Taherabad, Golahrood	276926	4076890	9232016
7	16	Cach kolah, Golestaneh, Zaker	294951	4059639	8240725
9	7	Kheir abad, Useph abad, Moshk abad	298965	4044378	5652286
10	17	Alvarloo, Churook sophla	219432	4113780	41000
11	18	Suphi lar, Chap Chap	228904	4102884	9386804
12	2	Eide loo, Chaver, Cohnab (Qahab), Seyph abad	241504	4094351	10730813
13	20	Qare aqaj, Talkhab	242728	4073052	9221308
13	21	Qezal tape bayat, Qezql tape ali qoli	246366	4069447	8622805
14	3	Baqluje sardar, Dulanab	245043	4088993	6729308
14	19	Bezosha, Qare qul	237139	4076425	5297903
15	22	Haji kandi, Agh bulaq hume, Galjik, Ebdal	240611	4065267	5923281
16	23	Haji arash, qare bulaq	246961	4064506	8850476
16	24	Dash kasan, Taze kand zya abad	250302	4066490	6725451
17	4	Amin adad, Chyar	257578	4069864	8992705
18	25	Mehtar, Saqal tuti	261797	4058118	6499649
18	26	Surm ali, Duran	263638	4052297	9852920
18	27	Bayandor, Reyhan, Papayi	265510	4047086	16762580
19	28	Up Dizaj, Zangol abad	271543	4054473	7560104
20	29	Qare tape, Sahle	277575	4052039	7971809
21	6	Noqte bandi, Dizaj abad	283690	4056880	11346401
21	30	Azad sophla, Azad olya, Ramin, qeynarje	280250	4045304	18554507
22	31	Govali, Ardin, Kordenab, Sabzedaraq	284583	4042493	22070612
22	32	Khoramdarraq, Korderaq	286534	4038491	10078795
24	33	Qal'e, Abas abad	300788	4037466	8649126
24	34	Olang, Arjin	297713	4030587	7689747
24	35	Kabud gonbad, Chap dare, Nadir abad (Nader abad), Shalvar (Cheshme sar)	295861	4029165	13744662

According to the results of the present study, the smallest area (41,000 m²) was obtained in complexes one and 17, while the largest area (23,848,295 m²) belonged to complex 12. However, no proper sites were obtained for complex one in its sub-catchment, while complex 17 at the adjacent sub-

catchment contained the proper site. Therefore, a sufficient area was available for the mechanical and natural treatment methods. Figure 4 depicts the complexes and optimal sites, and the selected lands are shown on the map using different colors based on priority.

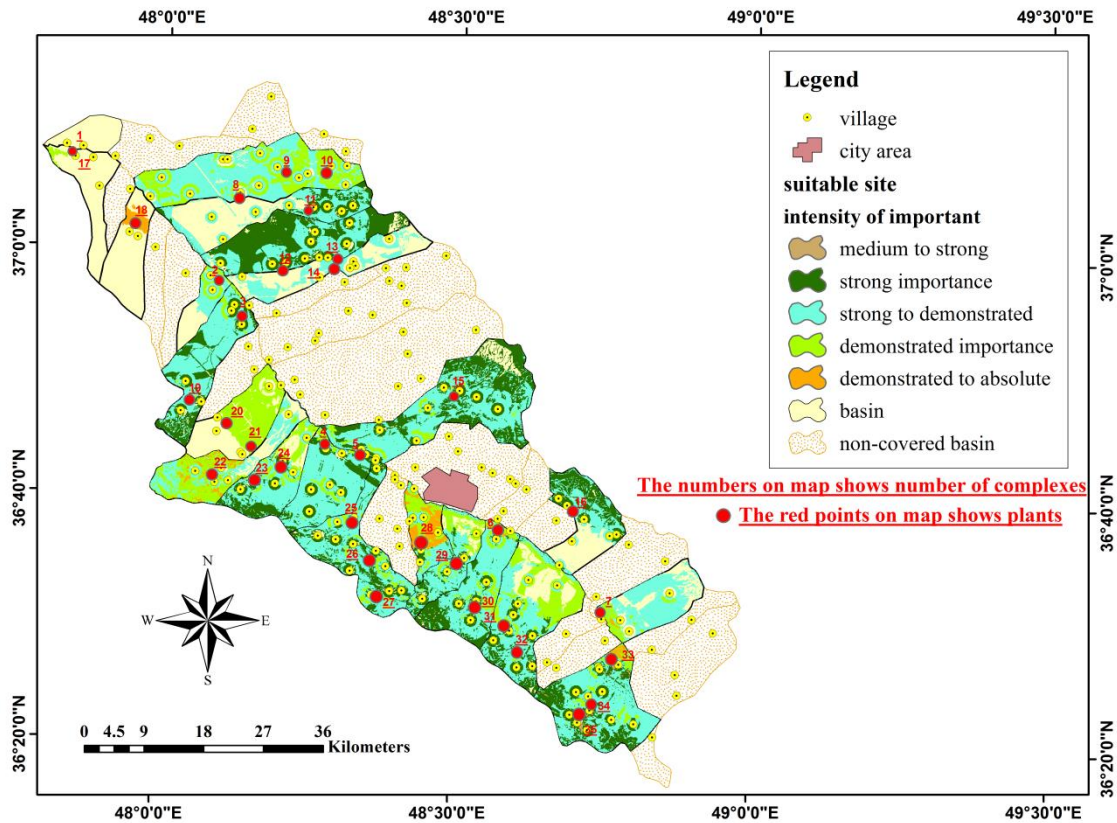


Figure 4: Optimal Site of Wastewater Treatment Plant in Rural Complexes

Zanjanrood catchment consists of 215 villages, 88 of which have the capability to be considered in a particular complex. In the current research, these villages were grouped into 35 complexes based on the criteria mentioned in study area section. The optimal land area for the treatment plant in the rural complexes was calculated to be 41,000-23,848,295 square meters. In each complex, the site was located at the lowest elevation with respect to the villages. Therefore, it was possible to transmit the collected wastewater using gravity. The considered parameters for site selection included the distance from residential areas, direction of the dominant winds, access ways, sufficient land for future development, land use, village layout, agricultural capability, soil type, geology, ground water table, access to receiving waters, land slope, water usage in the downstream, treatment process agreement with the use of the adjacent land, treatment and sludge disposal methods, land acquisition, and access to electricity transmission lines [26].

In the current research, all the mentioned parameters were taken into account, with the exception of the direction of the dominant winds. This parameter was overlooked since the complexes had been located in the vicinity of each other. Irrigation was the type of receiving water consumption in the downstream of all the rural complexes. In the studies in this regard, only some of these parameters have been considered. For instance, in a research conducted in Qeshm island (Iran) aiming to locate the wastewater treatment plant site, the considered criteria were geology, land slope, elevation difference in proportion to the city, vegetation, land use, transportation channel, distance from

the city, and layer boundaries (e.g., river areas, environmental protected areas, populated regions, and power transmission lines) [2]. Due to the specifications of location, other parameters may also be taken into account for site selection, such as temperature, raining, and wind speed [6].

4. Conclusion

Rural complexes were defined in this study, and the proper plant site was selected using the GIS and AHP for all the complexes. According to the results, the area of the proper sites was sufficient for the mechanical and natural methods. Moreover, proper sites were generally located in the downstream of the villages based on legal and safety boundaries. The integration of the GIS and AHP also provided an effective decision-making tool for the selection of appropriate wastewater treatment plant sites in rural complexes. In conclusion, it is recommended that further investigations be conducted to compare site selection using various advanced methods.

Authors' Contributions

This article was carried out by all the authors. M.P., S.T., Y.KH., and M.R.M., designed the manuscript, contributed to carry out, data collection, data analysis and wrote the manuscript.

Conflict of Interest

The Authors declare that there is no conflict of interest.

Acknowledgments

Hereby, we extend our gratitude to Zanjan University of Medical Sciences for the financial and moral support of this research project (grant No. A-12-124-5).

References

- World Health Organization. Drinking-Water. WHO. 2015. Available from: URL: <http://www.who.int/en/>.
- Fallah M, Faraj Zade M, Vaqar Fard H, Nik Kheslat A. Site Selection of Wastewater Treatment Plant Using Topsis and GIS Technique (Case Study: Qeshm Island). *Sarzamin Geogr J*. 2013; 10(37): 18.
- Mansouri Z, Hafezi Moghaddas N, Dahrazma B. Wastewater Treatment Plant Site Selection Using AHP and GIS: A Case Study in Falavarjan, Esfahan. *Geopersia*. 2013; 3(2): 63-72.
- Bahrani S, Ebadati T, Ehsani H, Yousefi H, Maknoon R. Modeling Landfill Site Selection by Multi-Criteria Decision Making and Fuzzy Functions in GIS, Case Study: Shabestar, Iran. *Environ Earth Sci*. 2016; 75(4): 1-14.
- Aydi A, Abichou T, Nasr IH, Louati M, Zairi M. Assessment of Land Suitability for Olive Mill Wastewater Disposal Site Selection by Integrating Fuzzy Logic, AHP, and WLC in a GIS. *Environ Monit Assess*. 2016; 188(1): 1-13.
- Munasinghe D, Pussella P, Gunathilaka M. Integration of GIS and AHP for Suitable Site Selection of Domestic Wastewater Treatment Plant: A Case Study of Akkaraipattu Municipal Council. *Proc Int For Environ Symp*. 2015; 20: 54.
- Deepa K, Krishnaveni M. Suitable Site Selection of Decentralised Treatment Plants Using Multicriteria Approach in GIS. *J Geogr Inf Sys*. 2012; 4(3): 254.
- Chehrehghan A, Rajabi M, Pazoki SH. Developing a Novel Method for Optimum Site Selection Based on Fuzzy Genetic System and GIS. *Int J*. 2013; 3(12): 165-74.
- Andarani P, Budiawan W. Multicriteria Decision Analysis for Optimizing Site Selection of Electronic and Electricity Equipment Waste Dismantling and Sorting Facility (Case Study: In Indonesia, Using AHP). 2015 *Int Conf Sci in Inf Technol (ICSITech)*. IEEE. 2015: 264-9.
- ÇAKIR M, Oral M, AYDIN A. Risk Factors Dependent Optimal Hospital Site Selection by Using ant Colony Optimization Algorithm. *Eng Sci*. 2011; 6(1): 195-208.
- Firouzabadi K, Rad M. Decision Support System for Refinery Site Selection. *Uncertain Supply Chain Manag*. 2014; 2(4): 261-70.
- Ren F. Site Selection Optimization for Thermal Power Plant Based on Rough Set and Multi-Objective Programming. *Adv Mater Res*. 2014; 960: 1501-7.
- Liu XD, Ming L, Huang LW, Sun HL. Research on Anchorage Location Selection in the Yangtze River Based on Multi-Objective Optimization. *Appl Mech Mater*. 2015; 738: 519.
- Ghasemi A, Saghafian B, Golian S. Optimal Location of Artificial Recharge of Treated Wastewater Using Fuzzy Logic Approach. *J Water Supply: Res Technol-Aqua*. 2017; 66(3): 141-56.
- Francisque A, Rodriguez MJ, Sadiq R, Miranda LF, Proulx F. Prioritizing Monitoring Locations in a Water Distribution Network: a Fuzzy Risk Approach. *J Water Supply: Res Technol-Aqua*. 2009; 58(7): 488-509.
- Hosseini Moghari SM, Araghinejad S, Azarnivand A. Fuzzy Analytic Hierarchy Process Approach in Drought Management: Case Study of Gorganrood Basin, Iran. *J Water Supply: Res Technol-Aqua*. 2017; 66(3): 207-18.
- Sargaonkar A, Nema S, Gupta A, Sengupta A. Risk Assessment Study for Water Supply Network Using GIS. *J Water Supply: Res Technol-Aqua*. 2010; 59(5): 355-60.
- Danner M, Hummel JM, Volz F, Van Manen JG, Wiegard B, Dintsios CM, et al. Integrating Patients' Views into Health Technology Assessment: Analytic Hierarchy Process (AHP) as a Method to Elicit Patient Preferences. *Int J Technol Assess Health Care*. 2011; 27(4): 369-75.
- Şener Ş, Şener E, Karagüzel R. Solid Waste Disposal Site Selection with GIS and AHP Methodology: A Case Study in Senirkent-Üluberlu (Isparta) Basin, Turkey. *Environ Monit Assess*. 2011; 173(1-4): 533-54.
- Bunruamkaew K, Murayam Y. Site Suitability Evaluation for Ecotourism Using GIS & AHP: A Case Study of Surat Thani Province, Thailand. *Procedia Soc Behav Sci*. 2011; 21: 269-78.
- Uyan M. MSW landfill Site Selection by Combining AHP with GIS for Konya, Turkey. *Environ Earth Sci*. 2014; 71(4): 1629-39.
- Saaty TL. The Analytic Hierarchy Process. *New York: McGraw-Hill*; 1980.
- Kalantari M, Qezelbash S, Khosravi Y. Analysis of Type and amount of Accessing to Tourism Infrastructure Using Analytic Hierarchy Process Case Study: Soltaniyeh, Qyidar, Katalahkhor. *Iran Conf Geogr Sci*. 2014.
- Zou X, Li D, Li Q, Chen S, Xu A. A Multidisciplinary GIS-based Approach for the Potential Evaluation of Land Consolidation Projects: a Model and its Application. *WSEAS Int Conf Proc Comput Sci Eng; World Sci Eng Acad Society*. 2008; 7: 551-6.
- Chakraborty S, Banik D. Design of a Material Handling Equipment Selection Model Using Analytic Hierarchy Process. *Int J Adv Manuf Technol*. 2006; 28(11-12): 1237-45.
- Management and Planning Organization-Ministry of Energy. Regulations of Technical Review and Approval of Municipal Wastewater Treatment Projects Publication 129-3. *Manag Plan Organization Ministry Energy*. 1993; 72/00/53.
- Gomez Ruiz JA, Karanik M, Peláez JI. Estimation of Missing Judgments in AHP Pairwise Matrices Using a Neural Network-based Model. *Appl Math Comput*. 2010; 216(10): 2959-75.
- Ministry of Energy Department of Water and Wastewater Affairs Office of Engineering and Technical Criteria for Water and Wastewater. Principles and Criteria for Design of Wastewater and Surface Water Networks (Revision of 118-3 and 163 Publications). *Ministry Energy Department Water Wastewater Aff Office Eng Tech Criteria Water Wastewater*. 2014; A-425.
- Ministry of Energy. Law of Water Section Part of Law about Stream, Ghanat, Spring and Boundry Zone. *Ministry Energy*. [2016/9/3]. Available from: URL: <http://law.moe.gov.ir>.
- Chang N, Parvathinathan G, Breeden JB. Combining GIS with Fuzzy Multicriteria Decision-Making for Landfill Siting in a Fast-Growing Urban Region. *J Environ Manag*. 2008; 87: 139-53.
- National Geoscience Database of Iran. Low of Geographical Features Boundry. *Boundry of Electric Transmission and Distribution Line*. 2006 [cited 2015 2015/7/1]. Available from: URL: <http://www.ngdir.ir/GeoportalInfo/PSubjectInfoDetail.asp?PID=803&index=3>.
- Shahmoradi B, Isalou AA. Site Selection for Wastewater Treatment Plant Using Integrated Fuzzy Logic and Multicriteria Decision Model: A Case Study in Kahak, Iran. *J Adv Environ Health Res*. 2013; 1(1): 51-61.
- National Geoscience Database of Iran. Earthquake Fault in West Section of Hemmat Highway. *National Geosci Database Iran*. 2008 [2015/7/1]. Available from: URL: <http://www.ngdir.ir/GeoportalInfo/PSubjectInfoDetail.asp?PID=1337&index=29>.
- Wang G, Qin L, Li G, Chen L. Landfill Site Selection Using Spatial Information Technologies and AHP: A Case Study in Beijing, China. *J Environ Manag*. 2009; 90: 2414-21.
- National Geoscience Database of Iran. Low of Geographical Features Boundry. *Boundry of Water Resource*. 2006 [2015/7/1]. Available from: URL: <http://www.ngdir.ir/GeoportalInfo/PSubjectInfoDetail.asp?PID=803&index=5>.
- Ministry of Petroleum. Safe Boundry of Petroleum Pipelines. *Ministry Petroleum*. 2014: 692.
- Islamic Parliament Research Center. Low of Safety Boundry for Natural Gas Lines, Iran. *Islam Parliam Res Center*. 2014 [2016/9/3]. Available from: URL: <http://rc.majlis.ir/fa/law/show/96646>.
- Islamic Republic News Agency. Constructure Prohibition in Agricultural Lands. *Islam Parliam Res Center*. 2016 [2016/8/29]. Available from: URL: <http://www8.irna.ir/fa/News/81091925/>.