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Evolution Site Selection by Using an Analytical Hierarchy Process for Decentralized Wastewater Treatment Plants in the City of Qom, Iran

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ABSTRACT

Introduction: Decentralized wastewater treatment facilities are an expensive approach for developing countries. Decentralized wastewater treatment plants (DWWTPs) are a flexible technology. They have low construction and operational costs. Site selection is the most significant stage in the implementation of a $DWWTP_S$. Therefore, the present study aimed to perform a site selection among the proposed locations for a $DWWTP_S$ in Qom.

Materials and Methods: In this experimental study, the criteria of $DWWTP_S$ site selection were determined, judged by interview experts, and analyzed by the analytic hierarchy process (AHP) using the Expert Choice 11 software. Finally, according to the performed judgments, the proposed locations (sites) were ranked in order of preference.

Results: The slope of the land held maximum importance, while the density of the population had minimum importance in the site selection process. The southern and north-eastern regions of Qom had appropriate sites.

Conclusion: The AHP is a decision analysis method that considers both the qualitative and quantitative information applicable for the various subjects, especially site selection. In this study, according to the expert's notices, the AHP technique could determine an appropriate site among the proposed locations for the construction of $DWWTP_S$.

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Introduction

Water resource limitations, increasing water demands, and the occurrence of frequent droughts have served as warnings to implement water saving programs and efficiently manage the available water supply in many countries [1]. With a share of 92 percent water consumption in agriculture, Iran is the greatest consumer of agricultural water in countries of the Middle East and North Africa (MENA) region [2]. Qom, a city located in a low-precipitation area, has dry weather and suffers from a shortage of suitable surface and groundwater resources. This calls for judicious management of the water and wastewater resources [3]. Therefore, the reuse of treated wastewater in agriculture will provide the supplementary water

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resource for irrigation [4, 5]. According to research by the United States Environmental Protection Agency's (USEPA),decentralized wastewater treatment plants (DWWTPs) area suitable approach for areas with low-density populations and residential townships; they are more cost-effective than centralized wastewater treatment plants [6]. In Qom, the issue of DWWTP application is followed up as an urban management approach [7, 8]. Site selection is one of the most significant stages in the implementation of a DWWTP in order to prevent adverse effects on the environment and on public health [9]. Generally, the analytic hierarchy process (AHP) is utilized in the decision-making process that was developed by Prof. Saaty (1990) [10]. This technique examines complex issues based on their interactions and converts them into a simple form. Therefore, the aim of the study is to choose the best site among the proposed sites for DWWTPs using AHP in the metropolitan of Qom.

Study Area

The study area is Qom. The geographic coordinates of Qom are34°38.406′ N latitude and 50°52.584′ E longitude (Figure 1). Qom is located in the central desert of Iran and has historically suffered from water scarcity problems. The water shortage and the unavailability of suitable potable water resources has been the most critical problem of this city for many years. The annual precipitation rate for Qom province is about 135 millimeters with an extremely high evaporation rate owing to the desert conditions [11]. Human immigration to this city has grown considerably in the last two decades, leading to an increase in water consumption.

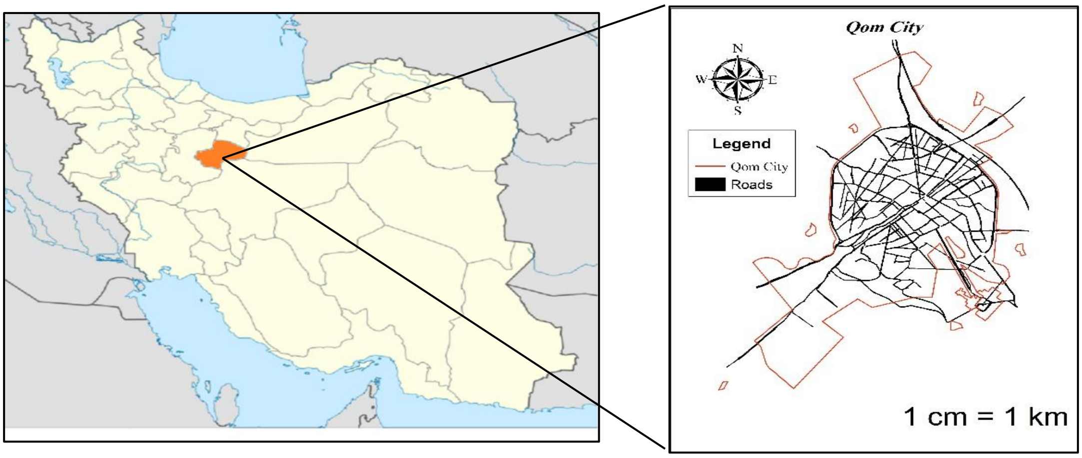

Figure 1: Location of Qom city

This city has an area of approximately 530 square kilometers with a uniform slope to the south and the west. The population was about 1,100,000 in 2013 with an annual growth rate of 1.03%. In Qom, there are important places such as the Holy Shrine and the great mosque, which annually host numerous tourists. The agricultural lands are mostly distributed in the east and south-east regions of the city. This city has a seasonal river called Qom rood, which is not a suitable site for disposing of the effluents from the wastewater treatment plants. In Qom, approximately 30 percent of wastewater collection networks was done, which was implemented mainly in the city's central zone. Therefore, due to its high population density and the defined land use of the city center, this area was unsuitable for the site selection.

Materials and Methods

Identification and selection of criteria and sub-criteria

Five sites had been proposed by the municipality for the construction of the DWWTPs. The proposed sites are shown in Figure 2. A30-member team comprising experts in water and wastewater

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engineering, geography, urban management, and environmental health science was formed. The team of experts selected the criteria and sub-criteria as follows: (A) population density, (B) land slope, (C) land use, and (D) reuse, with regard to the environmental, economic, and social conditions of Qom.

The criteria are defined as follows: 1) reuse refers to the distance of the proposed sites from the areas with potential reuse, 2) slope refers to the slope in the proposed sites, 3) land use refers to the type of land use appointed by the government, and 4) density refers to the population density in the proposed sites.

By carrying out an interview with the expert team, the population density was classified as follows: *high density* refers to 130–180 people in each hectare, *moderate density* refers to 80–130 people in each hectare, and *low density* refers to fewer than 80 people in each hectare.

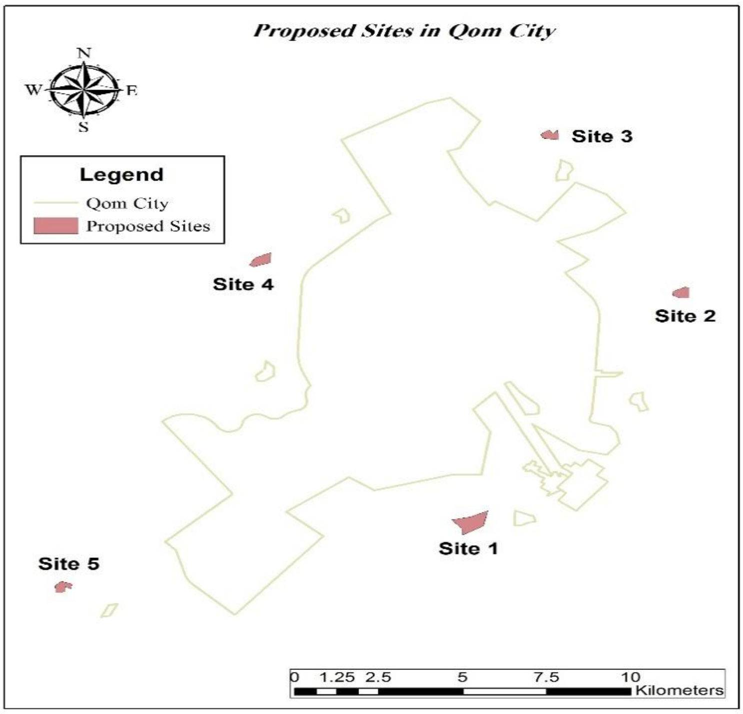

Figure 2: The proposed sites to construct the DWWTPs in Qom

Building a Hierarchical Structure

Nowadays, different decision making techniques can be used to optimize the selection of the ideal location for the industrial units [12, 13]. Building the hierarchical structure is an important part of the AHP [14]. Figure 3 shows the hierarchical structure of the criteria in this study.

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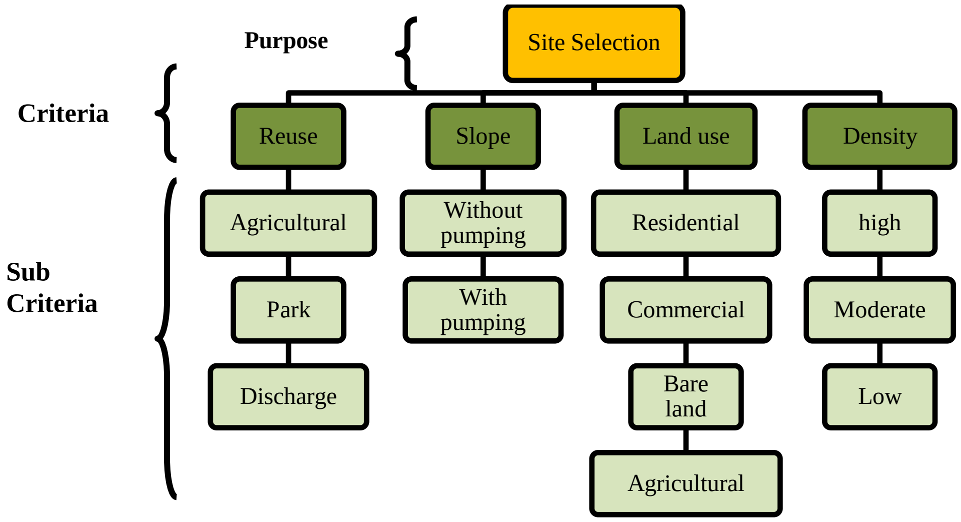

Figure 3: Hierarchical structure of the criteria and sub-criteria

Weighting for Criteria and Sub-Criteria

One of the most important and difficult stages of the multi-criteria decision process is weighting the criteria, which can be established as a considerable uncertainty in the decision-making process [15]. A common problem in the multi-criteria decision-making is the varying importance of the criteria for the decision-makers. Therefore, to determine the importance (weight) of each criterion, a pair-wise comparison was performed by the experts 'team. The pair-wise comparisons were assigned by Saaty's method, as shown in Table 1.

Table 1: The comparison scale in AHP (Satya's method)

Grade of importance	Definition	Explanation
1	Same importance	Two elements are equally important.
3	Relatively more important	An element is slightly more important than the other.
5	Some more important	An element is more important than the other.
7	Very more important	An element has a much higher importance than the other. Its importance is demonstrated in the observations.
9	Enormously important	All evidence shows preference for one element over the other. Maximum potential validity.
2, 4, 6, 8	Intermediate values	When conciliation is required.

Pair-wise comparison of the proposed sites for each criterion (scoring)

At this stage, the preference for each site in relation to each other and the sub-criteria were assessed and judged. This judgment was based on Satya's quantitative nine-point scale [14] (Table 1). For the comparison of the elements in the pairs, it was required that they are homogeneous or close with respect to the common attribute; otherwise, significant errors may be introduced in the measurement process.

Obtaining a final score (priority) for the sites

In a final step, the site scores user combined with the criterion weights to produce a final score for each site. The extent to which the sites satisfy the criteria is weighted according to the relative importance of the criteria. After this stage, the judgments of the criteria and sub-criteria in relation to the aim of this study, as well as the judgments (weight) of the sites in relation to each of the criteria and sub-criteria, were assessed and judged. The final scores (weight) of the sites were

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calculated according to the principle of the hierarchic structure. This principle leads to a “priority vector” with a consideration of all the judgments into all of the hierarchical stages**.** One of the AHP’s benefits is its capability to manage the compatibility decisions. The matrix inconsistency rate (IR) is achieved by using the inconsistency index (II) and the random inconsistency index (RII) [10].

IR = II / RII

The elements of the normalized eigenvector were weighted and classified with respect to the criteria or sub-criteria. In general, the acceptable level of inconsistency in a matrix or a system depends on the decision-maker. However, Saaty offered value of 0.1 as an acceptable quantity and believed that if the inconsistency rate exceeds 0.1, then a better judgment cannot be obtained.

All of the above four stages were conducted using the Expert Choice 11 software. Saaty suggested this software for multi-criteria decision-making.

Results

In the present study, the amount of IR is 0.1, which represented the acceptable level of decision-making.

The comparison matrices for the criteria and sub criteria in Expert Choice 11 are shown in Tables 2, 3, 4, and 5. These matrices were used based on the experts’ judgments.

The pair-wise comparisons that have been shown in Table 2 determined the importance of the criteria in the site selection for the DWWTPs. As shown in Table 2, the slope achieved the maximum importance in the site-selection process, while population density achieved the minimum importance in the site-selection process.

	Reuse	Slope	Land use	Density
Reuse		(7.0)	5.0	5.0
Slope			6.0	6.0
Land use				3.0
Density	Incon: 0.21			

Table 2: Compare the relative importance with respect to site selection

According to the judgment of the experts, the effluent discharge to acceptor resources has the maximum priority in the site-selection process in Qom (Table 3).

	Agricultura	Green Area	Discharge
Agricultural		3.0	(5.0)
Green Area			(3.0)
Discharge	Incon: 0.28		

Table 3: Compare the relative importance with respect to reuse

As shown in Table 4, the best land for constructing a DWWTPs was bare ground that has no other application.

	Residential	Commerica	Bayer	Agricultura
Residential		1.0	(7.0)	(3.0)
Commerical			(9.0)	(3.0)
Bayer				7.0
Agricultural	Incon: 0.05			

Table 4: Compare the relative importance with respect to land use

A dense population will produce a high amount of wastewater that DWWTPs will not be able accept, as this is a large amount of wastewater flow. Therefore, according to Table 5, the experts in Qom believed that the areas with a low population density have a higher priority for the construction of a DWWTPs.

	High	Moderate	Low
High		(5.0)	(7.0)
Moderate			(5.0)
Low	Incon: 0.17		

Table 5: Compare the relative importance with respect to population density

According to the effluent information of the Expert Choice software, the prioritized sites are shown in Figure 4.

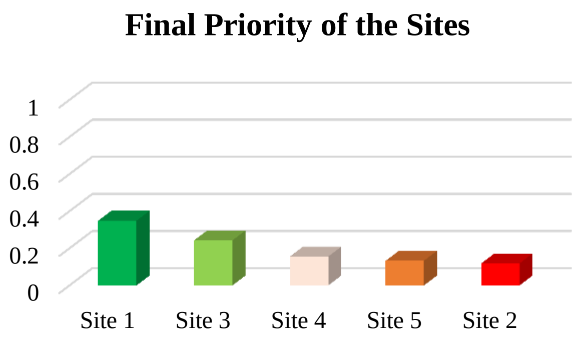

Figure 4: Final priority for the proposed sitesforthe DWWTPs

Site 1 is the first priority with a score of 0.349, Site 3 is the second priority with a score of 0.243, and Site 4 with a score of 0.156 is a tertiary priority. The prioritization of the sites is shown in the map of Qom in Figure 5.

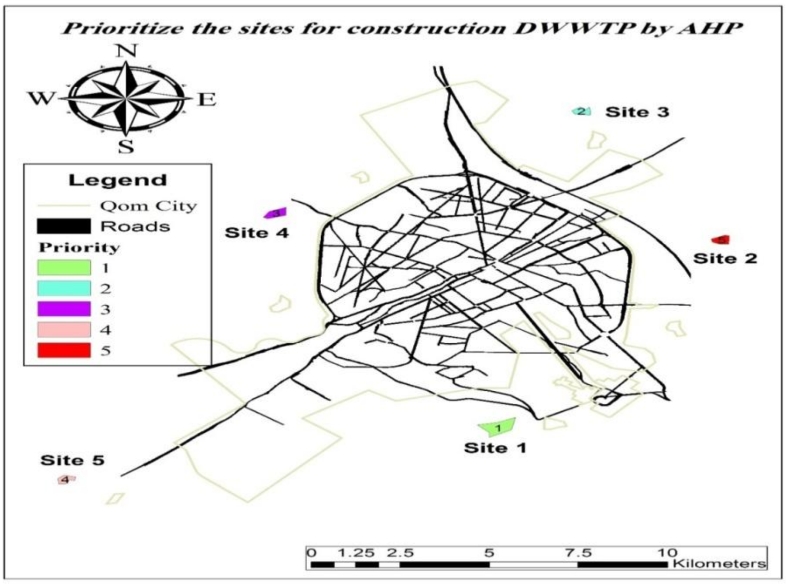

Figure 5: Final map of priority for the proposed sites

Discussion

In the studies in which the AHP method has been used for the selection of proper alternatives, there are several terms such as goals, criteria, alternative choices, and weight of importance level [16]. In the present study, we used the best priorities of the proposed sites for the construction of the DWWTPs as the main goal of this study. Furthermore, the population density, land slope, land use, and type of reuse as the criteria of study for determined of the proposed sites and the construction of DWWTPs. In the literature, the site-selection studies were classified in two classes. Some of them were studies that were conducted based on previous proposed sites [17], while the other studies were conducted based on the exploration and selection of a proper site [18]. In many studies that were done by the selection of proper sites for wastewater facilities, land slope, type of reuse, population, and land use were considered as the main criteria according to the experts' opinions [19]. These criteria covered comprehensive issues in the economic, social, and environmental areas. In the present study, the panel of experts has selected these criteria. In the study of Aydi et al, slope and land use were used as the criteria for selecting the olive mill wastewater disposal site [20]. Slope is a significant criterion when selecting a DWWTPs site since higher slopes would decrease the cost of wastewater transfer to the wastewater facilities site [21]. The selection of land use as a criterion in site selection holds importance in improving the public conflict situation. In the real world, the low-importance of land use in public judgment creates less struggle for DWWTPs sites and greater acceptance for high-importance land use. The proposed sites are shown in Figure 9. According to this figure; the southern and north-eastern regions of Qom are suitable for the construction of a DWWTPs. Considering the uniformity in slope in the city and based on the location of the proposed sites to the studied criteria, the expert judgments were appropriate and rational. The options for Proposed Site 1 were many agricultural lands, as well as bare ground. These existing conditions have been the responsible for the advantages of the site. Proposed Site 3 has a seasonal river (Qom rood) and a low population density. These factors are responsible for the selection of this site.

Conclusion

This paper was conducted by using the AHP method as a proper technique of multi-criteria decision-making to select an important location for the construction of the DWWTPs. AHP created a structured baseline for continuously improving decision-making processes for the selection of a proper site for the DWWTPs. This can be due to the participation of the experts and the managers in the determination of criteria and sub-criteria. In this study, we tried to select suitable criteria proportional to Qom’s situation. The AHP method provides an easy approach to check the various criteria. Owing to low available data, further attention to the opinions of the experts is necessary in dealing with the multiple-criteria decision-making problems.

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Conflict of interest

The authors declare that they have no competing interests.

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