Wastewater treatment plant site selection using AHP and GIS: a case study in Falavarjan, Esfahan

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Abstract

This paper presents the criteria and applied methods in the screening of potential sites for the wastewater treatment plant of the Falavarjan district, northwest of Esfahan province. For this the nine parameters that were selected as main criteria, 7 parameters were considered to define the buffer zones in the natural and artificial terrains. At the first stage of the study, unsuitable zones were excluded and the weights of the main and subclasses were calculated using AHP method. Then, each parameter was mapped into a GIS system as an individual data layer. The final susceptibility map, which had been produced by overlapping all data layers, was divided into 4 categories. Then, the three top ranked areas were selected from the very suitable class. In order to locate the site with the minimum effect on the environment, the Leopold Matrix was used. Finally, area 1 was selected, by both TOPSIS and EIA, as the most preferable option for the construction of the wastewater treatment plant.

Keywords: *AHP, Falavarjan city, site selection, wastewater treatment plant.*

Introduction

In addition to preventing environmental pollution, one of the aims of the wastewater treatment is to recover water for further consumptions, including agricultural purposes. Virtually, one third of the world's population live in the regions with irregular water stress. This situation may be more serious in the future (Reyhani *et al.,* 2007). The growth of urban population, the increasing health level, and public awareness have led to the construction of many wastewater treatment plants in the recent years (Monzavi, 2001). One of the most important stages of waste treatment plants, causing the least environmental effects, is the selection of a suitable site. Therefore, many countries and scientific organizations have issued their own standards for designing wastewater treatment plants)Zhao *et al.,* 2009; Ratnapriya & De Silva, 2009). Site selection studies usually utilize many parameters; thus, a systematic methodology is needed to combine the various information from a wide range of disciplines (Siddiqui *et al.,* 1996). Multi-criteria decision analysis (MCDA) involves a set of processes that assign the alternatives values evaluating for a specific purpose. In spatial MCDA, geographical data are gathered, processed, and transformed into a decision. In this process, multidimensional data and information can be reduced into one-dimensional values for the alternatives (Sharifi *et al.,* 2009). Researchers have used different methods for the site selection process (Sener *et al.,* 2010, Zao *et al.,* 2009, Chang *et al.,* 2008, Akbari *et al.,* 2008). Neshastehgir (2007) used integrated multi-criteria decision making method and GIS for wastewater treatment plant in Tehran, Iran. In the present study, distance from the sewage network, land use, population density, and wastewater reuse were chosen as main parameters. Final sites were chosen and compared using hierarchical analysis, fuzzy hierarchical analysis, and cutting-alpha methods. Ratnapriya and De Silva (2009) optimized wastewater treatment plant location using GIS and multi-criteria analysis in Upper Mahaweli, Sri Lanka. They used Boolean analysis to overlap the data layers. This study was performed to propose the most suitable site for wastewater treatment plant in Falavarjan district using GIS system along with AHP and TOPSIS methods.

Study Area

Falavarjan district covers an approximately 319 km^2 area near the bank of Zayanderood River, west of Esfahan city (Fig 1). The population was 232644 in 2006 with a growth rate of 1.03% (Statistical centre of Iran, 2013). Falavarjan district includes six towns, namely Falavarjan, Abrisham, Kelishad, Soderjan, Baharan, and Pirbakran. The region enjoys a wide variety of agricultural products because of the good condition of soil and water. Tables 1 and 2 show the characteristics of wastewater of Falavarjan district (Plan and

Researches of Water and Sewage Consulting Engineers Company, 2000).

Table 1: The quality parameters of wastewater in Falavarjan district

parameters	Values
BODs(mg/l)	37.5
COD (mg/l)	75
TSS (mg/l)	37.6
pH	7-7.5
DO (mg/l)	3-3.5
NH3-N(mg/l)	21.4

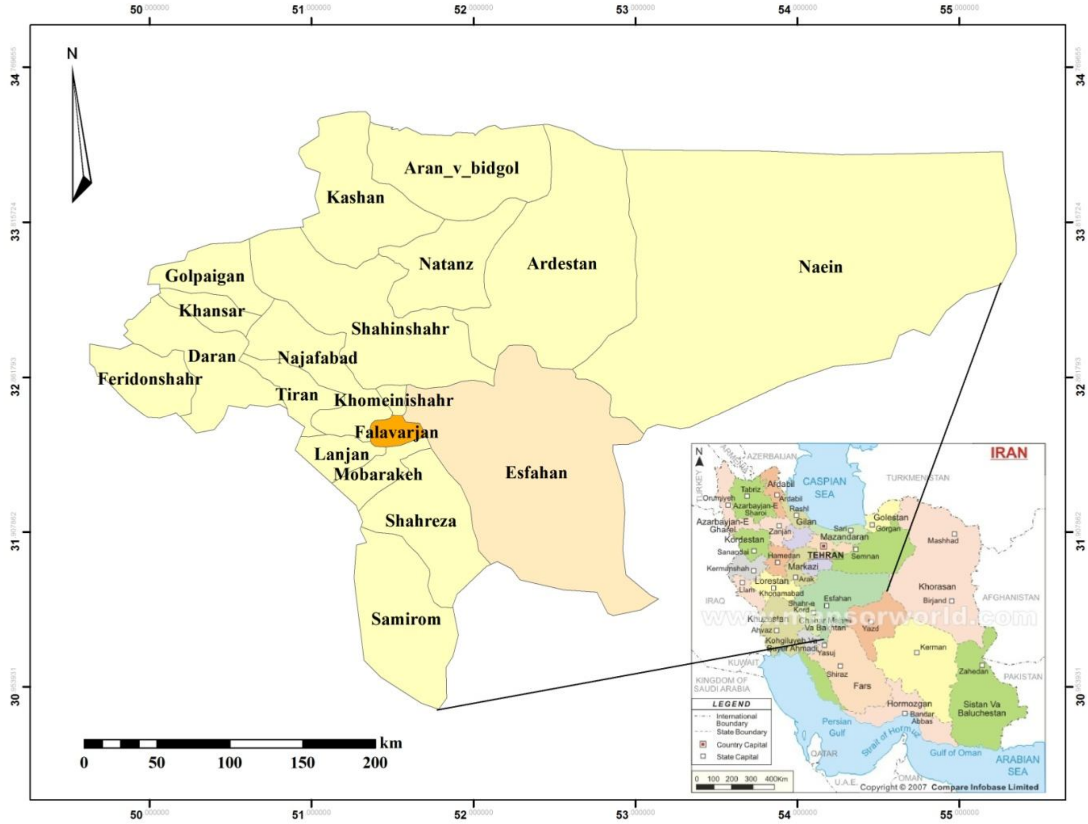

Figure 1: Location map of the study area

Table 2: Estimated volume of wastewater of Falavarjan district

city	Parameters / Years	2010	2021	2031
Falavarjan	Population	33264	38641	47125
	incoming sewage (m^3/day)	5214	6720	8012
Abrisham	Population	32434	39686	46747
	incoming sewage (m^3/day)	5105	6516	7998
Kelishad - Soderjan	Population	26309	30499	33973
	incoming sewage (m^3/day)	4415	5243	5979
Baharan	Population	20369	24624	28036
	incoming sewage (m^3/day)	3416	4307	5063
Pirbakran	Population	28467	33264	38260
	incoming sewage (m^3/day)	4705	5675	6730

Geology and Hydrology of the Area

In this area, the oldest geologic units are Upper Triassic sediments including black shale and interlayers of quartzite sandstone and limestone. Sandstone and shale outcrops of Shemshak Formation were observed in south and east of the study area on both sides of Zayanderood River. Cretaceous units start with red classic and dolomite layers and continue with Orbitolina and Ammonites limestone that gradually transform to marl. The last part of the Cretaceous sequence consists of limestone and shale whose thickness change in various parts of the region. The mountains in the region are made from limestone units. Red conglomerate units of Eocene are positioned beneath the Oligocene - Miocene units of Qom Formation. Falavarjan plain are overlaid with quaternary deposits of alluvial fan (gravel and sand), flood plain (gravel, sand, clay), and river terraces. The grain size reduces toward the west and centre of the area. Average level of groundwater changes from 5meters in the vicinity of the Zayanderood River up to 88 meters in the margins of the mountains. The injection of sewage disposal in absorbing wells has led to the increase of groundwater level in the area, in recent years.

Methodology

A variety of factors were considered in order to locate suitable areas for the construction of the wastewater treatment plant; such as climate, hydrology and hydrogeology, morphological indexes, soil texture, permeability, and social and economic parameters. Due to limitations in the methods and data gathering processes, it was not possible to include all of the parameters in the models. Hence, most effective factors were determined based on the purpose, scale and precision, local conditions, impact of each factor, sufficient data, and information availability (Hekmatpoor *et al.,* 2001).

In the present study, three groups of data, including the environmental, geological, and economic criteria and a total of 9 parameters, were used for selecting a suitable location for construction of wastewater treatment plant (Fig 2). Also, 7 parameters of faults, population, Main River, streams, floodplain, road, underground water sources, and transmission network were considered as excluding parameters.

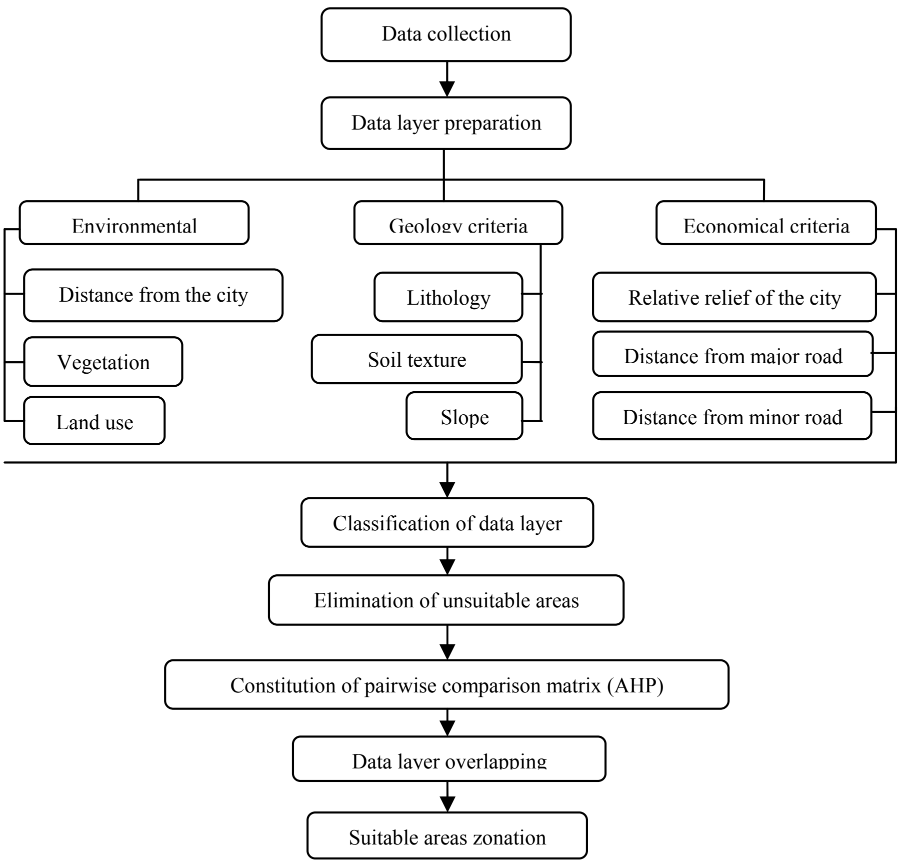

Figure 2: Flowchart of the methodology

Criteria Description and Their Application

In the present study, the criteria were classified into two groups of main and exclusion criteria. The main criteria consisted of 9 elements: slope, lithology, soil texture, relative relief to city, distance from major and minor road, distance from the city, vegetation, and land use. Each criterion was divided into four classes: very suitable, suitable, medium suitable and unsuitable, based on their importance and regional conditions. The excluded criteria were used to control the adverse environmental impacts of natural and artificial phenomena. They included the fault (major and minor), residential areas (urban and rural), main river, streams (major and minor), floodplain, road (major, minor, railroad), underground water resources (wells, springs, aqueduct, pond), and transmission lines. Buffer zones for each criterion were assigned according to the standards and former studies. In table 3, the buffer zones used in the present study and the distance proposed by some researchers are compared.

Table 3: Buffer zones considered in this research

Parameters	**Buffer zone(meters)**	
	Other studies	**This study**
Fault	500 -(Sumathi *et al.,* 2008); 1000- (Sharifi *et al.,* 2009)-	300 -(Major f.) 100- (Minor F.)
Urban area	5000- (Zeiss & Lefsrud ,1995); 500- (Sadek *et al.,* 2001); 3000- (Chan *et al.,* 2000)-	1000-(Urban area) 300-(Rural area)
River	800-(Siddiqui *et al,* 1996); 180-(Zeiss & Lefsrud, 1995); 2000-3000-(Lin & Kao, 1999)	1000-(Zayandehrood); 300-(Major river); 50-(Minor river)
Road	50-(Baban & Flannagan,1998); 1000-(Dikshit *et al.,* 2000); 1000-(Lin & Kao ,1999); 250-(Sener *et al.,* 2010)	500-(Major road and Highway); 50-(Minor road)
Spring and Wells	50-(Sumathi *et al.,*2008);50-(Chang *et al.,* 2008)	300

Slope

In site selection, slope is an important issue, both environmentally and economically. Construction of wastewater treatment plant in steep sites will increase the cost of excavation and embankment and also intensify the leachate sewage flow to surface and underground water resources. Appropriate slope for construction of wastewater treatment plant is 0-2 % steep, which is placed in the very suitable class. Lin and Kao (1999) stated that slopes that are less than 12% steep prevent the runoff pollution. The slope data layer of the study area was designed with a 10 × 10 resolution, using topographic maps.

Soil texture

Soil texture controls the seepage of sewage, absorption of pollutant, and surface water penetration into landfills (Thoso, 2007). Sand and gravel fraction, salinity, alkalinity, and solubility affect the permeability of soils. Soil with intermediate to heavy surface texture, pebbles ratio, salinity, and low alkalinity are beneficial for the wastewater treatment plant construction.

Land Use

Land is used for various purposes such as agricultural, industrial, and residential. Usually, land use is controlled by land vegetation. It aims at the protection of "sensitive" areas under economic development (Sharifi *et al.,* 2009). Residential areas, farms and gardens are important; thus, they were marked as unsuitable class. The 1:25000 scale land use map was designed in the GIS system. Pastures and grove of the region with the score of 0.16 had the appropriate conditions for the construction of wastewater treatment plant.

Distance From Major and Minor Roads

Distance from the roads increases the cost of wastewater treatment plant construction and maintenance; however, the presence of the wastewater treatment plant close to the roads affects the landscape, climate, and the public health. In this study, 4 categories of 0-500m, 500-1000m, 1000-1500m, and 1500-2000m from the buffer zone were used.

Lithology

The rocks outcrops in the study area include sedimentary rocks such as marl, shale, new and old alluvial terraces, conglomerate, and sandstone. Marl and shale made the best geological combination in the region thus scored at 0.5. The geological map of area was designed in GIS system and raster layer was produced with a 10 × 10 resolution (Fig3).

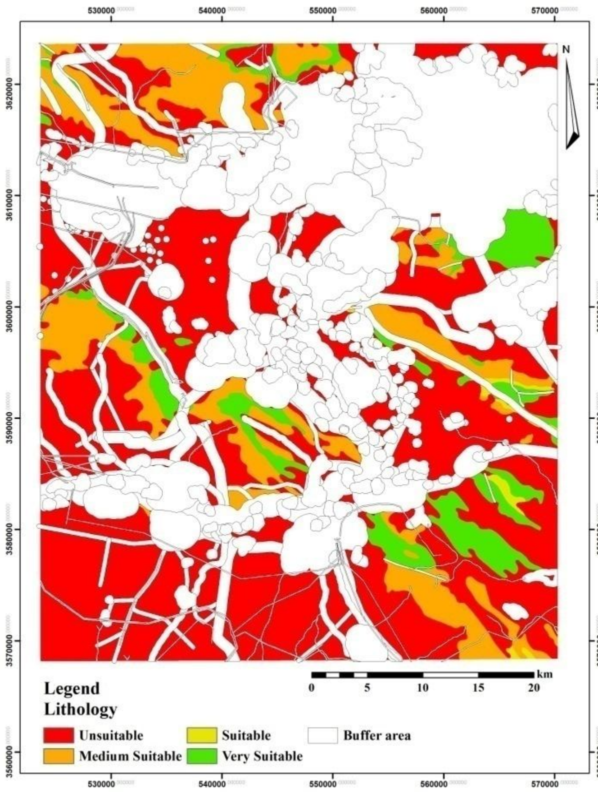

Figure 3: Lithology data layer

Relative Relief of the City

Relative relief with respect to the city is an important parameter in designing plants and sewage networks. During the construction of wastewater treatment plant, the path of the main collector of the sewage must be considered. In optimum design, the wastewater flows toward the treatment in an open channel. If the suitable gradient is not available, a pumping station, which is very costly, should be considered to convey the wastewater. Therefore, the elevation of the site should be lower than that of the lowest parts of the city. This feature along with other parameters was determined for selecting the final sites. Very suitable class belongs to the sites with relative relief of -15 to -50m.

Distance From the City

Due to unfavourable environmental conditions and creating unpleasant odours, wastewater treatment plant should be placed far from residential areas. A cost-benefit analysis with respect to the distance should be performed prior to making any decision. After considering the buffer zone of 1000 m from residential areas, the study area was classified. The best class is the distance of 0-1000 m from the buffer zone. Data layer of distance from the city is particularly sensitive due to the multiplicity of urban and rural residential areas in the study region. This data layer has been created with a 10 × 10 resolution and 1:25000 scale in GIS system (Fig 4).

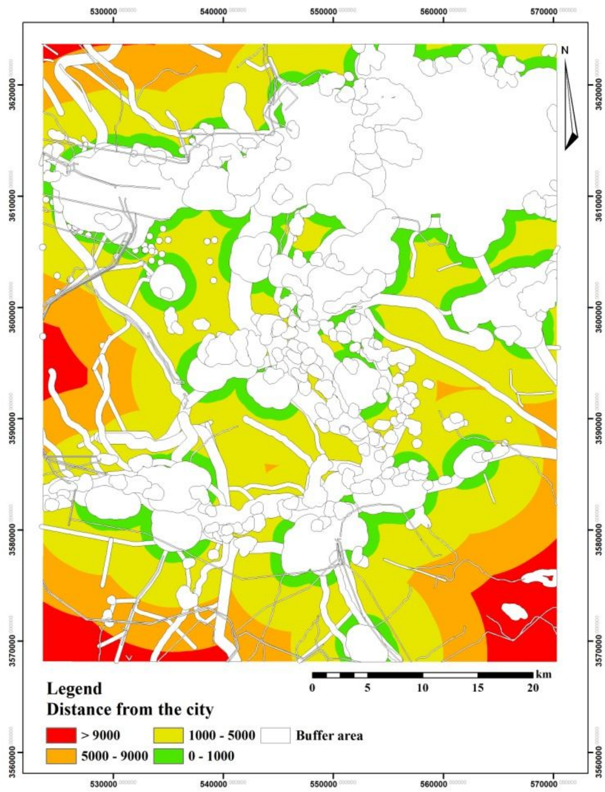

Figure 4: Map of distance from city

Vegetation

Vegetation is necessary to safeguard the value of the lands and prevent the destruction of forest areas. High scores and very suitable class are assigned to lands without cover. The data layer is designed with a 10 × 10 resolution and 1:25000 scales in the GIS system.

Weighting Methods

In this study, Analytic Hierarchy Process (AHP) method was used to determine the weights of the parameters. AHP is an analytical tool that enables one to explicitly rank tangible and intangible criteria for the purpose of selecting priorities. This process involves decomposing a problem from a primary objective to secondary levels of criteria and alternatives. Once the hierarchy has been established, a pair-wise comparison matrix of each element within each level is constructed. The AHP allows group decision-making, where group members can use their experience, values and knowledge to break down a problem into a hierarchy and solve it by the AHP steps.

Participants can weight each element against each other within each level. Each level is related to the levels above and below, and the entire scheme is tied together mathematically. To evaluate the numerous criteria, AHP has become one of the most widely used methods for the practical solution of MCDM problems (Cheng, 1997; Akash *et al.,* 1999; Chan *et al.,* 2000). In order to have a hierarchy of the main factors establish in this study, for example, environmental factors were divided to three elements of distance from the city, vegetation and land use. Then these elements were compared with each other in a pair wise comparison matrix.. This pair-wise comparison allowed for an independent evaluation of each factor contribution, thereby the decision making process would be simplified (Rezaei Moghaddam & Karami, 2008). Herein, the decision makers will use their personal and moral judgments. The judgments by Saaty[1980] were converted to quantitative amounts of 1 to 9; they have been identified in a matrix which is represented in Table 3.

Table 3: The comparison scale in AHP (Saaty, 1980)

Intensity of importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favour one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals of above nonzero	If activity I has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

In table 3, the higher value (number 9) belongs to the most important parameter, while value 1 is assigned to the least important parameters. In this study, each criterion was divided into 4 classes based on the same score method. The weights of classes were calculated by normalization elements in each matrix column (Table 4). One of the Analytical Hierarchy Process's benefits is its ability to control the compatibility decisions. The matrix inconsistency rate is obtained by using inconsistency index (II) and random inconsistency index (RII) (Oswald, 2004).

$$I.R = \overline{I.I}/\overline{R.I.I} \quad (1)$$

This ratio is calculated for each of the criteria and the original matrix. The pair-wise comparisons of various criteria were organized into a square matrix. The matrix diagonal elements were 1. The principal Eigen value and the corresponding normalized right eigenvector of the comparison matrix gave the relative importance of the criteria being compared. The elements of the normalized eigenvector were weighted and classified with respect to the criteria or sub-criteria and the alternatives (Bhushan & Rai, 2004).

In general, acceptable level of inconsistency in a matrix or a system depends on the decision maker. However, Saaty (2001) offers 0.1 as an acceptable quantity and believes if the inconsistency rate exceeds 0.1, better judgment can be obtained. In the present study, the amount of IR is 0.07 which represents acceptable decision-making.

Analysis and Disruption

The final sewage treatment plant susceptibility maps were produced by overlapping the 9 data layers in GIS system. The final scores vary from 834 to 4403 and they are classified into four classes of very suitable (scores of 4403-3040), suitable (scores of 3040-2628), medium suitable (scores of 2628-1914) and unsuitable (scores of 1914-834)(Fig 5). Based on the final map, 13 areas with higher scores from very suitable classes were chose as potential sites. Among them, 10 areas were eliminated based on field surveys, and three sites were selected for detailed studies. The direction of the wind was one of the criteria that helped the researchers to identify unsuitable areas. The direction of the dominant wind is toward the west and south west in the most seasons and toward the east and southeast in summers. Therefore, the areas that are placed on the opposite direction (upwind) had been omitted during the field survey. In order to rank the selected areas, the researchers used TOPSIS method and Leopold matrix. In TOPSIS method, diversity between each option on ideal and anti-ideal state or the distance from ideal and anti-ideal solution is calculated. In this study, 16 parameters of slope, lithology, soil texture, bedrock, distance from the city, distance from major and minor road, land use, vegetation, groundwater level, area, land price, tabulate cost, transmission lines, and relative relief of the city are used in TOPSIS analysis.

Table 4: Weights of main criteria, criteria and sub-criteria used in treatment plant site selection

∑ Weights	Sub criteria			criteria			Main criteria
		Weight	I.R		Weight	I.R	
0.1288	0.01	0.56	0 – 2	0.07	0.23	Slope (in percent)	Geology criteria
0.0621		0.27	2 – 5				
0.0253		0.11	5 – 15				
0.0138		0.06	>15				
0.08	0.01	0.50	Class 1		0.16	Lithology	
0.0496		0.31	Class 2				
0.0192		0.12	Class 3				
0.0112		0.07	Class 4				
0.096	0.06	0.60	Class 1		0.16	Specification soil	
0.0352		0.22	Class 2				
0.0192		0.12	Class 3				
0.0112		0.07	Class 4				
0.0714	0	0.51	0 – 1000		0.14	Distance from city area (m)	Environmental criteria
0.0462		0.33	1000 – 5000				
0.0154		0.11	5000 – 9000				
0.007		0.05	> 9000				
0.0098	0.05	0.49	Class 1		0.02	Vegetation	
0.006		0.30	Class 2				
0.003		0.15	Class 3				
0.0012		0.06	Class 4				
0.0549	0.07	0.61	Class 1		0.09	Land use	
0.0216		0.24	Class 2				
0.009		0.10	Class 3				
0.0054		0.06	Class 4				
0.0028	0.04	0.56	(-50) – (-15)		0.07	Relative relief of the city(m)	Economic criteria
0.0196		0.28	(-15) – 15				
0.0077		0.11	15 – 50				
0.0042		0.06	> 50				
0.0336	0.04	0.48	0 – 500		0.07	Distance for road major (m)	
0.0217		0.31	500 – 1000				
0.0098		0.14	1000 – 2000				
0.0049		0.07	> 2000				
0.023	0.008	0.46	0 – 50		0.05	Distance for road minor (m)	
0.0165		0.33	50 – 500				
0.007		0.14	500 – 1000				
0.0035		0.07	> 1000				

The numerical value of each option that is similar to the ideal state is calculated using similarity index (Ci). The more similar to ideal state is the option; the closer to number 1 will be the similarity index quantity.

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \quad (2)$$

As it was illustrated in Table 5, the most similar index belongs to area number 1.

Table 5: Similarity index calculations

Similarity index	S_i^+ (Distance from anti-ideal solution)	S_i^- (Distance from ideal solution)	Option
0.668	4.5	8.3	Option 1
0.486	5.7	6.1	Option 2
0.440	8	5.5	Option 3

Environmental Impact Assessment

Assessment is a practical method, for environmental observation of executive and construction projects and experts, which aids in determining the best option with highest efficiency. The aim of the environmental impact assessment is to ensure that the project policies and objectives comply with standards and governmental and environmental regulations. In the present study, for environmental impact assessment of wastewater treatment plant construction, Leopold matrix method is used. Thereby, the executive impact of refinery projects can be identified for physicochemical, biological, and socio – economically criteria. Matrixes are in fact two-dimensional list checks. Project activities fix on an axis, and environmental factors influence it on another axis. Each matrix unit cell represents two values. One value represents the magnitude effect (effect of violence) in numerator and the other value in denominator represents the cell value (effect of range) that varies between +5 to -5 [Hafezi Moghaddas, 2004]. The environmental impact assessment results of the present study are presented in Table 6.

Table 6: Results of environmental impact assessment matrix

Option 3	Option 2	Option 1	Options
631-	648-	591-	Values

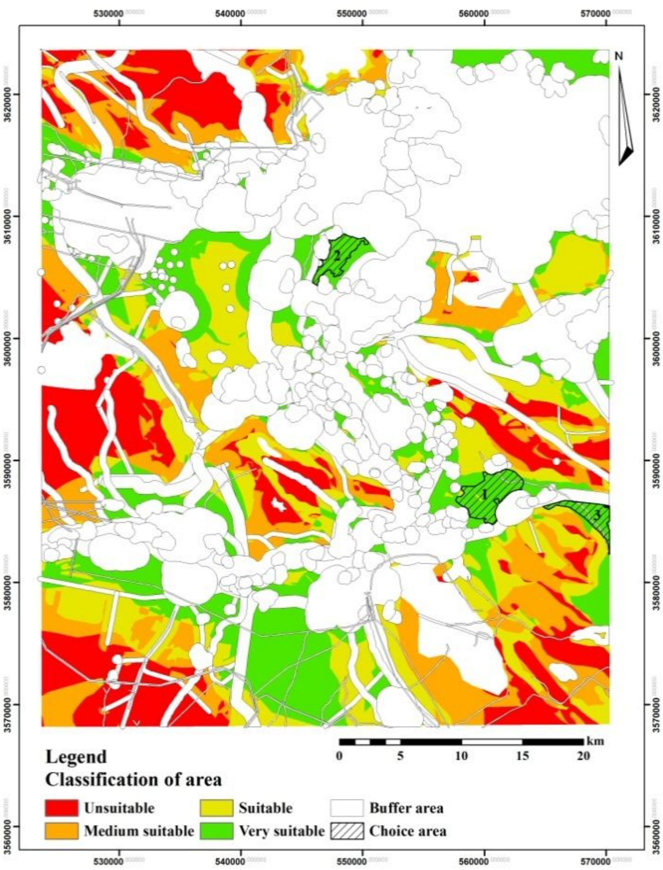

Figure 5: Wastewater treatment plant area suitability map

Conclusion

In order to prevent the pollution of Zayanderood River, the construction of wastewater treatment in the study area is necessary. In the present study, 16 criteria were used as main and exclusive parameters. Each criterion has been converted to numerical values and weighted using AHP method. The final map was prepared and classified by overlapping and using Quantile method. Finally, 3 suitable zones were selected, based on the maximum score. Based on the TOPSIS and Leopold Matrix analysis, area number 1 was introduced as the best choice for construction of wastewater treatment plant. This area is located 18 km southeast of Falavarjan city and has a limestone and marl bedrock.The area of selected zone is about 12 square kilometers, and has a good condition for future development.

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