

Article

# Landfill Site Selection Using a Multi-Criteria Decision-Making Method: A Case Study of the Salafcheghan Special Economic Zone, Iran

Hossein Yousefi <sup>1</sup>, Zahra Javadzadeh <sup>1</sup>, Younes Noorollahi <sup>1</sup>  and Amin Yousefi-Sahzabi <sup>2,3,\*</sup>

<sup>1</sup> Department of Renewable Energies and Environmental Engineering, Faculty of New Sciences and Technologies, University of Tehran, Tehran, Iran; hosseinyousefi@ut.ac.ir (H.Y.); zahra.javadzade@ut.ac.ir (Z.J.); noorollahi@ut.ac.ir (Y.N.)

<sup>2</sup> Department for Management of Science and Technology Development, Ton Duc Thang University, Ho Chi Minh City, Vietnam

<sup>3</sup> Faculty of Environment and Labour Safety, Ton Duc Thang University, Ho Chi Minh City, Vietnam

\* Correspondence: amin@tdt.edu.vn

Received: 12 March 2018; Accepted: 3 April 2018; Published: 8 April 2018



**Abstract:** Sustainable waste management, particularly in industrial areas, is one of the major challenges of developing countries. Among the important issues in the overall process of industrial wastes management is the necessity of suitable site selection for waste disposal. Considering the effects that the disposal sites exert on their surrounding ecosystem and environment, these sites should be located in places with the minimum destructive effects and the lowest environmental impacts. The aim of this research is to outline important criteria for industrial zone waste disposal site selection and to select optimal and proper disposal sites in the Salafcheghan special economic zone. This region, as one of the most important industrial areas and closest to the country's political-economic center, enjoys a privileged and unique position for producing, exporting, and transiting goods and products. There are various parameters involved in the optimal selection of suitable industrial waste disposal sites. In this case study, issues such as the depth of groundwater, distance from surface- and groundwater, access routes, residential areas, industries, power transmission lines, flood-proneness, faults, slope, and distance from gardens and agricultural lands were taken into account. Following selection and preparation of the maps related to the influential parameters, assigning weights was done through the Analytical Hierarchy Process (AHP) and using expert comments. At this stage, the maps and weights related to them were introduced into an index overlay model to obtain new maps from combining the influential parameters. Thereafter, the areas with the first and second priorities were selected and out of each one, four sites were suggested for disposing of industrial wastes. The sites with the first and second priorities were specified as A1, A2, A3, and A4 and B1, B2, B3, and B4, respectively. The area, groundwater depth, distance from residential areas, distance from the Salafcheghan special economic zone, the direction of the predominant wind, and the land use of the selected sites were also investigated.

**Keywords:** site selection; industrial waste; geographical information system (GIS); index overlay; analytical hierarchy process (AHP)

## 1. Introduction

The growth of population and in turn increased number of industrial units have resulted in a significant increase in the volume of wastes, especially industrial wastes. Currently, one of the most important environmental challenges of many developing countries, including Iran, is disposing of hazardous wastes in a sustainable way with minimum undesirable effects on natural resources,

especially water and soil. Historically, sustainable waste disposal has been a main concern in both developed and developing countries. Starting from 1980, with recognition of the adverse effects caused by unsystematic disposal of wastes in the environment, industrial countries commenced the implementation of extensive regulations for controlling hazardous and toxic compounds. The first regulations related to controlling hazardous and toxic materials have been implemented in the member countries of the European Economic Community (EEC) as well as the Organization for Economic Cooperation and Development (OECD). In 1987, the United Nations Environment Program (UNEP) approved the principles and policies of management of hazardous wastes, followed by signing the Basel Treaty (in Switzerland) to control international transportation of such wastes by 35 participating countries. Currently, the majority of the world's countries, including Iran, (since 1992) have joined this convention [1,2]. There are various models and methods involved in waste disposal, where the final goal is to find the most suitable site that has the lowest environmental impacts on the natural environment surrounding the disposal zone [3].

There is a growing need for well-developed environmental information systems to facilitate the flow of environmental information from data sources to decision-makers [4]. In recent years, ArcGIS software has developed an undeniable transformation in the environmental decision-making process [5–8]. It has transformed the organization and management of spatial data and has opened new horizons ahead of scientists and engineers [9]. Using traditional methods of site selection for industrial waste disposal, which involves in combining several data layers, could take a long time and result in the incidence of errors. The application of GIS science and technology in studies related to industrial waste disposal can highly accelerate the preparation and combination of different data layers in the form of different conceptual models. Given the type of combination theory in these models, the number of data layers and the value of each layer in the combination will be different. Examples of these models are the Boolean logic model, the weight of evidence model, the index overlay model, fuzzy logic, and the weighted linear combination model.

From 1950 with the emergence of GIS, Multi-Criteria Decision-Making (MCDM) methods have been used as essential tools to assist decision-makers [10]. MCDM includes steps for assigning values to alternatives that are analyzed for a specific purpose [11,12]. MCDM methods, including Analytic Network Process (ANP), Analytic Hierarchical Process (AHP), Simple Additive Method (SAM), Weighted Linear Combination (WLC), and fuzzy logic, have widely been used in landfill site selection [13]. Several studies have been conducted for site selection and disposal of solid wastes by applying Multi-Criteria Decision Analysis (MCDA) using GIS [14–22]. In a recent study, Chabuk et al. [23] combined multi-criteria decision-making and GIS applications for landfill siting in Al-Hashimiyah Qadhaa, Babylon, Iraq. They identified two suitable candidate landfill sites in their study area with a capacity to accommodate solid waste from 2020 to 2030. Korucu and Erdagi [24] expressed that municipal solid waste disposal has two main problems: the selection of a disposal method and the selection of a disposing site. Salman Mahini and Gholamalifard [25] and Moeinaddini et al. [26] carried out weighted overlay landfill site selection using the Weighted Linear Combination (WLC) method. Bottero et al. [27] applied the analytical hierarchy process and analytical network process in a landfill site selection study. Pandey et al. [28] used an expert-based ranking method for the selection of a municipal solid waste landfill site in Bhagalpur, India. Moghaddas and Namaghi [29] used a ranking method to find suitable hazardous waste landfill sites in the Khorasan Razavi Province of Iran. Isalou et al. [30] deployed fuzzy logic integrated into Analytical Network Process (ANP) in another region of Iran. Their findings demonstrated that the integration of fuzzy logic and ANP can define the site more suitably than applying them distinctly. Arkoc [31] used a combination of a constraint overlaying method and a point count index for municipal solid waste landfill site selection in the Çorlu District of Turkey. Gorsevski et al. [32] performed landfill site selection suitability evaluations in the Polog Region of Macedonia using a GIS-based multi-criteria decision analysis approach. Feo and Gisi [33] used AHP and an innovative criteria weighting tool for easier identification of the priorities of the evaluation criteria for hazardous waste landfill siting.

The aim of this research is optimal selection of suitable sites for disposing of industrial wastes in the Salafchegan special economic zone. This region, which is one of the important industrial centers in Iran, is located 185 km away from Tehran capital city and spans an area of 2000 hectares. Due to the higher groundwater level in the region, preliminary data, including topography of the selected site and possible environmental damages, such as groundwater contamination, as well as soil and water maps have been developed. Accordingly, proper site selection for the healthy disposal of industrial wastes considering the influencing parameters was carried out. This is the first study investigating industrial landfill sites' suitability using GIS-MCDM in the area, and the importance of Salafchegan special economic zone in terms of employment, stabilization of population, services, and infrastructures [34] as well as its proximity to major political, economic, and population centers indicates the significance of this research.

*Study Area*

Qom Province, with an area of 11,526 km<sup>2</sup>, is located between 34°15' and 35°15' of the northern latitude in relation to the equator and 50°30' to 51°30' of the eastern longitude in relation to the Greenwich meridian in the central part of Iran. The area of Qom accounts for 0.7% of the entire country's area. The Salafchegan special economic zone is situated in the southwest of Salafchegan County. The relational position of the Salafchegan region and its proximity to Qom as well as important meta-provincial industrial centers, such as Saveh, Tehran, Arak, and Isfahan, have caused the Salafchegan region to enjoy a suitable position for establishing the province's industries. Figure 1 shows the location map of the study area.

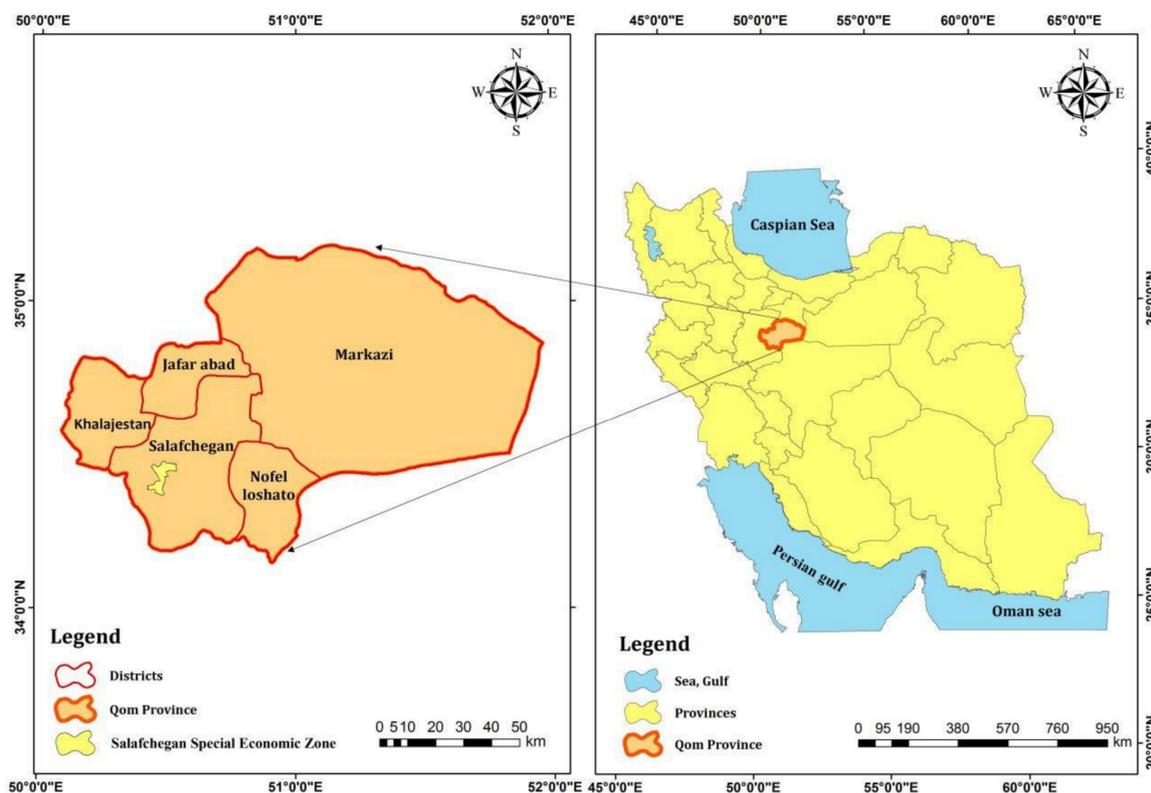


Figure 1. Location map of the study area.

## 2. Data and Methods

### 2.1. Data Collection, Preparation, and Weighting

Methodology implies the presentation of skills and experiences that make goal achievement easier and more feasible, whereby within a shorter time, more results are obtained. The method used in this research includes the identification and selection of general criteria and factors of every criterion, determination of the classes of every factor, and weighting and prioritizing the factors and their classes to select suitable hazardous solid waste. It also includes the preparation of factor maps using the defined classes followed by map overlaying and eventually the specification of suitable sites for the disposal of industrial wastes.

To obtain the criteria and factors affecting the optimal selection of suitable sites for disposing industrial wastes, firstly, different criteria and factors, which are used for the selection of similar sites by various national and international studies, were evaluated. Thereafter, expert comments from regional authorities, the Department of Environment, the Qom Province Regional Water Company, and university professors were obtained. To classify each of the factors, different standards presented by Iran's Department of Environment, the Management and Planning Organization of Iran, and the Natural Resources and Watershed Management Department of Tehran Province were used (Table 1). To overlay the maps and combine the factor maps, an index overlay method was used. In this model, in addition to giving weight to data layers, the units present in every data layer have a special weight according to their potential. In this method, in order to combine the factor maps (multi-class maps), Equation (1) was employed [35,36].

$$S_j = \frac{\sum w_i s_{ij}}{\sum w_i} \quad (1)$$

where  $W_i$  is the weight of the  $i_{th}$  map,  $S_{ij}$  represents the weight of the  $j_{th}$  class of the  $i_{th}$  map, and  $S_j$  shows the weight of the  $j_{th}$  class in the output map.

For valuation of the criteria, different methods, such as weight of evidence, the Delphi process, ratio estimation, logistic regression, and Analytical Hierarchy Process (AHP), could be selected. AHP is one of the most efficient decision-making techniques, and was first propounded by Thomas Saaty [37]. This analytical method is one of the most comprehensive systems designed for multi-criteria decision-making, as it provides the possibility for formulating problems in a hierarchical fashion [38]. AHP's main characteristic is based on paired comparisons. It helps to break down a complex problem with multiple criteria into a number of one-to-one comparisons [39]. This method is a powerful and flexible tool for quantitative and qualitative investigation of multi-criteria problems [40]. For this reason, to give value to the criteria and select a suitable place, the AHP model was used in this study. The integration of a GIS and AHP significantly facilitates the decision-making process [41,42].

**Table 1.** Classification of factors, criteria, and sub-criteria according to standard methods of site selection.

Factors	Criteria	Sub-Criteria	Description	Reference
Physical	Floodway (m)	<80	Less-suitable	[43]
		80–160	Suitable	
		>160	Highly-suitable	
	Surface waters (m)	<1000	Less-suitable	[43]
1000–2000		Suitable		
>2000		Highly-suitable		
Fault (m)		<200	Less-suitable	[43]
		200–1000	Suitable	
		>1000	Highly-suitable	
Slope (%)		<2, >20	Less-suitable	[44]
		2–10	Highly-suitable	
		10–20	Suitable	

Table 1. Cont.

Factors	Criteria	Sub-Criteria	Description	Reference
Technical-operational	Groundwater depth (m)	<10	Less-suitable	[44]
		10–20	Suitable	
		>20	Highly-suitable	
Technical-operational	Groundwater (m)	<400	Less-suitable	[45]
		400–800	Suitable	
		>800	Highly-suitable	
Technical-operational	Access roads (m)	<300	Less-suitable	[45]
		>300	Highly-suitable	
Social-economical	Residential areas (m)	<1000	Less-suitable	[43]
		1000–3000	Suitable	
		>3000	Highly-suitable	
	Industries (m)	<1000	Less-suitable	[43]
		1000–1500	Suitable	
	>1500	Highly-suitable		
Social-economical	Power lines (m)	<200	Less-suitable	[46]
		>200	Highly-suitable	
Social-economical	Orchards and agricultural lands (m)	<300	Less-suitable	[43]
		>300	Highly-suitable	

The steps of research include collection of required data, processing and preparation of the data, analyzing factor maps, assigning weight to the factor maps using the AHP method, overlaying and combining the factor maps using the index overlay method, selection of suitable sites for disposal of industrial wastes, and validation of the results.

Considering the criteria determined by different methods, as shown in Table 1, the information, digital maps, and data related to every criterion were requested and purchased from relevant organizations, including the National Cartographic Center of Iran (NCC), the Qom Province Regional Water Company, and the Geological Survey of Iran (GSI).

Since the data used in different organizations and companies are developed and compiled for particular applications, they have different formats and scales, and use different projection systems. Considering the objective of the current study and the required accuracy, those data were converted into an appropriate format, scale, and projection system so that all could be used in the defined conceptual model to obtain reliable results. This included the following processes:

1. Conversion of the projection system of all maps into Universal Transverse Mercator (UTM Zone 39 N)
2. Unification of identical land use in the land use map
3. Separation of information considering the studied range (clip)

#### 2.1.1. Preparation of Factor Maps

Several factors should be taken into account for site selection of industrial landfills. For site selection in GIS systems, map layers of effective factors, criteria, and constraints should be processed and analyzed. In this research, the following steps were taken for the preparation of factor maps (Figure 2):

1. Rasterizing the format of input maps: the vector maps of polygon, point, and line type were rasterized by the Path Distance function. However, polygon-type maps were rasterized using the direct command for polygons.
2. Reclassification: At this stage, rasterized maps were classified using the Reclassify tool while considering the classes determined in Table 3.
3. In order to prepare a slope factor map using contour lines, the slope command was used. Further, using Radial Basis Functions (RBF), the factor map of groundwater depth was prepared.

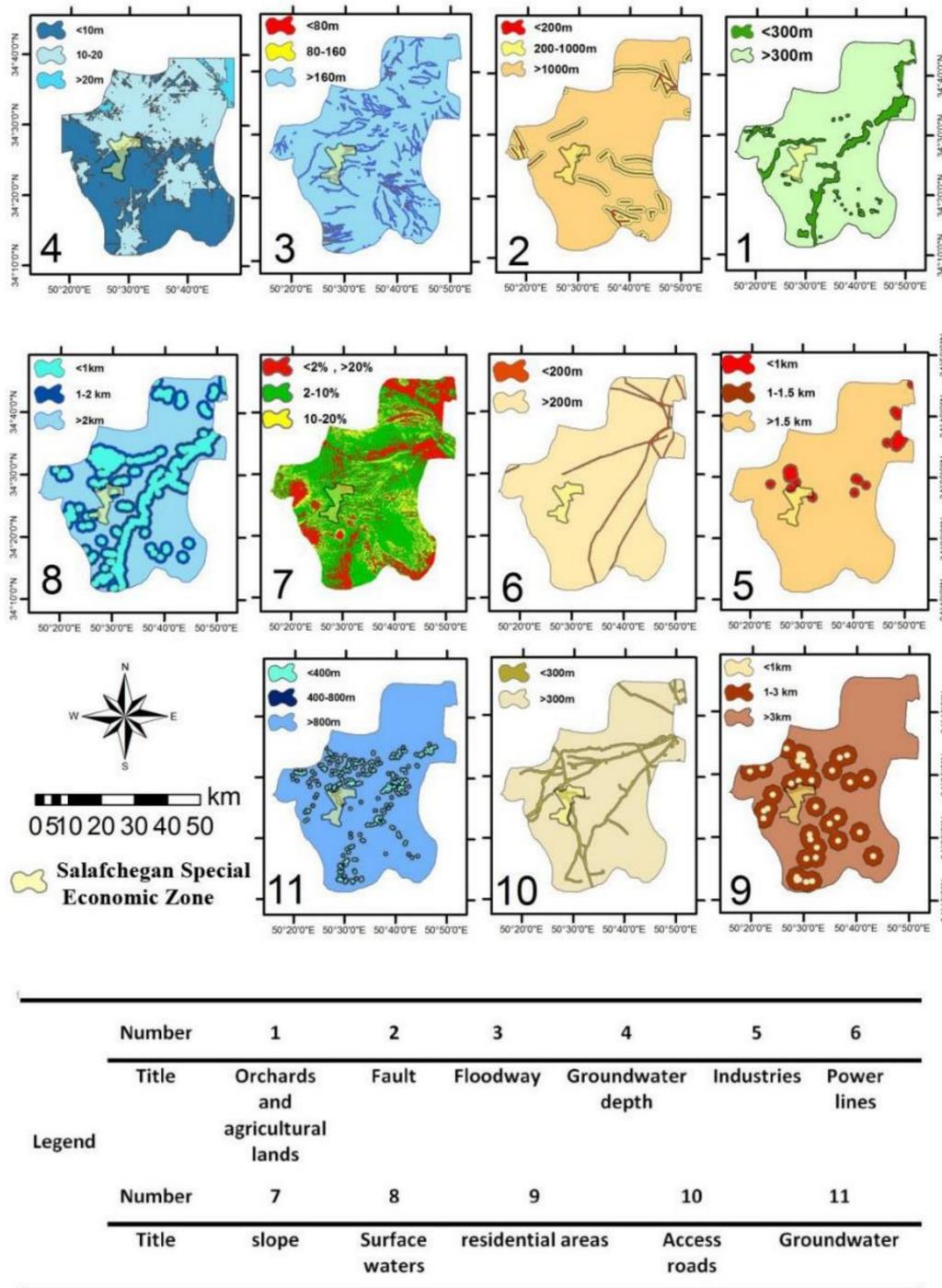


Figure 2. Factor maps of the study area.

### 2.1.2. Weighting Parameters Using AHP Analysis

Giving weight to the criteria and options was done through paired comparisons. In the paired comparisons method, for every pair of criteria, it should be determined which factor or criterion is more important than the other. The paired comparisons method turns qualitative comparisons into quantitative weights for all factors. The comparisons were conducted using the scale shown in Table 2.

**Table 2.** Ranking scale for criteria and alternatives (Saaty scale) [37].

Explanation	Definition	Intensity of Importance
Two factors contribute equally to the objective	Equal importance	1
Experience and judgment slightly favor one over the other	Somewhat more important	3
Experience and judgment strongly favor one over the other	Much more important	5
Experience and judgment very strongly favor one over the other. Its importance is demonstrated in practice.	Very much more important	7
The evidence favoring one over the other is of the highest possible validity.	Absolutely more important	9
When compromise is needed	Intermediate values	2,4,6,8

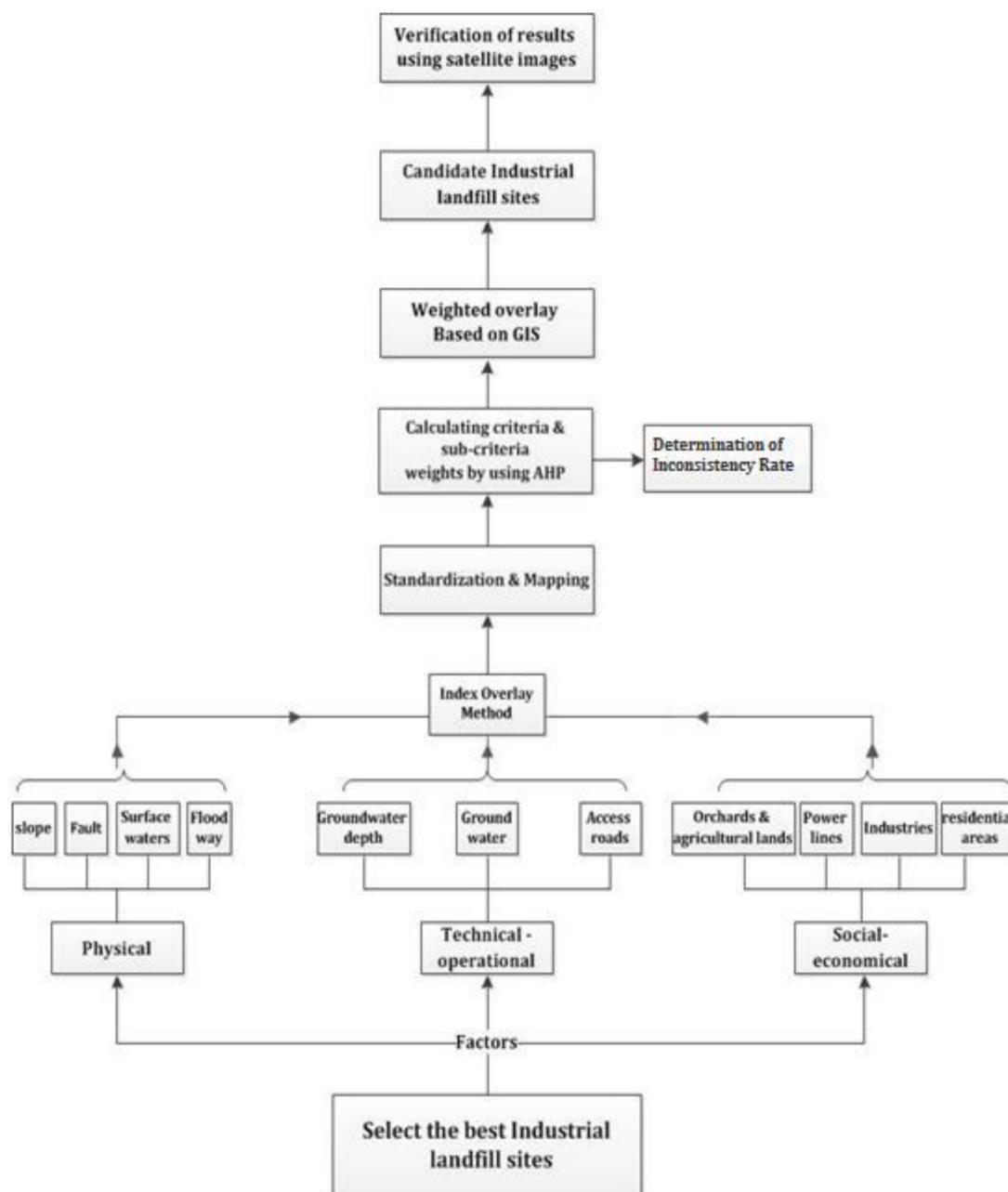
The weight of each factor represents its significance and value in relation to other factors. Therefore, informed and proper selection of weights greatly assists in determining the goal of interest. In this structure, the elements of each level are influenced by some or all of the elements in the level above it. AHP matrices were prepared and confirmed by a number of experts familiar with the waste disposal site selection process and environmental issues by considering previous studies. These matrices were eventually introduced into Expert Choice software, which was followed by calculation of AHP coefficients (Table 3).

**Table 3.** Analytical Hierarchy Process (AHP) coefficients of criteria and sub-criteria.

Criteria	Weights	Sub-Criteria	Sub-Weights
Floodway (m)	0.03	<80	0.109
		80–160	0.309
		>160	0.582
Surface waters (m)	0.091	<1000	0.109
		1000–2000	0.309
		>2000	0.582
Fault (m)	0.051	<200	0.109
		200–1000	0.309
		>1000	0.582
Slope (%)	0.184	<2, >20	0.109
		2–10	0.582
		10–20	0.309
Groundwater depth (m)	0.227	<10	0.109
		10–20	0.309
		>20	0.582
Groundwater (m)	0.053	<400	0.109
		400–800	0.309
		>800	0.582
Access roads (m)	0.072	<300	0.1
		>300	0.9
Residential areas (m)	0.103	<1000	0.109
		1000–3000	0.309
		>3000	0.582
Industries (m)	0.024	<1000	0.109
		1000–1500	0.309
		>1500	0.582
Power lines (m)	0.015	<200	0.1
		>200	0.9
Orchards and agricultural lands (m)	0.15	<300	0.1
		>300	0.9

The Inconsistency Rate is a mechanism that represents the reliability of the obtained priorities, where if it is lower than 0.1, the comparisons are acceptable; otherwise, the comparisons should be repeated. In this study, the inconsistency rate was calculated to be lower than 0.1 across all of the

comparisons. Figure 3 represents the conceptual model proposed for the site selection process for disposal of industrial wastes in this research.



**Figure 3.** Flow chart of the industrial landfill site selection methodology.

## 2.2. Data Integration and Decision-Making

The proposed model for landfill site selection was accomplished through the integration of factor maps. In this study, all of the prepared factor maps that were rasterized were imported using the index overlay method along with the weight (AHP coefficients) of relevant classes (Table 3). The only difference is that the AHP coefficient of the restriction layer of every factor was set as restricted. The results obtained from overlaying all factor maps are presented in Figure 4. As can be seen in the map, the index overlay method has classified lands in the Salafchegan region in terms of suitability for disposing industrial wastes as *much less suitable*, *less suitable*, *moderately suitable*, and *highly suitable*. The area of each priority class is given in Table 4. Also, the pie chart in Figure 5 shows the percentage

of each class. The highly suitable areas are considered as the lands with first priority for waste disposal. Moderately suitable areas are the lands with second priority. The much less suitable areas can also be considered as not suitable. It should be noted that for landfill site selection, the special economic zone was not excluded as a constraint layer because, at the decision-making stage, a suitable disposal site inside its boundary could have more economic favorability, as moving wastes outside the zone would require extra costs for transportation as well as other possible costs related to custom regulations of the special economic zone.

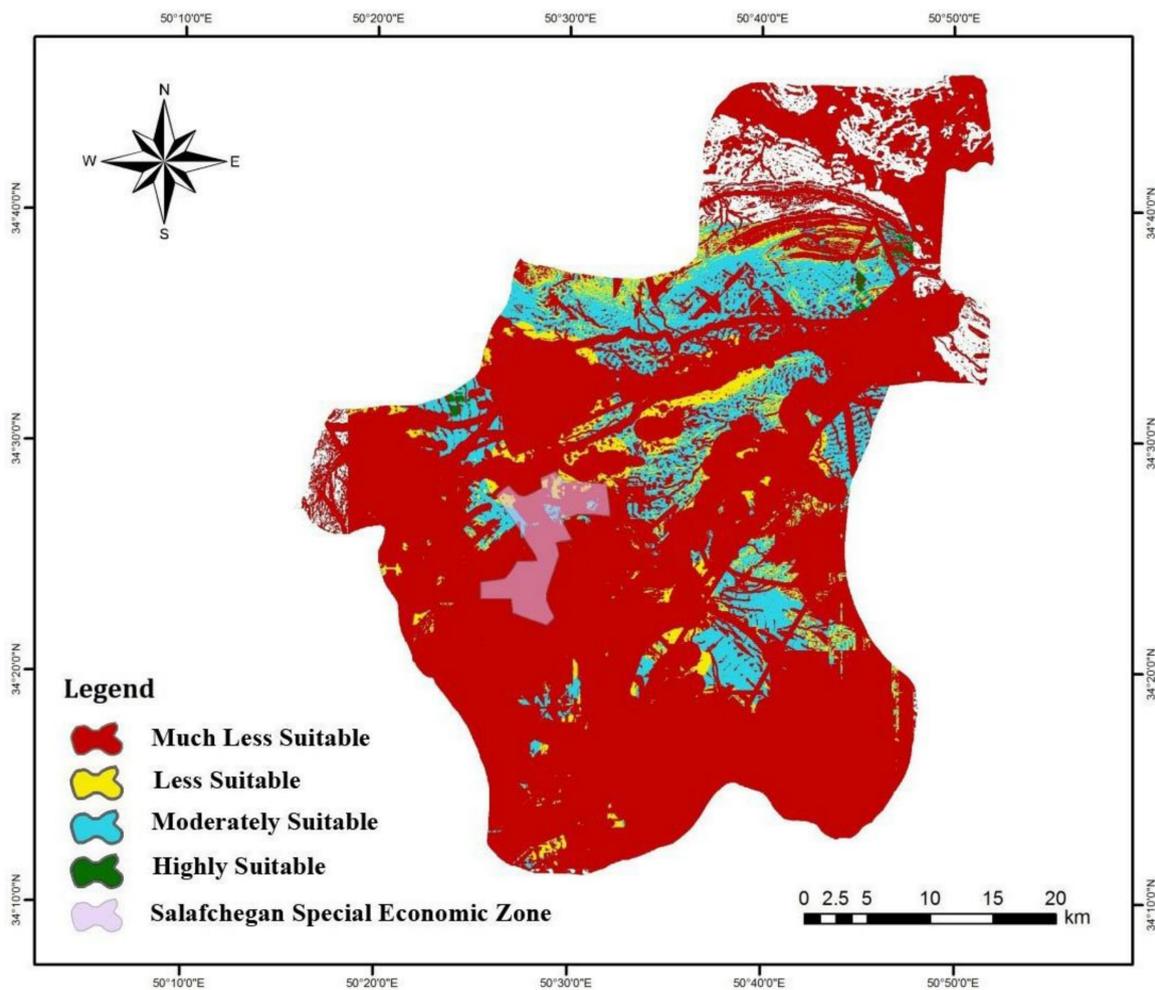


Figure 4. Industrial landfill sites suitability map by the index overlay method.

Table 4. Areas of selected priorities by the index overlay method.

Highly Suitable	Moderately Suitable	Less Suitable	Much Less Suitable	Selected Priorities
4.77085	237.1891	92.54218	1571.45	Area (km <sup>2</sup> )

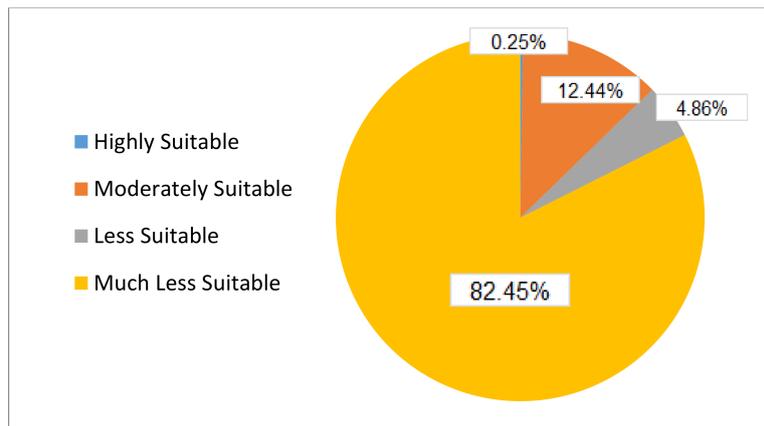


Figure 5. Pie chart of the selected priority areas.

### 3. Results

Considering the results obtained from the integration of factor maps (Figure 4) and the selection of two options, *highly suitable* and *moderately suitable*, as the first and second priorities, respectively, final selection of suitable sites for disposing of industrial wastes was performed. The first priority locations were specified as A1, A2, A3, and A4, while second priority areas were specified as B1, B2, B3, and B4. The location map of selected sites with the first and second priorities is shown in Figure 6.

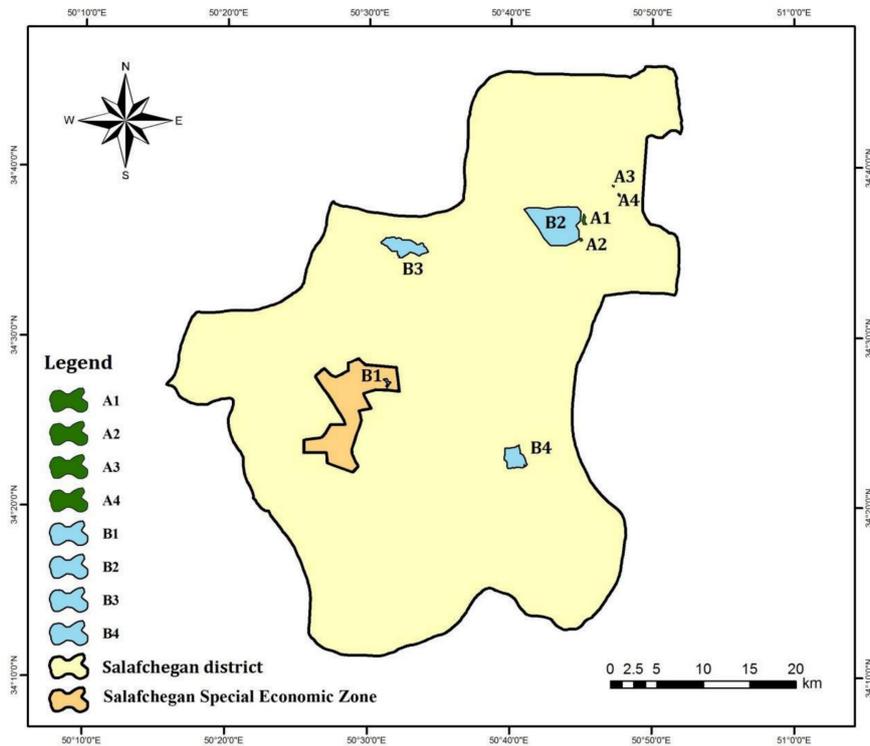
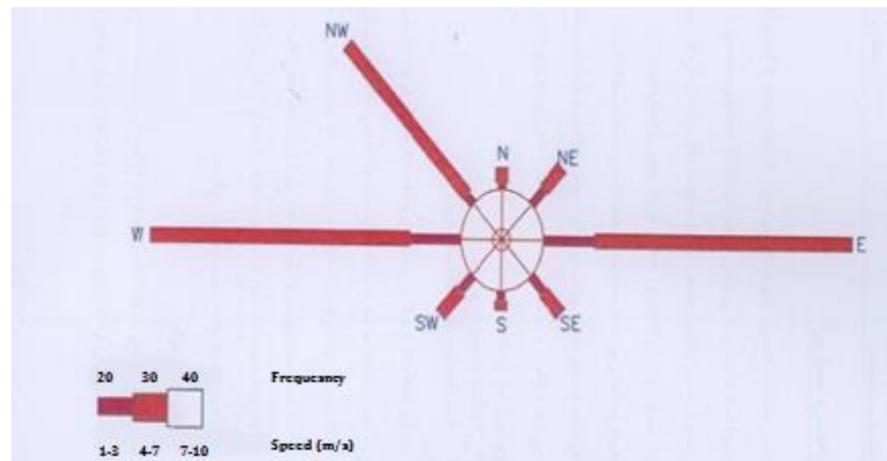


Figure 6. Map of the selected sites with the first and second priority in the study area.

As shown in Figure 6, four sites with the first priority and four sites with the second priority were chosen for disposing industrial wastes in the Salafchegan region. Table 5 summarizes the specifications of the selected sites, including area, groundwater depth, distance from residential areas, distance from the Salafchegan special economic zone, the direction of the predominant wind, and land use.

**Table 5.** Specification of selected sites by the Index Overlay method.

Selected Areas	Area (ha)	Groundwater Depth (m)	Distance of Residential Areas (km)	Distance of Salafchegan Special Economic Zone	The Prevailing Wind Direction	Land Use
A1	35.2	>20	>3	26.7	East–West	moderate rangeland–barren land
A2	7.9	>20	>3	24.9	East–West	moderate rangeland
A3	3.5	>20	>3	31.4	East–West	moderate rangeland
A4	6.8	>20	>3	31.1	East–West	barren land
B1	26.2	10–20	>3	inside	East–West	moderate rangeland
B2	1849.3	10–20	>3	22.6	East–West	moderate rangeland–barren land
B3	632.7	10–20	>3	12.7	East–West	moderate rangeland
B4	428.6	10–20	1–3	14.1	East–West	Poor rangeland

**Figure 7.** The windrose map of the Salafchegan region.

In terms of area, the selected sites have at least 3 hectares of area, which is suitable for waste disposal. A 10 m depth for groundwater and a distance shorter than one kilometer from residential areas are considered the restrictions in selection of a suitable site for waste disposal. Further, the closer the selected site for waste disposal to the Salafchegan special economic zone, the higher its priority. This is because closer areas are subject to lower cost associated with transportation. Furthermore, the custom rules that govern the Salafchegan special economic zone require the payment of extra charges for transferring wastes to the outside of the spatial economic zone. Thus, if possible, the managers of this region are required to find a suitable waste disposal site inside of the region.

The direction of the dominant wind in the region can also be a controlling factor, since the site selected for waste disposal should not be in the dominant wind direction. Wind causes displacement of unpleasant odor resulting from buried wastes (Figure 7). The land use of the selected sites was also reinvestigated, which included medium and poor rangelands and barren lands. These land uses did not impose restrictions on waste disposal.

#### 4. Validation of the Results

At the last stage, an accuracy adjustment should be tested to ensure the precision of the process [26]. To this end, a field visit was carried out to compare the actual field situations with the modeling results. The field visits indicated that all land uses will be acceptable with some percentage of error. Therefore, in this research another step was included in the process as the validation step, which was that the results were validated by not only site visits but also satellite images. Figure 8 shows the satellite images of each selected site.

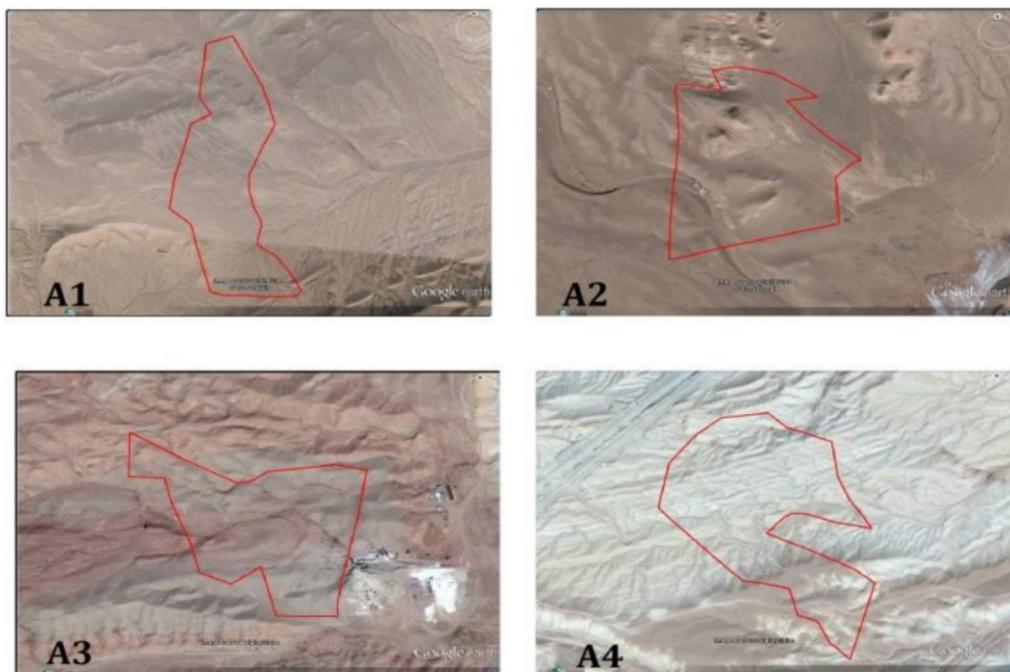
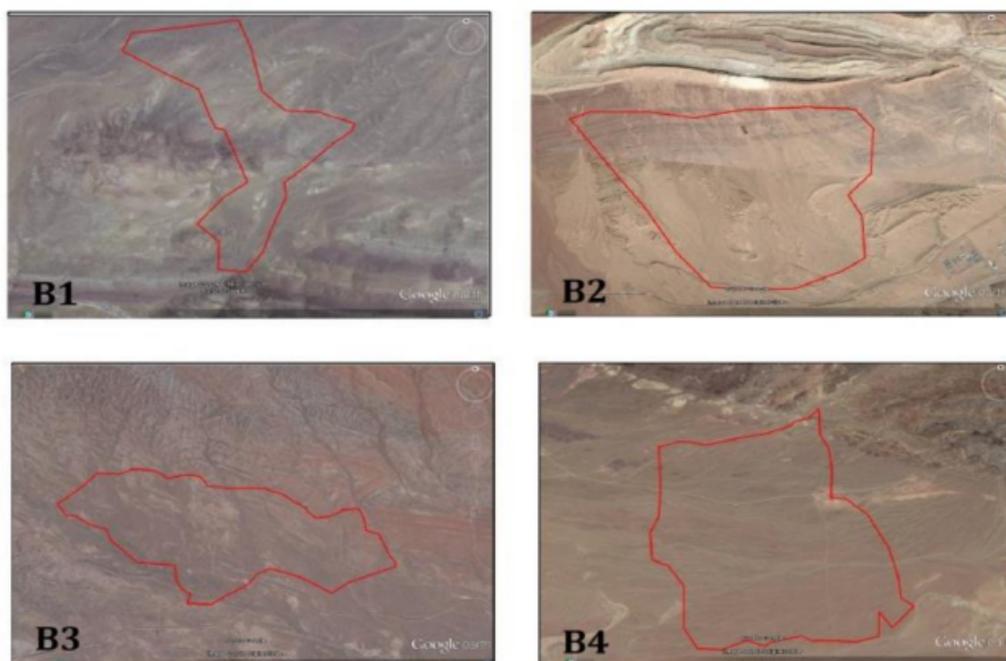


Figure 8. Cont.



**Figure 8.** Satellite images of selected sites with the first and second priority.

## 5. Discussion and Conclusions

Planning and management begin with problem description and continue by several types of analysis, including modeling and simulation [25]. This study combined GIS applications with decision support tools and field observations for industrial landfill site selection; however, the employed approach can also be applied for other site selection studies as well. For the optimal selection of suitable sites for disposing of industrial wastes, there are various models and methods. In this research, the index overlay method was chosen to consider the existent parameters and also for the high accuracy of this method in comparison with other weighting methods. Following selection and preparation of the maps related to the effective parameters, weighting was carried out by the AHP method while considering expert comments. At this stage, the maps and weights related to them were introduced into the index overlay model, where the map obtained from combination of the effective factors was achieved. Thereafter, the sites with the first and second priorities were chosen, and four sites from each priority were introduced for disposing of industrial wastes. The selected sites have at least 3 and up to 1849 hectares of area, which makes them suitable for waste disposal. The land use of about 60% of the selected areas was moderate rangeland and other areas were barren lands and poor rangelands; none of these imposed restrictions on waste disposal. Also, unlike [23,28,29,31,32], in this research the wind patterns and directions were taken into account together with other criteria in order to select the best possible sites for waste disposal.

Validation is a fundamental part of the site selection process for determination and confirmation of the suitability of the selected locations. In several previous studies, the landfill siting was modeled in a GIS environment using datasets and without field observations. Within this research, however, to assess the accuracy of the created maps and to validate them, site visits and a satellite image analysis were performed. The validation was carried out followed by analyzing all eight selected options' specifications. The B1 option with an area of around 26 hectares, located in the developmental lands of the Salafchegan special economic zone, albeit among the second priority areas, could be more feasible at the moment for its cost-effectiveness from the managerial and regulatory points of view. Therefore, this site is suggested for near-term industrial waste disposal.

**Author Contributions:** Hossein Yousefi and Zahra Javadzadeh conceived the study, conducted the initial research, and wrote the manuscript. Younes Noorollahi contributed to the analysis and results. Amin Yousefi-Sahzabi contributed to the discussions and conclusion, critically reviewed and modified the overall manuscript, applied the editorial corrections, and handled all versions of the manuscripts submission.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

- Persson, L.; Karlsson-Vinkhuyzen, S.; Lai, A.; Persson, A.; Fick, S. The Globally Harmonized System of Classification and Labelling of Chemicals—Explaining the Legal Implementation Gap. *Sustainability* **2017**, *9*, 2176. [[CrossRef](#)]
- Fathi, T. Environmental Site Selection Criteria for Hazardous Waste Landfills. In Proceedings of the Third National Conference on Waste Management, Tehran, Iran, 21–22 April 2007.
- Kianbakhsh, M.; Saeedi, M. Site Selection and Prioritize Industrial Waste Landfill of Shahid Rajaee Qazvin Powerhouse Using Geographic Information System (GIS). In Proceedings of the Twenty-fourth International Conference on Electricity, Tehran, Iran, 16–18 November 2009; Tavanir Company: Tehran, Iran.
- Yousefi-Sahzabi, A.; Sasaki, K.; Yousefi, H. Some Thoughts on the Notion of Environmental Information Science. *Electron. Green J.* **2014**, *1*, 1–16.
- Yousefi, H.; Noorollahi, Y.; Hajinezhad, A.; Alimohammadi, A. GIS-based spatially integrated bioenergy resources assessment in Kurdistan Province-Northwest Iran. *Sustain. Energy Technol. Assess.* **2017**, *23*, 11–20. [[CrossRef](#)]
- Noorollahi, Y.; Yousefi, H.; Mohammadi, M. Multi-criteria decision support system for wind farm site selection using GIS. *Sustain. Energy Technol. Assess.* **2016**, *13*, 38–50. [[CrossRef](#)]
- Yousefi-Sahzabi, A.; Sasaki, K.; Yousefi, H.; Pirasteh, S.; Sugai, Y. GIS aided prediction of CO<sub>2</sub> emission dispersion from geothermal electricity production. *J. Clean. Prod.* **2011**, *19*, 982–1993. [[CrossRef](#)]
- Yousefi-Sahzabi, A.; Sasaki, K.; Djamaluddin, I.; Yousefi, H.; Sugai, Y. GIS modeling of CO<sub>2</sub> emission sources and storage possibilities. *Energy Procedia* **2011**, *4*, 2831–2838. [[CrossRef](#)]
- Rezai, A.; Dehzad, B.; Omrani, G.H.; Hashemipoor, Y.; Fakhim Ahmadi, H. Studies of Site Selection and Optimal Disposal of Solid Waste Management, New City of Hashtgerd. In Proceedings of the Tenth National Conference of Environmental Health, Hamedan, Iran, 30 October–1 November 2007.
- Sumathi, V.R.; Natesan, U.; Sarkar, C. GIS-based approach for optimized siting of municipal solid waste landfill. *Waste Manag.* **2008**, *28*, 2146–2160. [[CrossRef](#)] [[PubMed](#)]
- Sharifi, M.; Hadidi, M.; Vessali, E.; Mosstafakhani, P.; Taheri, K.; Shahoie, S.; Khodamoradpour, M. Integrating multi-criteria decision analysis for a GIS-based hazardous waste landfill sitting in Kurdistan Province, western Iran. *Waste Manag.* **2009**, *29*, 2740–2758. [[CrossRef](#)] [[PubMed](#)]
- Yousefi, H.; Zahedi, S.; Niksokhan, M.H. Modifying the analysis made by water quality index using multi-criteria decision making methods. *J. Afr. Earth Sci.* **2018**, *138*, 309–318. [[CrossRef](#)]
- Gbanie, S.P.; Tengbe, P.B.; Momoh, J.S.; Medo, J.; Kabba, V.T.S. Modelling landfill location using geographic information systems (GIS) and multi-criteria decision analysis (MCDA): Case study Bo, southern Sierra Leone. *Appl. Geogr.* **2013**, *36*, 3–12. [[CrossRef](#)]
- Singh, A.P.; Vidyarthi, A.K. Optimal allocation of landfill disposal site: A fuzzy multi-criteria approach. *Iran. J. Environ. Health Sci. Eng.* **2008**, *5*, 25–34.
- Abessi, O.; Saeedi, M. Site selection of a hazardous waste landfill using GIS technique and priority processing, a power plant waste in Qazvin province case example. *Environ. Sci.* **2009**, *6*, 121–134.
- Nas, B.; Cay, T.; Iscan, F.; Berkay, A. Selection of MSW landfill site for Konya, Turkey using GIS and multi-criteria evaluation. *Environ. Monit. Assess.* **2010**, *160*, 491–500. [[CrossRef](#)] [[PubMed](#)]
- Pires, A.; Chang, N.-B.; Martinho, G. An AHP-based fuzzy interval TOPSIS assessment for sustainable expansion of the solid waste management system in Setúbal Peninsula, Portugal. *Resour. Conserv. Recycl.* **2011**, *56*, 7–21. [[CrossRef](#)]
- Jafari, H.R.; Rafii, Y.; Ramezani Mehrian, M.; Nasiri, H. Urban landfill site selection using AHP and SAW in GIS environment, case study: Kohkiluyeh-o-Boyer Ahmad Province, Iran. *J. Environ. Stud.* **2012**, *38*, 37–39.

19. Demesouka, O.E.; Vavatsikos, A.P.; Anagnostopoulos, K.P. Suitability analysis for siting MSW landfills and its multicriteria spatial decision support system: Method, implementation and case study. *Waste Manage.* **2013**, *33*, 1190–1206. [[CrossRef](#)] [[PubMed](#)]
20. Davami, A.H.; Moharamnejad, N.; Monavari, S.M.; Shariat, M. An urban solid waste landfill site evaluation process incorporating GIS in local scale environment: A case of Ahvaz city, Iran. *Int. J. Environ. Res.* **2014**, *8*, 1011–1018.
21. Beskese, A.; Demir, H.H.; Ozcan, H.K.; Okten, H.E. Landfill site selection using fuzzy ahp and fuzzy TOPSIS: A case study for Istanbul. *Environ. Earth Sci.* **2015**, *73*, 3513–3521. [[CrossRef](#)]
22. Khan, D.; Samadder, S.R. Municipal solid waste management using Geographical Information System aided methods: A mini review. *Waste Manag. Res.* **2014**, *32*, 1049–1062. [[CrossRef](#)] [[PubMed](#)]
23. Chabuk, A.; Al-Ansari, N.; Hussain, H.M.; Knutsson, S.; Pusch, R.; Laue, J. Combining GIS Applications and Method of Multi-Criteria Decision-Making (AHP) for Landfill Siting in Al-Hashimiyah Qadhaa, Babylon, Iraq. *Sustainability* **2017**, *9*, 1932. [[CrossRef](#)]
24. Korucu, M.K.; Erdagi, B. A criticism of applications with multi-criteria decision analysis that are used for the site selection for the disposal of municipal solid wastes. *Waste Manag.* **2012**, *32*, 2315–2323. [[CrossRef](#)] [[PubMed](#)]
25. Salman Mahini, A.; Gholamalifard, M. Siting MSW landfills with a weighted linear combination methodology in a GIS environment. *Int. J. Environ. Sci. Technol.* **2006**, *3*, 435–445. [[CrossRef](#)]
26. Moeinaddini, M.; Khorasani, N.; Danehkar, A.; Darvishsefat, A.A.; Zienalyan, M. Siting MSW landfill using weighted linear combination and analytical hierarchy process (AHP) methodology in GIS environment (case study: Karaj). *Waste Manag.* **2010**, *30*, 912–920. [[CrossRef](#)] [[PubMed](#)]
27. Bottero, M.; Comino, E.; Riggio, V. Application of the analytic hierarchy process and the analytic network process for the assessment of different waste water treatment systems. *Environ. Model. Softw.* **2011**, *26*, 1211–1224. [[CrossRef](#)]
28. Pandey, P.C.; Sharma, L.K.; Nathawat, M.S. Geospatial strategy for sustainable management of municipal solid waste for growing urban environment. *Environ. Monit. Assess.* **2011**, *184*, 2419–2431. [[CrossRef](#)] [[PubMed](#)]
29. Moghaddas, N.H.; Namaghi, H.H. Hazardous waste landfill site selection in Khorasan Razavi Province, Northeastern Iran. *Arab. J. Geosci.* **2011**, *4*, 103–113. [[CrossRef](#)]
30. Isalou, A.A.; Zamani, V.; Shahmoradi, B.; Alizadeh, H. Landfill site selection using integrated fuzzy logic and analytic network process (F-ANP). *Environ. Earth Sci.* **2013**, *68*, 1745–1755. [[CrossRef](#)]
31. Arkoc, O. Municipal solid waste landfill site selection using geo-graphical information systems: A case study from Çorlu, Turkey. *Arab. J. Geosci.* **2014**, *7*, 4975–4985. [[CrossRef](#)]
32. Gorsevski, P.V.; Donevska, K.R.; Mitrovski, C.D.; Frizado, J.P. Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: A case study using ordered weighted average. *Waste Manag.* **2012**, *32*, 287–296. [[CrossRef](#)] [[PubMed](#)]
33. Feo, G.D.; Gisi, S.D. Using MCDA and GIS for hazardous waste landfill siting considering land scarcity for waste disposal. *Waste Manag.* **2014**, *34*, 2225–2238. [[CrossRef](#)] [[PubMed](#)]
34. Darban Astaneh, A.R.; Tavakoli Nagmeh, M.; Talkhabi, A. Review of Socioeconomics Impacts of Special Economic Zones (Case Study: Salafchegan Special Economic Zone in Qom Province). *J. Reg. Plan.* **2016**, *5*, 111–124.
35. Jones, C.B. *Geographical Information Systems and Computer Cartography*; Routledge: Abingdon-on-Thames, UK, 2014.
36. Bonham-Carter, G.F. *Geographic Information Systems for Geoscientists: Modelling with GIS*; Pergamon Press: New York, NY, USA, 1994; p. 416.
37. Saaty, T.L. *The Analytic Hierarchy Process*; McGraw-Hill International: New York, NY, USA, 1980.
38. Yousefi, H.; Yousefi-Sahzabi, A.; Masih, M.; Ghaleh, S.; Mirzaaghabek, M. Urban Parks Prioritization Concerning the Age-friendly Criteria in Sari, Northern Iran. *Int. J. Occup. Hyg.* **2017**, *8*, 116–123.
39. Ali, S.; Lee, S.-M.; Jang, C.-M. Determination of the Most Optimal On-Shore Wind Farm Site Location Using a GIS-MCDM Methodology: Evaluating the Case of South Korea. *Energies* **2017**, *10*, 2072. [[CrossRef](#)]
40. Lyu, H.-M.; Shen, J.S.; Arulrajah, A. Assessment of Geohazards and Preventative Countermeasures Using AHP Incorporated with GIS in Lanzhou, China. *Sustainability* **2018**, *10*, 304. [[CrossRef](#)]

41. Stojković, S.; Đurđić, S.; Anđelković, G. Application of multi-criteria analysis and GIS in ecotourism development (Case study: Serbian Danube region). *Glasnik Srpskog Geografskog Društva* **2015**, *95*, 51–66. [[CrossRef](#)]
42. Serbu, R.; Marza, B.; Borza, S. A Spatial Analytic Hierarchy Process for Identification of Water Pollution with GIS Software in an Eco-Economy Environment. *Sustainability* **2016**, *8*, 1208. [[CrossRef](#)]
43. Environmental Protection Organization of Iran. Set Rules and Regulations of the Environmental Protection. In *Waste Management Law*; Environmental Protection Organization of Iran: Tehran, Iran, 2014.
44. Makhdoom, M. *Fundamentals of Land Use Planning*; Tehran University Press: Tehran, Iran, 2001.
45. Golchin, A. *Heavy Metal Contamination Sources of Soils and Agriculture Products in Zanjan Province*; Research Report; Zanjan Management and Planning Organization: Zanjan, Iran, 2005.
46. Qom Environmental Protection Organization. *Preliminary Landfill Site Suitability Report*; Qom Environmental Protection Organization: Qom, Iran, 2004; p. 11.



© 2018 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).