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Research Article

Determining Optimal Locations for Biogas Plants: Case Study of Tehran Province for Utilization of Bovine and Aviculture Wastes

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A B S T R A C T

Given the world's growing population and energy demand, modern methods are developed to contribute to generating alternative energies. They aim to maintain the renewability of the supplied energy and decrease environmental contaminations. Biogas is a renewable energy carrier that has recently been under consideration in Iran. One objective of such plans is to find proper locations for installing and running the existing potentials and infrastructures. In this paper, Tehran, Iran is selected as the study area which is ranked the 1st in population density and proper infrastructures available here are accessible. According to the widespread poultry and cow-breading farms in this province, bovine and aviculture excreta are considered as raw materials in producing biogas. An inference network was established in this research for evaluating the process taking into account the infrastructural parameters, geomorphological constraints, resource availability factors, and limiting parameters such as protected/prohibited areas.In this paper, the fuzzy method was used to standardize the data and the fuzzy-analytical hierarchy process method was employed to weight the locating criteria in the geographical information system. The evaluation outcomes suggested certain zones in southern parts of the province in which the industrial livestock farms become frequently widespread and the suburb areas of smaller cities on the eastern part of the province are the most proper areas for this purpose.

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1. INTRODUCTION

The location of proper places for constructing power plants is among important issues for energy decision-makers. Access to primary energy resources, nearness to necessary infrastructures like electricity network, transportation roads, water resources, and no interference to prohibited areas such as environmental protected areas or military zones are the most noted factors that should be considered in selecting proper places for constructing power plants. For power plants that exploit renewable energy resources, besides the above considerations, considering the proper potential of and access to the renewable energy resources is of great importance. From the viewpoint of location and potential evaluation of different types of renewable energies, a large number ofstudies have been carried out in Iran and other parts of the world. For instance, one can point to the studies of Segheli et al. [1], Kiani & Veisinezhad [2], and Azadeh et al. [3] concerning the location selection for wind power plants and Nooshad et al. [4], Torabi et al. [5], and Ghadimi et al. [6] regarding small hydroelectric power plants. Similarly, several studies have been done in Iran and the world regarding the location of bioenergy-based power plants, among which the research by Omarni et al. [7] for solid waste incinerator power plants or Duarte et al. [8] for biofuels production facilities as well as the work of Franco et al. [9] for locating biogas plants might be mentioned.

Site selection of renewable energy generation plants is a sophisticated process that should take several influential parameters including limiting factors and criteria into account. One key step of this process is weighting various criteria in order to make a justified comparison and evaluate the importance of each criterion. Among the methods for weighting the criteria, Analytical Hierarchy Process (AHP), Equal Weighting, and Analytic Network Process (ANP) are more frequently applied.

One of the very powerful tools for locating various project plans (i.e., power plants, garbage disposal sites, or industrial complexes) is Geographical Information System (GIS) that is capable of combining criteria weighting tools and provides wide abilities of multi-layer spatial data processing. To establish energy plants, GIS is utilized for different purposes, as suggested in the studies of Klassen et al.[10] and Delaney et al. [11], for selecting proper locations for wind turbine power plants and as suggested in the study of Martin and Hannah [12] for locating conventional power plants, and Voets et al. [13] for determining the location of biomass power plants. Few studies including Ghazi and Omrani [14] have considered determing proper location for biogas power plants in Iran and surveyed the potentials of biogas in Iran's provinces using GIS software.

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On the other hand, eliminating environmental contaminations caused by livestock excreta release represents another motivation for simultaneous production of energy and sanitary organic fertilizer using anaerobic digestion process out of these sources [15-17]. Wahyudi et al. studied the applicability of the concept of biogas production to industrial dairy farms in Indonesia in terms of sustainability [18]. The role of biogas technology in solving the Peri-urban sanitation problems was also investigated by Sibanda et al. [19]. Of note, using biogas technology in medium- and large-scale plants for the purpose of energy generation and electricity sale to the national power grid has increasingly drawn much attention over the last decades in Iran. As a sub-activity of the current research, the talented regions of Iran for biogas production were appraised and consequently, Tehran province was identified as one of the appropriate areas due to the high potential of biodegradable resources and abundance of energy consumer entities and suitable infrastructures. One significant category of biomass resources in Tehran province is livestock wastes resulting from many animal breeding activities in suburb and rural areas. In terms of the logistics management of raw materials, the industrial cattle and poultry farms are more preferred than traditional counterparts due to their centrality and automated tools. In terms of proper site selection, it is important to identify the most appropriate locations for establishing biogas generation facilities taking into account various parameters and restricting issues. Therefore, this paper aims at employing GIS system along with multi-objective criteria evaluation for the purpose of presenting the most proper and talented areas for industrial biogas installation feeding by aviculture and bovine wastes on the provincial scale.

2. EXPERIMENTAL

In this research, the bovine and aviculture's excreta of industrial livestock farms were considered as the source of bioenergy and Tehran province was considered as the surveyed area. The importance of the selected bioenergy source is described in brief in Sub-section 2.1. Afterwards, important factors in determining the proper location for establishing biogas plants and effectiveness of each factor were further determined. With respect to the nature and the extent of the studied area and also incompleteness of required information in each of existing map scales, it is necessary to perform the process of location planning in a hierarchal manner in different stages. In this way, initial locations were determined ona smaller scale; then, a more precise study was done ona broader scale and proper locations were selected. To this end, the scale of 1:25000 was adopted to be surveyed following the appraisal of different types of provincial maps and information layers.

2.1. Short description of the study area

Tehran city as the capital is located between 34 to 36.5 degrees of northern latitude and 50 to 53 degree of eastern longitude and its surface area is about 12,981 km^2 [20].This province, as shown in Fig. 1, is confined to Mazandaran province from north, to Qom province from south, Markazi province from south west, to Alborz province from west, and to Semnan province from east. The city is home to 13 million population as of the latest sensus 2016 which composes 19 percent of the total Iran's population. It should be noted that 12,252,000 out of the province population (94 %) live in urban areas, while 1,161,000 individuals reside in rural residents [20]. This research generally covers the Tehran province and marginal parts of the neighboring provinces. According to the auxiliary survey in this research, there is a potential of more than 73 million cubic meters per year biogas production from bovine and aviculture wastes in this province, implying a figure of 5,620 cubic meter per sq. km per year biogas production density. Tehran province stands as one of the highly ranked provinces in Iran in this regard.

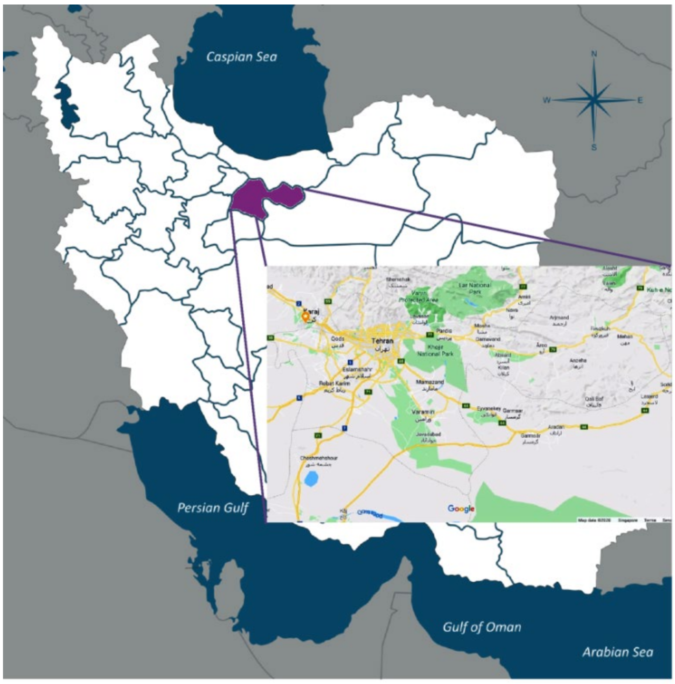

Figure 1. The location of the study area on the national map (source: Google maps)

3. METHOD

3.1. Methodology

The research method is implemented as follows; first, effective factors in determining the location of installing anaerobic digestion were specified and then, Boolean and fuzzy models were selected to combine the information. The objectives of selecting these models is to specify and eliminate the constrained areas for construction of anaerobic digestion using Boolean logic and binary maps and to determine the better remaining areas (allowed areas) for constructing anaerobic digestion plants.

3.2. The survey of effective factors and selection criteria

Determining aproper location for installing the anaerobic digestion greatly depends on complete and accurate knowledge of effective factors and the way of selecting them. The technical, economic, social, and environmental factors are determined by consulting the experts on anaerobic digestion and studying the relevant literature. Then, the factors with possibility of providing relevant data and modeling were selected. In fact, providing location layers for some factors and preparing them for the decision model can bedifficult, or even impossible.

Effective factors in determining the location of anaerobic digestion, the reason for their effectiveness, and the type of their effectiveness are given in Table 1. It should be noted that some factors may be eliminated or added depending on circumstances. The selection of factors in this research was mainly done following the method that had been employed by Rezaeisabzevar et al. [21] as well as by Cheng and Thompson [22]. Closure to the industrial units of cattle breeding or poultry farms as the sources of raw biomass is one of the most important factors in biogas plants; hence, the distance of no more than 10 km to the sources was adopted as a positive factor [19]. Regarding the availability of water resources, the distribution of legal underground water extraction wells or surface water transfer channels was taken into account for evaluating the process of site selection. Since access to the transportation network is another influential factor, the distance of less than 200 m to the asphalt roads or no more than 500 m from gravel roads was considered a positive parameter [22]. A buffer distance of minimum 200 m to the protected or prohibited areas or natural water bodies and a buffer distance of 75 m from the roads' axes were taken into account for biogas plant sites. Furthermore, experts' judgments and existing data from Tehran province were also employed in this procedure.

Table 1. Site selection criteria [21-23]

Criterion	Sub criteria	Importance reason	Criterion type	Standardization function	(f1, f2)
Raw materials	Water resources ranges	Water requirement for anaerobic digestion	Same distance	Fuzzy small	(200, 5)
Raw materials	Range of livestock	Reduction of shipment costs of raw material to anaerobic digestion	Density	Fuzzy small	(1000, 5)
Infrastructure	Asphalt roads, gravel roads, Foot routs	Ease of transportation	Same distance	Fuzzy small	(2000, 5)
Infrastructure	Power and gas transfer lines	Possibility of connecting the produced electricity or gas to the electricity or gas network	Same distance	Fuzzy small	(200, 5)
Population areas	Urban, rural	Nearness to the consumer	Density	Fuzzy large	(2000, 5)
Earth form	Slope, altitude	Possibility of construction	DEM	Fuzzy small	(10, 5)
Earth form	Flood way, fault	Possibility of construction	Same distance	Fuzzy large	(500, 5)
Constraint	Protected and prohibited areas	Possibility of establishment	Boolean	Real	Zero: prohibited area, 1: allowed area
Constraint	Forest	Possibility of establishment	Boolean	Real	Zero: prohibited area, 1: allowed area
Constraint	Mine	Possibility of establishment	Boolean	Real	Zero: prohibited area, 1: allowed area
f1 and f2 are middle point and dispersion values of fuzzy parameters, respectively.					

3.3. The studied combination model

Simultaneous attention to effective factors in determining the location of anaerobic digestion requires combining the related information layers. In this research, the Boolean and fuzzy models were used to combine the information and modeling in the GIS environment. ArcGIS was employed as a powerful software product along with ModelBuilder as one of its applied tools for this purpose. The steps of this combined model are given below [23]:

a) Determining the required locative and descriptive information;
b) Creating the required layers in ArcGIS;
c) Defining the proper factors for each information layer;
d) Preparing the factor map and re-categorizing them;
e) Determining the weights of the factor maps that affects the location;
f) Combining the factor maps and determining the optimal location;
g) Evaluating the results and drawing the suggestions.

3.3.1. Boolean logic

In the Boolean logic, membership of an element in a set is stated as zero (no-membership) or one (membership) [24]. In order to use the Boolean model in location, an input map is first prepared for each factor in the binary form. In this way, the value of one for each pixel unit represents the properness, while value of zero represents the improperness of location of that pixel. For example, the value of zero is assigned to protected areas in location of anaerobic digestion, while value of one is assigned to other areas. Then, the input maps are combined by Boolean operators AND/OR and create an output binary map. If the combination of maps is done using AND operator, then the pixels with the value of one represent locations where all criteria are satisfied. If the combination of maps is done using OR operator, then the pixels with the value of one represent locations where one or several criteria are satisfied [22].

Following this method, for instance, value of one is assigned to proper locations for building the anaerobic digestion facility in the output map, while the value of zero is assigned to improper locations in the output map.

1) All of the input factors are of the same value. In practice, it is not usually proper to consider equal importance for all location criteria. The weight of factors should be determined with respect to their relative importance.
2) The location units of each factor map that have the same value with that factor lie in one of the zero/one classes. For example, the value of one is assigned to all points that are

in a specific range of the roads in the map of connection roads, whereas those points are at different distances of the roads.
3) In the output map, the selected areas cannot be prioritized with respect to their properness with the related activity. In other words, the selected areas would have the same value in this model.

3.3.2. The fuzzy logic

The main characteristic of fuzzy logic compared to the classic logic is that it is able to state knowledge and experience of the human in the mathematical form. With respect to the fuzzy theory, membership of members in a set may not be complete, such that each member has a membership degree of one to zero. Unlike the Boolean (classic) logic, there is no certainty in fuzzy logic to consider an area fully proper or fully improper. The fuzzy sets are versus classic sets[25].

The OR operator is defined through Equation (1):

$$\mu c = \max\{\mu_1(x), \mu_2(x), \ldots, \mu_n(x)\} \tag{1}$$

where μA, μB, and μC represent the membership values of the pixel in the related layer.

This operator represents the union of the sets such that it extracts the maximum membership degree of the members and has not much accuracy in location. This operator uses the maximum function in combination and is equivalent to union. When using this operator for two membership functions, the maximum value of membership function is selected.

The AND operator is defined as Equation (2):

$$\mu c(x) = \min\{\mu_1(x), \mu_2(x), \ldots, \mu_n(x)\} \tag{2}$$

This operator represents the intersection of the sets such that it extracts aminimum membership degree of the members, i.e., it extracts the minimum value (weight) of each pixel among all information layers and applies it to the final map. This operator uses the minimum function in overlap and is defined as equivalent as intersect.

In independent parameters and when two or more parts of evidences necessary to prove the hypothesis must exist, using the AND operator is proper. The fuzzy multiplication operator is defined as relation (3):

$$\mu_{prod.} = \prod_{i=1}^{n} \mu_i \tag{3}$$

where μi represents the membership value of the pixel in the related layer of factor i.

In this operator, all of the information layers are multiplied. Due to the nature of zero and one numbers, which are the membership degrees in the fuzzy set, this operator causes the numbers to become smaller and tend to be zero in the output map. Therefore, fewer pixels would be in a very good class. For this reason, this operator is high sensitive concerning location. The fuzzy sum operator is defined in the equation:

$$\mu_{sum} = 1 - \prod_{i=1}^{n} (1 - \mu_i) \tag{4}$$

where μi represents the membership value of the pixel in the related layer of factor i.

In this operator, the complement of multiplication of complement of sets is calculated. For this reason, the values of pixels in the output map tend to one, unlike the algebraic multiplication operator. Therefore, more pixels would be placed in a very good class and the values of the final map would be greater. In other words, the strength of the factors with respect to each other and combination of maps would have incremental effect. For this reason, this operator applies very low sensitivity to the location.

The fuzzy gamma operator is defined as multiplication of fuzzy multiplication and fuzzy sum operators, as stated in Equation (5).

$$\mu_g = (\mu_{sum})^{\gamma} \times (\mu_{prod.})^{1-\gamma} \tag{5}$$

where the operators are described in Equations (3) and (4). The value of gamma (γ) is a number between zero and one by which a certain limit of gamma makes the mean value of μ>0.5; otherwise, the amount of gamma provides a normal distribution for the value of μ [26]. The accurate and informed selection of gamma creates the output values that represent flexible consistency between the decreasing tendencies of fuzzy multiplication and the increasing tendencies of fuzzy sum [27]. The data are gathered from various sources by different producers such that the method and procedures of data gathering and standardization are different. After preparing the data, the information layers are converted to raster and the pixel's dimensions are considered on the scale of 1:25000 and 30*30 meters. Then, the maps are standardized.

3.4. The maps of the Boolean model

The purpose of these maps is to specify and eliminate the areas with no possibility of constructing anaerobic digestion. These maps were created for geographical features such as lakes, mines, etc. If there are such features in a place, severe constraints would be imposed on constructing anaerobic digestion in that place or even ata specified distance to it. Therefore, maintaining a specified distance from geographical features is necessary. It should be noted that the objective of Boolean maps is only elimination of constrained areas and it is not necessary to rank the eliminated areas [22].In the raster mode, a binary constraint map is prepared for each constraining factor in which the value of zero is assigned to constrained areas for constructing anaerobic digestion and value of one is assigned to other areas. The factors for which the binary maps are prepared include protected areas, forests, and mines.

3.5. The maps of the fuzzy model

In the fuzzy maps, each feature is prepared such that the value of each location unit represents the properness of that location for constructing the anaerobic digestion. Being successful in using the fuzzy mathematics in different applications depends greatly on the definitions of proper membership functions. With respect to the effects of different factors in location of the anaerobic digestion and status of existing relevant data, small fuzzy and large fuzzy membership functions are used to fuzzify them [21].

Small fuzzy: f1 and f2 represent the middle point and the dispersion, respectively. The dispersion is stated as a number between 1 and 10. Equation (6) represents the related function in which the changes are depicted in Figure 2. As can be seen in this figure, the smaller the dispersion, the smoother the curve.

$$\mu(x) = \frac{1}{1+\left(x/f_2\right)^{f1}} \qquad (6)$$

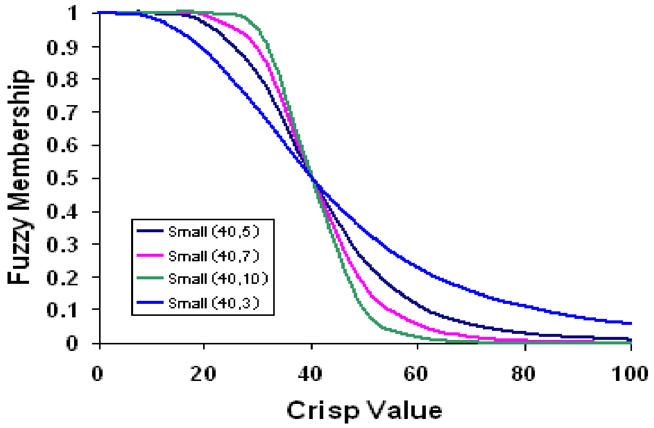

Figure 2. The small fuzzy chart

Big fuzzy: f1 represents the middle point and f2 represents the dispersion. The dispersion is a number between 1 and 10. Equation (7) represents the relation in whichits changes are given in Figure 3 and it is evident that the larger the dispersion value, the wider the fuzzy membership.

$$\mu(x) = \frac{1}{1+\left(x/f_2\right)^{-f1}} \qquad (7)$$

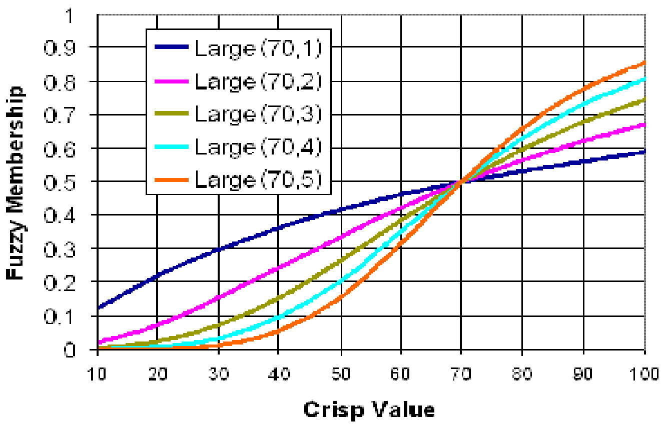

Figure 3. The big fuzzy chart

4. RESULTS AND DISCUSSION

4.1. The standardized fuzzy maps

In the following, some of the maps that are standardized with fuzzy method are given. The fuzzy map of rural population is depicted in Figures 4 as rural residents are influential population according to their employment in biomass production practices such as agriculture and animal husbandary, and they are potential consumers of anaerobic digestion products including energy carriers (biogas, electricity, heat) and digestate [17]. Figure 5 shows the fuzzy map of the roads. As mentioned before, road accessability is quite important for the projects that handle wastes such as landfills, solid waste recycling plants, and large biogas facilities. In this manner, a range of distances with lower and upper limits is significantly influential since the minimum distance to the roads is mandatory according to their legal buffer zones as well as some environmental concerns such as odor emission or landscape downgrading [21]. On the other hand, economical aspects of feedstock transportation impose an upper limit of economic distance from the roads, as emphasized by Franco et al, for locating biogas plants for a certain district in Denmark [9]. The areas marked by blue in Figure 5 are of high suitability in terms of access to the transportation network. These areas comply with the residential and industrial areas, but do not necessarily represent the suitable areas for biogas facility installations. The fuzzy map of rivers is combined with the maps of groundwater extraction wells and water transmission channels in order to form the fuzzy map of water resources, as shown in Figure 9.

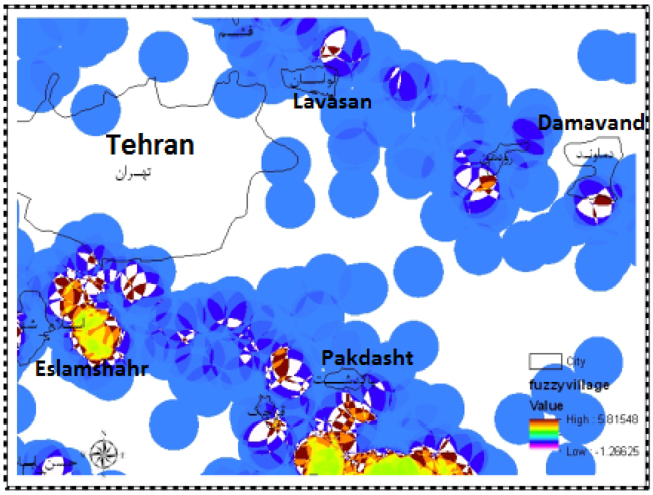

Figure 4. The fuzzy map of rural population

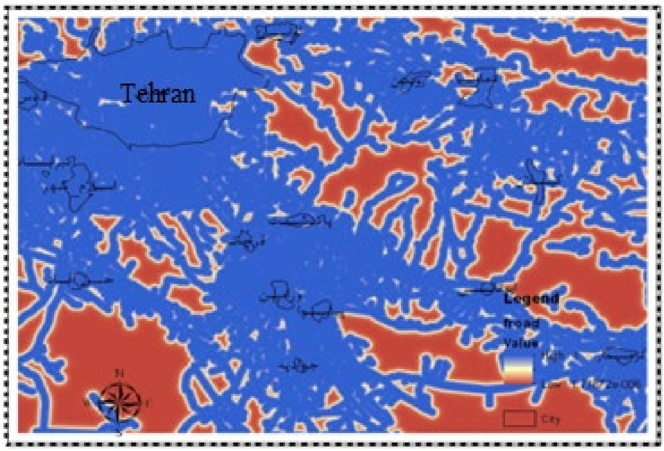

Figure 5. The fuzzy map of roads

4.2. Weighting the factors

In order to determine the relative importance of different factors of location, a weight is considered for each. In the location of anaerobic digestion plant, the weights of factors are determined using the AHP method based on the published relevant articles as well as experts' judgments [22]. In the AHP method, the decision-maker is asked to state a number from 1 to 7 for the relative importance of each criterion with respect to other criteria [24, 28]. Number 1 represents very low relative importance and Number 7 very high relative importance. However, in real world, it is very difficult to extract precise data pertaining to measurement factors since all human preferences are subject toa degree of uncertainty.

For this reason, fuzzy AHP methods effectively resemble human thoughts and perceptions. The weight of each factor is specified by fuzzy weighted averaging. The application of experts' opinion in the weighting procedure was also employed by Franco et al. for biogas plants locations [9]. A consistency ratio of 0.5 was allocated to acceptance in this research since the values below 0.1 were considered as acceptable, according to Saaty [28]. As a result of judgement amounts, the weights of criteria are givenin Table 2.

Table 2. Weighting the criteria [22, 26]

Main criterion	Weight of main criterion	Sub criterion	Weight of sub criterion
infrastructure	0.40	Asphalt road	**0.8**
		Gravel road	**0.2**
		Foot rout	**0.1**
Consumer	0.35	Town	**0.76**
		Village	**0.24**
Earth form	0.12	slope	**0.33**
		Altitude	**0.23**
		Flood	**0.24**
		Fault	**0.20**
Raw materials	0.13	Water	**0.4**
		Raw manure availability	**0.6**

4.3. Combining the maps and designing the network

After developing the factor maps of Boolean and fuzzy models, these maps are to be combined using operators of each model. The proper locations are identified by combining the maps obtained by Boolean and fuzzy models through a similar procedure examined by Cheng and Thompson [22].

The maps of Boolean model were combined using AND operator. In the obtained output map, the location units with value of one in all maps of constraining factors were assigned value of one. Likewise, the location units with value of zero in at least one map were assigned value of zero. In terms of the convinence, performance speed, and also its conceptual consistency to the maps of constraining factors, the Boolean model is the best model to combine these maps [22]. In these maps as shown in Figure 6, the objective is the complete elimination of constrained areas. The dark-pink colored areas in this map might be considered for biogas plants establishment; nevertheless, other factors should also be taken into account in order to filterize the inappropriate zones accordingly. Therefore, it is not necessary to considerthe weight value of factor or a specific class of a factor.

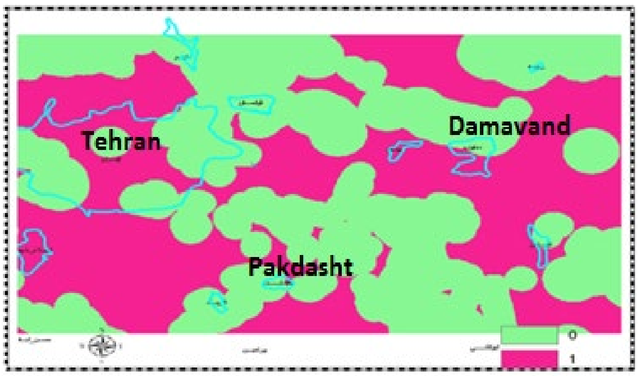

Figure 6. The map derived from combining the Boolean maps

4.4. Combining the fuzzy maps

After preparing maps of the fuzzy model, it is necessary to combine the maps using fuzzy operators. Selection of a proper fuzzy operator to combine different layers is done with respect to the relations and interactions of factors of those layers [21]. Usually, it is not possible to combine all required layers of an application only with one operator. Therefore, different operators are often used to combine different information layers instead of a single network operator. In this research, the designed inference network is depicted in Figure 7.

In the designed inference networks, instead of combining all factor maps in one stage, the factors are classed based on experts' knowledge, their nature and role in determining the proper location, and their relationships. The pertaining information layers are combined in different stages. For example, factors such as the earth slope and application, both of which are relevant to the physical form and morphology of the earth, can be considered in a class and combined from a certain viewpoint. It should be noted that selection of the fuzzy operators can be different according to different logics. If the role of water resources in the location is confined to only supplying the required water, no difference is considered between the surface water and underground water, and only one water resource is enough for supplying the required water; then, the water layers can be combined using OR operator.In this way, the pixels' values of the output map are determined with the value of one of input layers with the highest value in that pixel and the weighted values of two other factors are interfered in the output value. In other words, closeness to two or three water resources does not make any substantial advantage compared to closeness to only one water resource. Figure 8 depicts the obtained map.

In the combined fuzzy map of the connection roads, three information layers are used for the roads that include asphalt roads, gravel roads, and foot routs. With respect to the importance of each road type, the weight of asphalt road is considered as 0.8, the weight of gravel road is considered as 0.2, and the weight of foot rout is considered as 0.1 following the suggestions made by Rezayisabzevar et al. [21]. It is notable that the weight of crierion for transportation roads was adopted within a range of 0.286 to 0.499 as lower and upper limits by Franco et al. [9]. Figure 9 depicts the output fuzzy map. This map proposes many locations mostly in suburb areas and around the transportation roads with significant traffic.

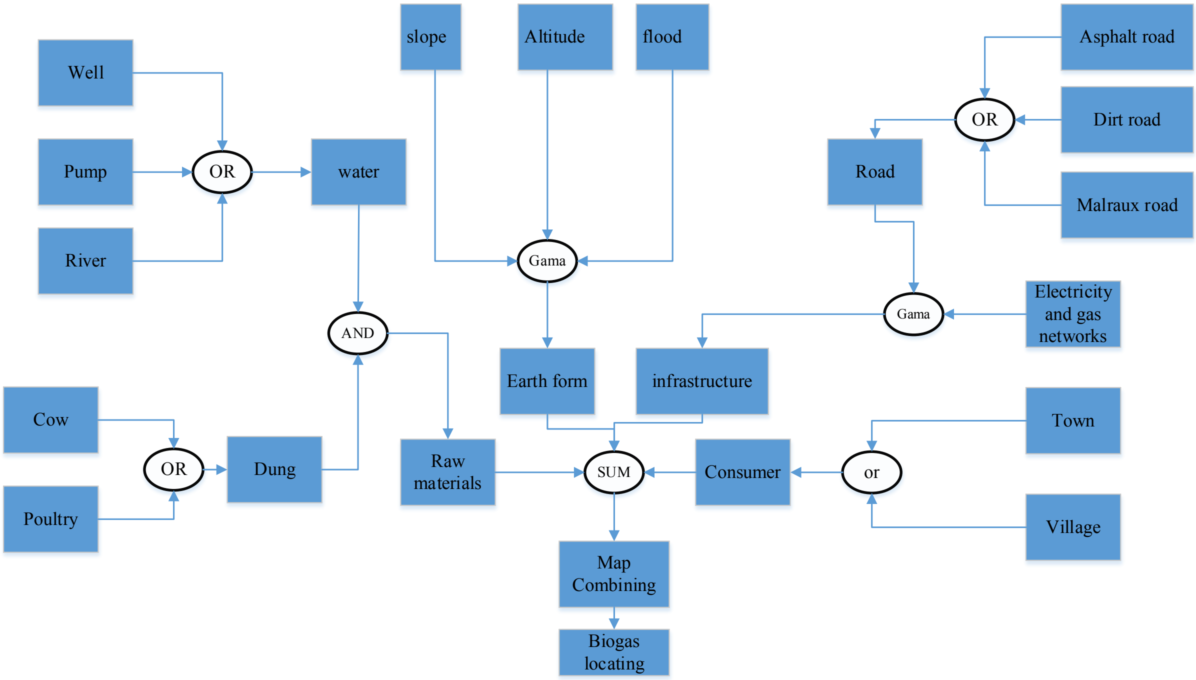

Figure 7. The inference network model

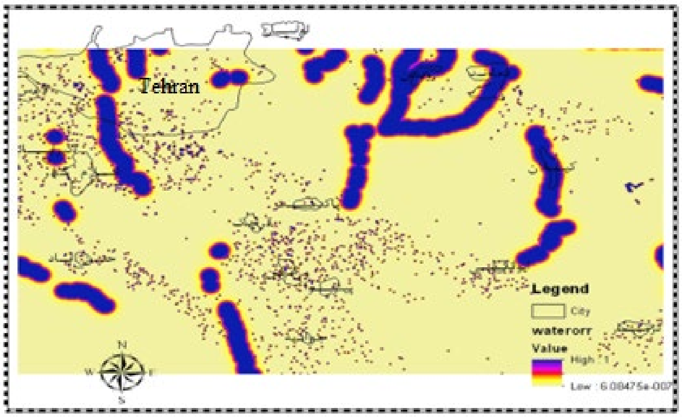

Figure 8. The combined fuzzy map of water resources

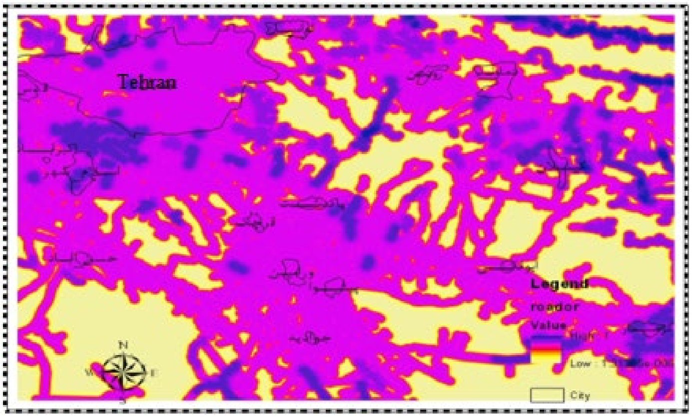

Figure 9. The combined fuzzy map of connection roads

By considering gamma equal to 0.8, the infrastructures map, which is obtained by combining information layers of electricity fuzzy network and connection roads, is depicted in Figure 10 which shows highly ranked zones for biogas plants as a function of closure to the transportation roads as well as to the power transmission lines.

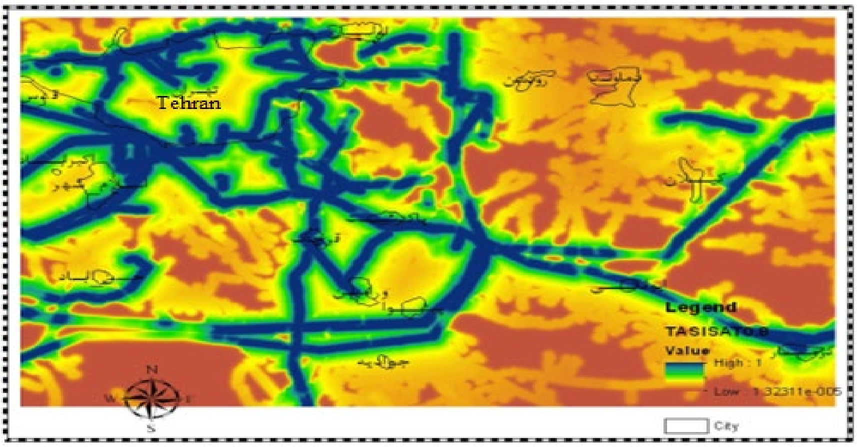

Figure 10. The fuzzy map of infrastructures

According to Figure 11, obtained by fuzzy combination of all layers, the dark blue areas are the most proper locations for constructing biogas power plants. In addition, the yellow-white areas are the least proper locations for this purpose. The areas marked by dark-blue color in southern parts of Tehran province certainly comply with the locations of abundant cattle farms and poultry farms such as the suburb of Eslamshahr. Furthermore, three other zones have been realized as appropriate locations for such purposes in the northern suburb of Lavasn, southern suburb of Rudehen, and southern part of Damavand county. The evidence of industrial livestock farms in the aforementioned locations along with the essential infrastructures complies with the outcomes of location evaluating process in this research.

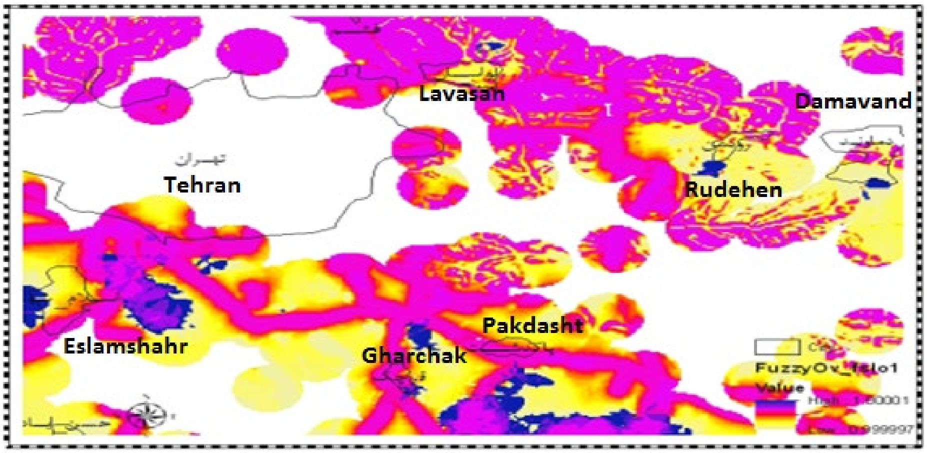

Figure 11. Ranking of proper locations for installation of industrial biogas plants

5. CONCLUSIONS

Utilization of fuzzy analysis method has many advantages including continuity of numbers in the map and greater closeness to the real world, which can guide managers and decision-makers to the right choices and greatly assist them in identifying proper locations for establishment of biogas plants. The final map shows that although there are proper areas in north Lavasan, Rudehen, and southern Damavand county for constructing such biogas plants, there are more proper areas in the southern part of Tehran province in the margin of Eslamshahr, Gharchak, and Pakdasht.

6. ACKNOWLEDGEMENT

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NOMENCLATURE

AHP	Analytical Hierarchy Process
ANP	Analytic Network Process
DEM	Digital Elevation Model
GIS	Geographical Information System
Greek letters	
μ	Fuzzy logic operator
μ_{prod}	Fuzzy multiplication operator
μ_{sum}	Fuzzy sum operator
Subscripts	
f1	The middle point of fuzzy value
f2	Dispersion of fuzzy value

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