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A comprehensive multi-criteria decision making-based land capability assessment for municipal solid waste landfill sitting

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Abstract
The municipal waste management has always been one of the most challenging environmental concerns. Today, although different strategies have been developed, sanitary disposal of municipal waste is still considered as one of the most widely used alternatives, especially in developing countries such as Iran. To investigate the land capability of Pishva, for landfill sitting, the important criteria were categorized in two groups of ecological and socioeconomic and then a multi-criteria decision-making model was used with decision-making trial and evaluation decision-making trial and evaluation (DEMATEL)-analytical network process (ANP) approach. First and foremost, the interaction of criteria was determined implementing DEMATEL. It was found that the soil depth criterion not only is the most effective but also is the most influenced one. Moreover, ANP structure was developed to weigh the criteria. In comparison to socioeconomic criteria, ecological ones play a more significant role. Afterwards, factor maps and constraints were standardized using fuzzy and Boolean logic, respectively, and all layers were combined to generate the final capability map of Pishva applying WLC method. The capability map showed that 71% of the area is not capable of landfilling, and only 5% of Pishva has a high capability. The results proved the great effectiveness of the methods proposed in this study.

Keywords ANP · Site selection · Fuzzy logic · Boolean logic · WLC · DEMATEL · Waste management

Introduction

Since the major human activities have always been along with the production of waste, directly or indirectly, considering the important impacts of wastes on the environment and public health in municipal solid waste management (MSW) is

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undoubtedly critical (Yan et al. 2017; Yukalang et al. 2017). Studies indicate that more than 1.3 billion tons of municipal waste was generated in 2012, and it is expected to increase to 2.2 billion tons a year, by the year 2025 (dos Muchangos et al. 2015). Therefore, urban waste management is a major challenge, globally (Eskandari et al. 2015). Numerous studies have proved that despite the various options in waste management, the sanitary landfill is still the most common one (Talalaj and Biedka 2016;Torabi-Kaveh et al. 2016; Yadav and Samadder 2018). Due to the fact that in the process of locating a landfill, a great range of different factors is effective such as technical, ecological, socio-economic, and environmental ones, this process involves the collection, storage, and processing of a significant amount of data (Demesouka et al. 2013; Hamzeh et al. 2015). Moreover, in addition to data quantity, the ranking of the criteria and comparing them with each other in terms of the degree of importance complicates the decision-making process. Hence, several studies suggest that using the geographic information system (GIS) and multi-criteria decision-making methods (MCDMs) is necessary due to the multiple criteria of site selection process (Kabak and Keskin 2018; Kharat et al. 2016). It should be noted that there are several approaches for MCDM, among which the most

common ones are analytic hierarchy process (AHP) and analytical network process (ANP) (Gemitzi et al. 2007). AHP is a method of assessing the relative significance of the criteria based on the pairwise comparison using a hierarchy structure (El Baba et al. 2015). The prerequisite of a hierarchy structure is that the priority of criteria of each level should not depend on the lower level criteria. Otherwise, AHP method is ambiguous, and the results are not reliable (Saaty 2004). Therefore, to modify this process, ANP was presented based on the super-matrix technique. By employing this technique, decision-makers will be able to decide based on inter- and intra-relation of the criteria in different levels of decision-making procedure to solve complex problems with non-classification structure (Khan and Faisal 2008). Literature review shows that various studies have been carried out conducting the mentioned method to locate municipal waste landfill sites, including MCDM method which is implemented through AHP and GIS to locate municipal solid waste landfill in Jaroft (Javaheri et al. 2006). The geomorphology, hydrology, and land use were the main criteria which have been taken into consideration in this study. The authors in Aragonés-Beltrán et al. (2010) reported that ANP is a significant method to help decision makers to make reliable decisions. In this study, four main groups of criteria named technical, economic, legal, and socio-environmental have been considered to site an adequate landfill in the Metropolitan Area of Valencia (Spain). In Ferretti (2011), ANP-based MCDM and simple additive weighting (SAW) were carried out to locate a suitable waste landfill in Torino considering both exclusionary and non-exclusionary criteria. The result of this study proved that this method is traceable. In Nazari et al. (2012), the authors used MCDM method based on Chang's fuzzy AHP and noted that it is more convenient for decision makers to set a value for an alternative by applying linguistic terms and fuzzy numbers. The researchers in El Baba et al. (2015) applied MCDM method with the help of AHP and weighted linear combination (WLC) to select an appropriate landfill in Gaza Strip, Palestine, considering different criteria such as land use, distance from the road, groundwater depth, elevation, and rainfall. Finally, three regions were suggested to establish landfills. The work proposed in Kharat et al. (2016) carried out a hybrid Fuzzy Delphi, Fuzzy AHP, and decision-making trial and evaluation (DEMATEL)-based MCDM approach to identify landfill sitting criteria evaluation. The considered criteria were public acceptance, hydrology, climate, soil, faults, land use, sensitive areas, habitat, site capacity, distance from road, and cost. The results indicated that this method is substantially capable of identifying the structures and interrelationships of mentioned criteria to be assessed by the decision makers. The authors in Rahmat et al. (2017) applied AHP-based MCDM to study the criteria preferences to investigate the suitable MSW landfills through site selection procedure in Behbahan (Iran). Moreover, simple additive weighting

(SAW) method was applied to combine the criteria of water resources, sensitive ecosystems, land cover and land uses, built-up areas, roads, slope, soil type, and waste generation places and their respective weights. As a result, five sites were candidate for more detailed surveys to establish a proper MSW landfill. In Jamshidi-Zanjani and Rezaei (2017) the combination method of ordered weighted average (OWA) and WLC was used to select the MSW landfill sites in Markazi province, Iran. In this study, 12 factors were categorized under the titles of environmental and socioeconomic criteria and studied their interaction patterns by ANP model. The results proved that these techniques are greatly qualified to reveal the reliable results in landfill sitting. The researchers in Liu et al. (2018) DEMATEL-based ANP was conducted as a GIS-MCDM approach to study the environmental, economic, and social criteria relations and preferences to site select the suitable food waste composting facilities. Although it seems slightly irrelevant to MSW landfill sitting, food wastes are the most considerable part of MSW, especially in sanitary landfills. The result of this study claimed that this method is highly potential in sitting procedures.

The present research aimed to

1. Develop an integrated approach in land capability assessment for municipal solid waste landfill site selection as a world wild challenging multi-criteria task
2. Employ ANP-DEMATEL-based MCDM, emphasizing two comprehensive logics named Fuzzy and Boolean

Materials and methods

The study area

Pishva, with an area of 21,000 ha and dry and very dry climatic conditions (low and unpredictable precipitation), is allocated in the southeast of Tehran province, in Iran between 35°18′29″N latitude and 51°43′36″E longitude (Fig. 1). The study area is 937 (m) above sea level. Demographic analysis proved that significant population growth has been observed between 2006 and 2016. Detailed information noted that the population rose sharply from 4521 to 75,750 people. Moreover, the municipality of Pishva acknowledged that the daily production of municipal solid waste in the study area has increased 1.75 times over these years, and it is beyond the scope of the current landfill capacity. Therefore, the necessity of determining the appropriate regions for new sanitary landfill in the region is critical (Khadamatshahri n.d.).

The steps of the study framework are presented in Fig. 2.

In this study, regarding the literature review and the study area features, various criteria involved in landfill site selection procedure were determined. Afterwards, by designing a questionnaire and consulting with experts, final criteria for landfill
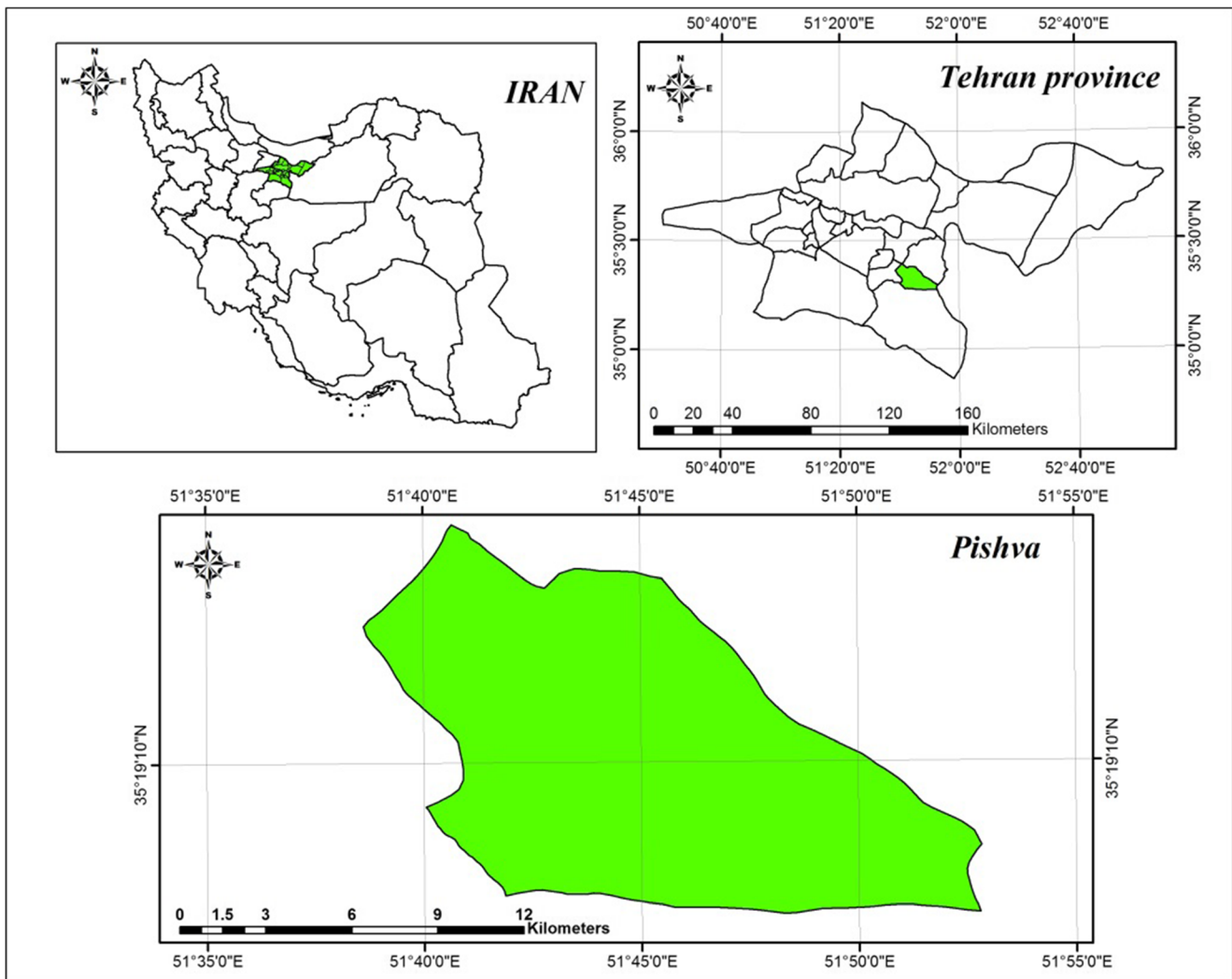
Fig. 1 Location map of the study area

sitting were selected based on Delphi method. Delphi is one of the most common, interactive, and structured techniques which relies on the experts' opinions that are driven with well-designed questioners. The fundamental principle of this commonly used method is that the decisions made by the structured group of individuals are more precise than those from unstructured ones (Hoa et al. 2018). Moreover, the reliability of Delphi only depends on the academic credit of the experts (the professionality level) not the number of them (Feo et al. 2018). In this study, the criteria were divided into two main groups: ecological factors including soil (depth and erosion), physiography (slope, direction), geology, and faults, and socioeconomic criteria including distance from the road, distance from the lands constructed, and distance from the airport and infrastructures. Then, their digital layers (thematic information) were provided, collected, and scrutinized to develop the database in GIS environment. It is important to be mentioned that the number of required questionnaires was calculated by Cochrane's formula and Morgan's Table, which is one of the most common methods (Aliani et al. 2017).

These questionnaires were designed employing Delphi method and including effective criteria to be distributed among 20 experts (20 questionnaires). These experts were asked to do pair wise comparison based on Tables 1 and 2 to identify the internal relations between criteria (DEMATEL) as well as the criteria preferences (ANP), later.

Decision-making trial and evaluation

In this study, DEMATEL method in MATLAB software was used to accurately assess the internal relations of criteria for evaluating the land capability of Pishva city for municipal solid waste landfill site selection. This is a comprehensive method based on the graph theory for developing and analyzing a structural model associated with complex cause-and-effect relationships among the factors of a problem. Diagraphs can describe the concept of the intensity of the causal interaction (relationship) numerically. Hence, the complex interaction between the components of a system can be modeled with DEMATEL method. In this case, the initial
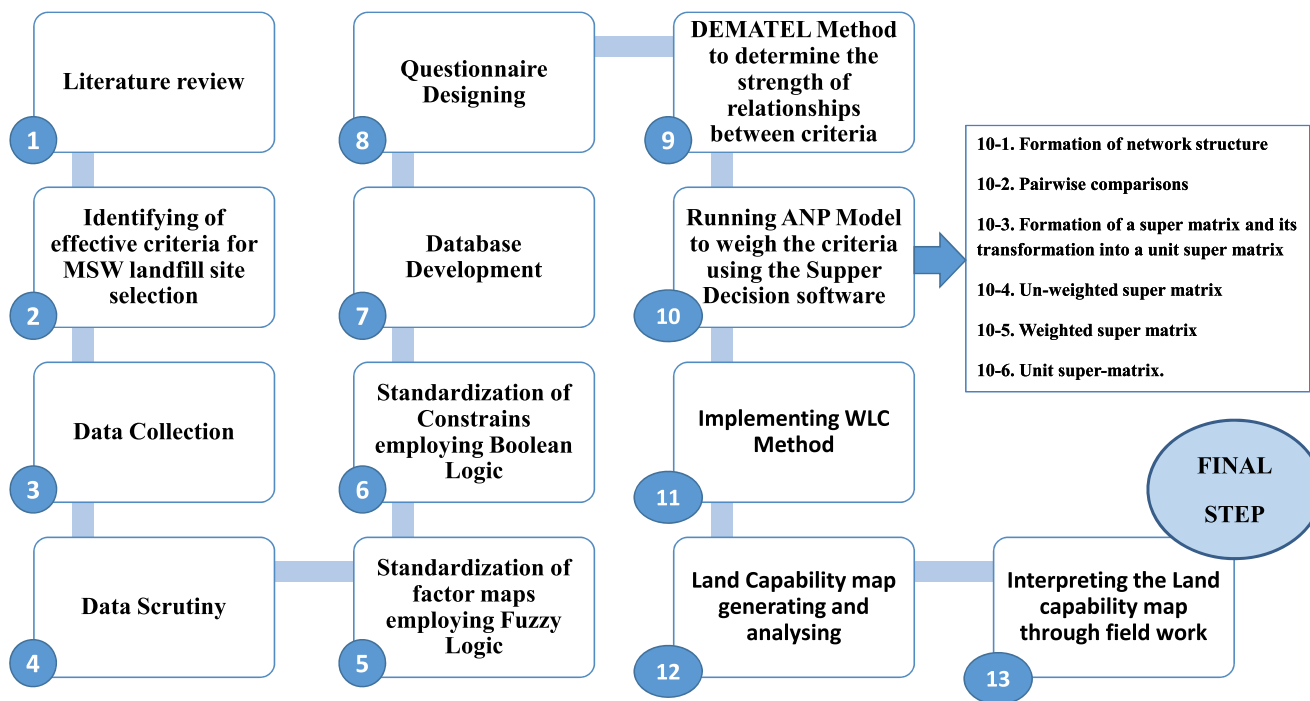
Fig. 2 Methodological flowchart of land capability assessment for MSW landfill sitting

effect of an element to the other one is shown as a value between 0 (no effect) and 1 (the absolute effect) (Ali Taghizadeh Herat 2012). The steps of implementation of this method are summarized as follows (Sadehnezhad et al. 2013):

1. Construction of the initial matrix of the direct relation and calculation of the mean matrix: In this step, H and n are the numbers of experts and the considered criteria, respectively. Each expert is asked to specify a level reflecting the effects of criterion i on the criterion j. These pairwise comparisons between the two criteria are expressed with, based on integers from 0 to 5 (Table 1 (Tseng 2009)).

The scores given by each expert form a matrix as follows:

$$X^K = \left[X_{ij}^K \right]_{n \times n}, 1 < K \leq H \tag{1}$$

In this case, $X^1, X^2, X^3, \ldots, X^H$ are the response matrices for each expert H, and each X^K element is the number resulting from X_{ij}^K. Finally, the $n \times n$ mean of matrix A for the opinions

of all experts can be calculated by averaging the H scores of experts, as follows (Gupta and Barua 2018):

$$A = \left[a_{ij} \right]_{n \times n} = \frac{1}{H} \sum_{K=1}^{H} \left[X_{ij}^K \right]_{n \times n} \tag{2}$$

2. Calculation of the normal matrix of the direct relationship: The initial matrix of the direct relation D is normalized through the following equations:

$$D = A \times S \quad i, j = 1, 2, 3, \ldots, n \tag{3}$$

$$S = \min \left[\frac{1}{max_1 \sum_{j=1}^{n} |Z_{ij}|}, \frac{1}{max_j \sum_{j=1}^{n} |Z_{ij}|} \right] \tag{4}$$

3. Calculation of the total relationship matrix: This matrix (T) is calculated using the equation below. In this equation, I represents the unit matrix:

Table 1 The linguistic variables and influence score in DEMATEL method

Linguistic variable	Influence score
No influence	0
Very low influence	1
Low influence	2
Moderate influence	3
High influence	4
Very high influence	5

Table 2 ANP pairwise comparison scale

Intensity of importance	Definitions
1	Equally important
3	Weakly important
5	Strongly important
7	Demonstratively important
9	Absolutely important
2, 4, 6, 8	Intermediate value between adjacent scale values

$$T = D(I-D)^{-1} \qquad (5)$$

In this matrix, the sum of rows and columns are represented with vectors r and c, respectively. Values c and r are calculated according to the following formulas:

$$c = \left(\sum_{j=1}^{n} T_{ij} \right) = [c_i]_{n \times 1} \qquad (6)$$

$$r = \left(\sum_{j=1}^{n} T_{ij} \right) = [r_i]_{1 \times n} \qquad (7)$$

The horizontal axis vector (r + c) is called the superiority vector, indicating the importance of each criterion. In addition, the vertical axis (r-c) is the relationship vector, representing the net effect that criterion i applies to the whole system (Pandey and Kumar 2017).

4. Determination of the threshold value: Since matrix T shows the effectiveness of a criterion, it is necessary for the decision makers to consider a threshold value for filtering minor effects. Since, only the effects larger than the threshold are considered in the diagram (Baykasoğlu and Gölcük 2017).

Implementation and analysis of cause-and-effect diagram: This diagram is obtained by drawing the ordered pairs (r + c,r-c) that provides a basis for better decision-making by identifying the internal relationships of the factors. To illustrate this diagram, a matrix called F is made (Wu et al. 2016). The values of this matrix are determined based on the matrix T and the threshold value (ω). So that if $\leq$ tij, then, fij = 1; otherwise, fij = 0 (Sadehnezhad et al. 2013).

Analytical network process

After assessing the questionnaires, using the results obtained from the implementation of DEMATEL method, the ANP model structure was developed in Super Decision software to weigh the criteria according to experts' opinions. It should be noted that in this study, Cochran method and Morgan table were applied to determine the number of questionnaires (Aliani et al. 2016) and accordingly, 30 questionnaires were designed by Delphi method to score the criteria as inputs to the ANP model after drawing the experts' opinions. The analytical network process (ANP) model represents a decision-making based on a network of criteria and options categorized in clusters. Given that all elements in the network can influence each other in any way, relatively complex conditions are created for modeling. In fact, the ANP model consists of two parts. The first part is a network of criteria and sub-criteria, and the second part involves a network of interactions between criteria and clusters (Eldrandaly 2013).

ANP consists of six steps:

1. Formation of network structure: At this stage, the criteria, sub-criteria, and effective options in the final decision are determined according to the experts' opinions and the DEMATEL method outcomes; in addition, the internal and the external relation between the criteria of a cluster are specified. It should be noted that in this study, Cochran method and Morgan table were used to determine the number of required questionnaires (Aliani et al. 2016), and accordingly, 30 questionnaires were designed by Delphi method to score the criteria and indicators as inputs to the ANP model, then the questionnaires were distributed among the experts.

2. Pairwise comparisons: It should be mentioned that the ANP model has been developed based on a pairwise comparison according to the internal and external relationships in the network structure (Wu et al. 2016). At this stage, the pairwise comparison matrices of the interaction between the criteria and the sub-criteria were formed considering the higher levels of the network and internal relations, in order to calculate the final weight of the criteria and sub-criteria. The pairwise comparison range can be seen in Table 2 (Aliani et al. 2016).

Once the pairwise comparison is completed, the weight vector (w) is calculated according to the following relation:

$$AW = \lambda_{max}W \qquad (8)$$

In this relation, the components of the relation are as follows:

A = pairwise comparison matrix
W = Eigen vector
λ_{max} = the highest numerical value

Then, the compatibility of the comparisons is evaluated by the following equation called the incompatibility coefficient. So that only the incompatibility coefficient less than 0.1 is acceptable (Azizi et al. 2014).

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (9)$$

3. Formation of a super matrix and its transformation into a unit super matrix: A super matrix is a partitioned matrix in which each section of the matrix represents the relationship between two levels of decision-making in the entire decision-making procedure. In order to achieve the general priorities in a system with interactions, the internal priority vectors (calculated Ws) are entered in the proper columns of a matrix. Therefore, a super matrix is obtained, each part of which indicating the relationship between two clusters in a system. As relation (10) shows, a super

matrix contains three levels of objective, criterion, and option in a hierarchy (Aliani et al. 2017):

Objective criteria option

$$W = \begin{array}{c} \text{Objective} \\ \text{Criterion} \\ \text{Option} \end{array} \begin{bmatrix} 0 & 0 & 0 \\ w_{21} & w_{22} & 0 \\ 0 & w_{32} & I \end{bmatrix} \quad (10)$$

In this matrix, vectors w_{21} and w_{22} typically show the impact of objective on the criteria, while vector w_{32} represents the impacts on the option. Here, I is the unit matrix (Arsić et al. 2018).

4. Unweighted super matrix: The elements of the (initial) unweighted super-matrix are obtained with the sum of Eigen vectors or the weight matrix obtained from the pairwise comparison between the clusters. The unweighted super matrix should be converted to a weighted super matrix, which means the sum of the all items in each column is one (stochastic matrix).

1. Weighted super matrix: After obtaining the unweighted super matrix, the sum of the elements of some columns is not equal to one. Therefore, in order to obtain a weighted super matrix, the weight of each element of the unweighted super-matrix column clusters should be multiplied into the relative significance of that cluster. So, a weighted super-matrix is obtained in which the sum of the elements in each column is equal to one (Arsić et al. 2018). The considerable point is that the assumption of equal weights for each cluster does not lead to have reliable outcomes. This is the common form of ANP which is not as capable as DEMATEL-based ANP to investigate the criteria interaction. Therefore, it is crucial to calculate the total matrix to identify the pattern of criteria relations. The infinite sequence of both direct and indirect impacts of criteria on each other is calculated in a form of geometric progressions and regarding the Graph theory (Gupta and Barua 2018). It is shown as $D(I-D)^{-1}$ in the following equation (Chen et al. 2018):

$$lim_{m \to \infty} D^m = [0]_{(n \times n)}, \left[lim_{m \to \infty} \left(I + D + D^2 + D^3 + \cdots + D^m \right) = (I-D)^{-1} \right] \quad (11)$$

Here,

$[0]_{n \times n}$ null matrix
I   the defining matrix
D   criteria

Moreover, the total matrix (T) is defined as follows:

$$T = \left[t_{ij}, \quad i, j = 1, 2, \quad , n \right] \quad (12)$$

$$T = D + D^2 + D^3 + \dots + D^m$$
$$= D \left(I + D + D^2 + D^3 + \dots + D^{m-1} \right.$$
$$= D \left[\left(I + D + D^2 + D^3 + \dots + D^{m-1} \right) (1-D) \right] (I-D)^{-1}$$
$$= D(I-D)^{-1}$$

$$(13)$$

2. Limit super-matrix: After calculating the weighted super matrix, it is time to form a limited super matrix. For this purpose, the weighted super matrix reaches to a limit power so that the matrix elements converge. In other words, the matrix row values became equal. The matrix obtained in this manner through the weight matrix is a limit matrix of the values of each row of which are equal (Chen et al. 2018). If the super matrix has a chain effect (meaning that the indices of the criterion "x" affect indices of the criterion "y," and the indices of the criterion y affect indices of the criterion "z" as well), then it is necessary that these impacts are also calculated. In this case, the relation is as follows:

$$W^\infty = \lim_{k \to \infty} W^k \quad (14)$$

In this relation, W is a weighted super-matrix and K is a very large arbitrary number (Azizi et al. 2014).

In order to consider influential factors in landfill sitting and carry out further analysis and combination, all criteria should be normalized by conducting Fuzzy and Boolean logic method. This procedure is because of the variety of scale ranges which is used in measurement of criteria (Mahini and Gholamalifard 2006). First and foremost, it should be taken into consideration that there are two sets of crucial criteria (layers), which are factor maps and constraints.

Factor maps (layers)

In the present study, the factor maps have been standardized based on the Fuzzy logic on the scale of (0–1) regarding the fuzzy membership functions. In the considered range of (0–1), as a value gets higher, it clearly indicates greater desirability. Therefore, to normalize the factor maps through Fuzzy approach, the threshold values of the criteria as well as the fuzzy membership function type is undoubtedly essential (Table 3).

As it is mathematically presented below, the linear scale conversion model used to convert factor layers to fuzzy forms (Aliani et al. 2016):

$$X_i = \frac{R_i - R_{min}}{R_{max} - R_{min}} * \text{Standardized Range} \quad (15)$$

Table 3 Fuzzy membership function type of the criteria (factor maps) in WLC- based MCDM method to assess land capability for MSW landfill sitting in Pishva

Criteria	Fuzzy membership type	Primitive limits	Fuzzy formats and values
Geology	Discrete		Value of sandstone, siltstone, marl and bituminous shale are 0.8; value of sandy clay and conglomerate are 0.6; value of limestone and sandstone are 0.2, sand equal to 0
Aspect (based on wind direction)	Discrete		Value of E is 1, value of NE, SE are 0.7, value of N,S are 0.4, value of W, SW, NW are 0.2
Slope (%)	Discrete		Value of 0–15% is 1, value of 15–25% is between 0 and 1, value of more than 25% is 0
Soil depth (cm)	Discrete		Value of very deep is 1, value of deep is 0.8, value of moderately deep is 0.6, value of semi-shallow is 0.4, value of shallow is 0.2
Erosion	Discrete		value of high erosion is 0.7, value of moderate erosion is 0.3
Distance from built-up area (m)	Monotonically decreasing (Linear)	0–2500 (m) buffer	Value of 2500–4500 m is 1, value of 4500–6000 m is between 1 and 0, value of more than 6000 m is 0
Distance from road (m)	Monotonically decreasing (Linear)	0–500 (m) buffer	Value of 500–2500 m is 1, value of 2500–4000 m is between 1 and 0, value of more than 4000 m is 0
Distance from fault	Monotonically increasing (Linear)		Value of 0–1500 m is 0, value of 1500–3000 m is between 0 and 1, value of more than 3000 m is 1
Distance from infrastructure	Monotonically increasing (linear)		Value of 0–600 m is 0, value of 600–1500 m is between 0 and 1, value of more than 1500 m is 1
Distance from airport (m)	Monotonically increasing (linear)		Value of 0–8000 m is 0, value of 8000–10,000 m is between 0 and 1, value of more than 10,000 m is 1

In this formula, X_i represents the pixel's value following standardization, while R_i, R_{min}, and R_{max} note the pixel's value before the standardization, the minimum value in the factor layer, and the maximum value in the factor layer, respectively. Also, standardized range denotes the range of changes in standardization procedure (Davtalab and Alesheikh 2018). For some criteria such as erosion, soil depth, geology, aspect, and slope because of discrete fuzzy membership type and no continuity between descriptive values, first and foremost, formula (12) was used and then a fuzzy field in the attribute table of these factor layers in GIS was defined. Afterwards, fuzzy values were added to the mentioned field.

Constrains

In this study, the Boolean logic was used to standardize the constraints. In this way, the limitation layers (constraints) were presented as maps with pixel values of (0 and 1), in which the 0 and 1 values indicated the appropriate and inappropriate regions, respectively (Aliani et al. 2016).

Weighted linear combination

In order to combine both factor layers and constraints, weighted linear combination method (WLC) was implemented. This method is based on the concept of weighted average. In this method, first, the weight of each criterion is multiplied into the corresponding layer of

that criterion and, finally, all the results are combined together. Moreover, it should be multiplied into the limit layers (constraints). The WLC method is applied according to the following mathematical formula (Gemitzi et al. 2007):

$$S_t = \left(\sum_{i=1}^{N} W_i X_i \right) \times \left(\sum_{j=1}^{K} b_j \right) \tag{16}$$

Here, the definition of the symbols of the mentioned formula is as follows:

W_i weight of criterion "i"
X_i criterion i (as a digital layer)
N   the total number of factor layers (criteria)
K   the total number of constraints
b_j each constraint's suitability index value
S_t total suitability

Result and discussion

Decision-making trial and evaluation-based analytical network process

Regarding the literature review and study area features, effective criteria for locating the MSW landfill site were determined. Due to the fact that several different criteria

are effective in the process of land capability evaluation for landfill sitting, the DEMATEL-ANP-based MCDM method was applied. Because the ANP model examines the relationships among criteria in the network to weigh the criteria, it was necessary to use the DEMATEL method to solve the problem of internal dependence of the criteria and find the way they interact with each other. Thus, first, the total relationship matrix (T) (Table 4) and then the total effects of the criteria (Table 5) were developed.

In the above table, (r + c), for each criterion means the sum of the effects that the criterion has accepted from the other criteria and the degree of significance that the criterion plays in the whole system. Moreover, (r-c) is the main effect that each criterion puts on the system. If (r + c) is positive, the criterion is the main influencer and if (r − c) is negative, the criterion is considered to be the main influenced. Therefore, in this study, according to Table 4, three criteria of soil depth, erosion, and distance from the road, which have the highest r + c, respectively, were considered as the main influencers in the site location process. Furthermore, the most negative values (r − c) in this table belong to the depth of the soil, distance from the fault, and distance from the infrastructure, respectively. This suggests that these three criteria are the most influenced criteria in the whole system. In addition, the important role of soil depth criterion in the whole system is known as the most effective and most influenced criterion. Afterwards, the affectability, effectiveness, and role of each criterion in the whole process of the multi-criteria decision-making method have been identified. The results were presented to the experts, so after drawing their opinions in the

form of questionnaires, the structure of the ANP model was designed to determine the weight of the criteria. As shown in Fig. 3, the important criteria were classified into two main categories of ecological and socioeconomic criteria.

As seen in the above table, the internal relations among the criteria, their impact and affectability have been investigated. In fact, this matrix is used to analyze the total effects of the criteria (Table 4).

By implementing the above model in Expert Choice software, the final weight of the criteria was determined. As shown in Table 6, ecological criteria with a total weight of 0.5607 compared with the socioeconomic criteria with a final weight of 0.4393 had a more important role in the land 7 assessment process in the studied area to determine the appropriate landfill sites. It is noteworthy that criteria of soil depth, erosion, and distance from the road with weight of 0.2, 0.1697, and

Table 5 Interaction between criteria in DEMATEL method

Criteria	r	C	r + c	r − c
Geology	3.133	1.443	4.575	1.691
Aspect (based on wind direction)	2.237	1.871	4.108	0.367
Slope (%)	1.977	2.156	4.132	− 0.177
Soil depth (cm)	2.189	10.354	12.57	− 7.752
Erosion	2.574	3.455	6.028	− 0.878
Distance from built-up area (m)	2.996	2.677	5.673	0.319
Distance from road (m)	2.836	3.142	5.978	− 0.305
Distance from fault	2.167	3.274	5.445	− 1.105
Distance from infrastructure	2.189	2.831	5.019	− 0.642
Distance from airport (m)	2.842	2.228	5.072	0.617

Table 4 Total relationships matrix in DEMATEL method

| Criteria	Geology	Aspect (based on wind direction)	Slope (%)	Soil depth (cm)	Erosion	Distance from built-up area (m)	Distance from road (m)	Distance from fault	Distance from infrastructure	Distance from airport (m)
Geology	0.135	0.223	0.283	0.305	0.413	0.345	0.421	0.404	0.315	0.287
Aspect (based on wind direction)	0.111	0.124	0.17	0.224	0.335	0.282	0.266	0.319	0.248	0.16
Slope (%)	0.106	0.148	0.122	0.178	0.281	0.22	0.247	0.271	0.235	0.158
Soil depth (cm)	0.162	0.168	0.233	0.189	0.359	0.264	0.333	0.356	0.181	0.238
Erosion	0.132	0.215	0.218	0.265	0.259	0.272	0.358	0.321	0.303	0.227
Distance from built-up area (m)	0.224	0.255	0.253	0.287	0.42	0.233	0.364	0.386	0.334	0.252
Distance from road (m)	0.195	0.172	0.277	0.281	0.4	0.296	0.26	0.345	0.333	0.27
Distance from fault	0.119	0.18	0.191	0.228	0.287	0.241	0.261	0.206	0.241	0.208
Distance from infrastructure	0.107	0.173	0.178	0.208	0.338	0.217	0.275	0.269	0.182	0.237
Distance from airport (m)	0.15	0.207	0.226	0.317	0.367	0.305	0.364	0.391	0.33	0.188
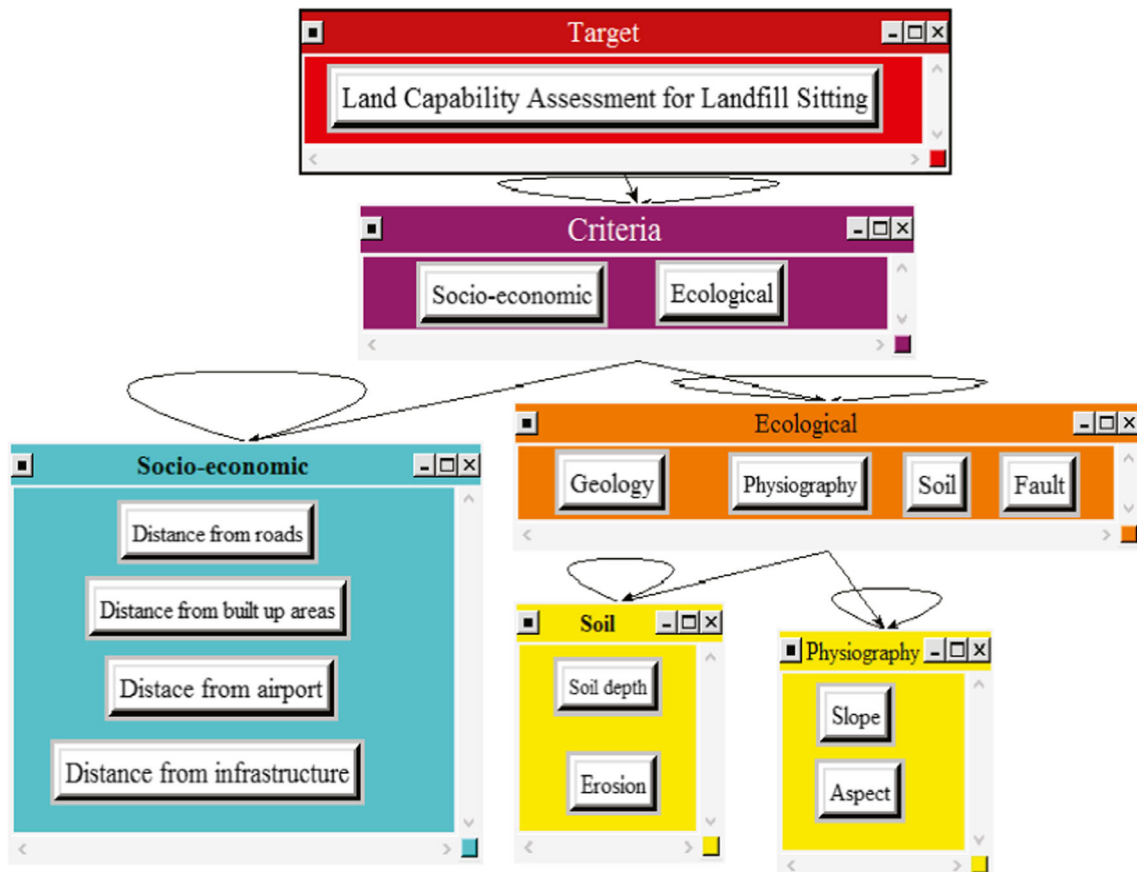
Fig. 3 ANP structure of MCDM based the land capability assessment for landfill sitting

0.153 are the most important criteria in comparison with other ones, respectively.

Combination of factor maps and constrains applying weighted linear combination

After determining the final weight of the criteria, preparing and standardizing all the required layers based on fuzzy logic and Boolean logic, the WLC process was performed. Then, after obtaining the final capability map (Fig. 4), it was reclassified based on Table 7 (Aliani et al. 2016).

As it can be observed in the final land capability map of the study area, the largest area of Pishva is categorized in the "no capability" class, which is almost uniformly visible in the region. Field studies showed that these parts were intended for residential, service, and some local small-scale industries, and it is clear that these lands do not have the capacity for landfills.

However, in the central part of Pishva, some parts are less capable for landfill sitting. According to the field survey, the agricultural lands of this section were cultured as dry farming, the most of which has undergone a change in use and currently, this section has been considered as a third-class agricultural land (poorly favored) in the land use map of the city of Pishva. However, in the central part of Pishva, some parts are less capable for landfill sitting. According to the field survey, the agricultural lands of this section were cultured as dry farming, the most of which has undergone a change in use and currently, this section has been considered as a third-class agricultural land (poorly favored) in the land use map of the city of Pishva. In addition, according to Fig. 4, it can be seen that the parts with medium and high capability for landfills are located in the south-east of the study area. Field surveys show that these regions are wholly arid and semi-arid areas, respectively, which have

Table 6 Total weight of criteria using DEMATEL-based ANP model

Criteria	Geology	Aspect	Slope	Soil depth	Erosion	Built-up area	Road	Fault	Infrastructure	Airport
Weight	0.05	0.02	0.024	0.2	0.1697	0.0903	0.153	0.097	0.11	0.086

Fig. 4 Land capability map of
Pishva for MSW landfill site
selection
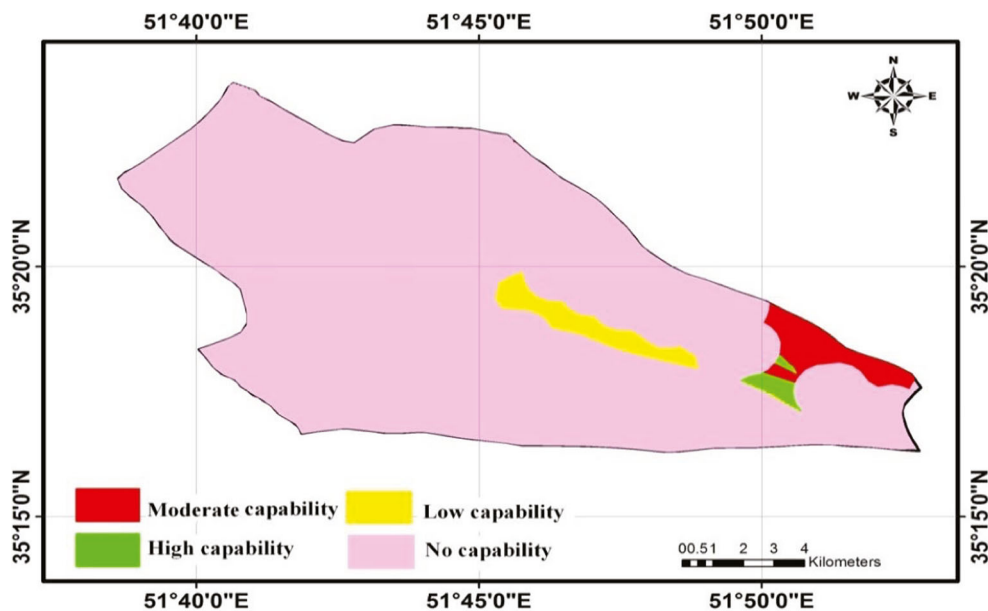
lost their past agricultural use due to land use and climate
changes. The area of the land capability classes of Pishva
is shown in Fig. 5.

Statistical analysis in Fig. 5 indicates that 71% of the study
area is categorized in incapability class. Meanwhile, 9 and 5%
of Pishva have the lowest and the highest capability for MSW
landfill sitting, respectively. Therefore, it can be concluded
that only a small area is capable of this utility. Nevertheless,
this means that these parts are potentially capable and other
factors like landfill social and environmental impacts, public
acceptance, and economic considerations and even land own-
ership should be taken into account in the final decision
(Gbanie et al. 2013). Furthermore, it should be noted that the
results of the study support the investigations reported by
Kharat et al. (2016) (El Baba et al. (2015), and Nazari et al.
(2012). They mentioned that MCDM method based on fuzzy
logic is one of the most applicable ways to consider both
qualitative and quantitative data to assist decision makers to
consider several criteria in the decision-making process. In
contrast to the mentioned studies and to evaluate the land
capability of Pishva, fuzzy logic has been carried out as well

as Boolean logic. This is because of considering constraints
such as airport, infrastructure, and built-up polygons.

Moreover, although the result of the present study is in
agreement with Kharat et al.'s (2016) conclusion regarding
the potential of DEMATEL method to provide the decision
makers with a comprehensive view of the problem and make
the decision-making procedure more reliable, the applied type
of this method made the significant difference between the
studies (Kharat et al. 2016) carried out AHP-based
DEMATEL while the ANP based one has been employed in
the current study. The current study strongly proves the claim
of Liu et al. (2018) that D-ANP is the proper technique of
MCDM to reveal precise results. It should be mentioned that
AHP process organizes the components of a system in a hier-
archical model so that each hierarchical element can only be
related to its high-level element, and this dependency can
continue linearly up to the highest level. In other words, in a
hierarchy, dependencies should be linear (from top to bottom
and vice versa) (Rashidi et al. 2017).Therefore, in this study,
the ANP model was conducted due to the inability of AHP to
consider the internal dependencies of the criteria. In the
other hand, in contrast with AHP, ANP model is greatly
able to identify correlations and interrelationships be-
tween effective criteria and consider them in the
decision-making process (Chen 2016). Moreover, the
pattern of criteria influences can be easily investigated
to identify the most and the least influential criteria,
better. This feature significantly assists the urban plan-
ners to make decisions, accurately. Another important
point is that the literature review suggests that various
studies have considered different criteria for locating
landfill sites. Although the selection of effective criteria
in the study depends on the study area features, it is

Table 7 Reclassification of WLC generated Pishva land capability map
based on the pixel value

Land capability class number	Land capability class type	Pixel value
1	Extreme capability	0.8–1
2	High capability	0.6–0.8
3	Moderate capability	0.4–0.6
4	Low capability	0.2–0.4
5	No capability	0–0.2

Fig. 5 Area of land capability classes in Pishva (ha)
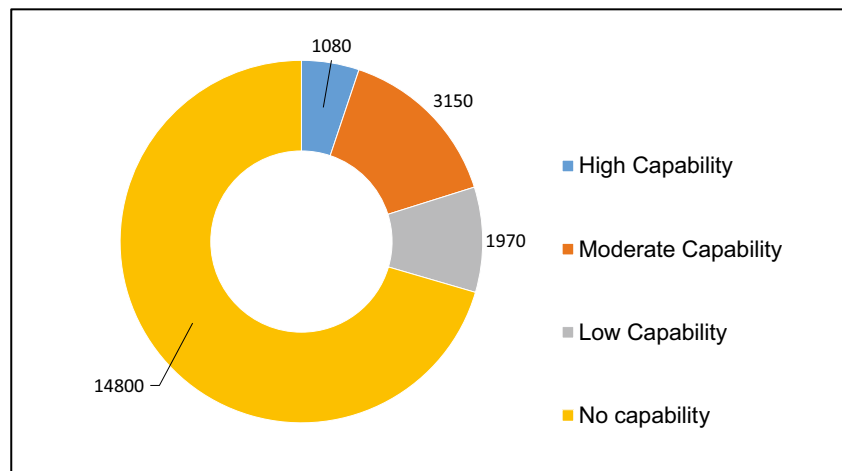
undoubtedly necessary to consider criteria like soil depth, erosion, geology, and a safe distance from infrastructures in all studies of land capability assessment for landfill sitting. Some similar studies regarding the investigation of the mentioned criteria are compared in Table 8.

Considering soil depth and erosion is crucial due to the leachate permeability and contamination of soil and water resources. Furthermore, by considering geology criterion, the areas with permeable bedrocks or active tectonic plates are taken into account. It is noteworthy that criteria of safe distance from infrastructures like energy transmission lines, gas pipes, and so on is essential in these studies (Basnet 2015). Obviously, in this study, criteria including distance from the mine, railways, sensitive areas of the environment, historical buildings, and surface water resources like rivers, springs, and lakes have not been considered due to the lack of being in the study area and the adjacent areas. Moreover, there were no groundwater resources in the region because of the severe drought in the study area.

Table 8 The comparison between MSW landfill site selection investigations based on the considered criteria

Reference	Criteria			
	Infrastructure	Geology	Soil depth	Erosion
Chabuk et al. (2017)	✓		✓	
Alexakis and Sarris (2014)		✓		
Basnet (2015)	✓			
Foomani et al. (2017)			✓	✓
Jafari et al. (2017)	✓	✓		
Yazdani et al. (2017)	✓	✓		
The current study	✓	✓	✓	✓

Conclusions

Nowadays, MSW management has become a pressing concern, undeniably. Although waste separation, recycling, composting, reuse, reduce, and energy recovery are some of the critical strategies, in many countries, especially in developing ones such as Iran, sanitary disposal is still the most common option. Regarding the environmental risks of the MSW landfills, landfill sitting has become a severe challenge, globally. In Pishva, because of the immigration to the urban areas and growing population, the per-capita production of MSW has increased dramatically. Studies indicate that the existing landfill capacity will be completed in the next 5 years. Therefore, it is necessary to assess the land capability of the study area to identify suitable regions for other landfills. Thus, in this study, according to the experts' opinions and literature reviews, effective criteria were investigated and grouped into two groups of ecological and socioeconomic criteria, which means not only the natural but also the important man-made factors were taken into consideration. Soil depth, erosion, geology, and infrastructure are the most common crucial criteria that occasionally are neglected in MSW landfill sitting process, but the significant point is that they were clearly considered in this study. Furthermore, the DEMATEL-ANP combined model was applied to consider both the internal and external relationships of the criteria, as well as weighing them. As this hybrid model has a great potential to take even slight relationships between the criteria into account, it boosted the accuracy of this procedure. This is the considerable difference between this approach and other frequently used ones such as ANP, AHP, or even DEMATEL-AHP. Also, due to the multiplicity of criteria, the necessity of making accurate decisions, considering experts' comments and the study area features, MCDM approach emphasizing WLC model was employed based on the Fuzzy and Boolean logic to generate Pishva land capability map of MSW landfill sitting. It is crucial to be mentioned that all these complex procedures were carried

out using GIS which is a proper tool for landfill sitting regarding its high capability to manage and analyze a substantial amount of spatial and attributive data (non-spatial) obtained from various sources (Ranjbar et al. 2018). In this study, since the landfill sitting is a multi-task process and it undeniably needs to take numerous criteria, regulations, and details into consideration, GIS was a significant platform for database designing, data scrutiny, data conversions and preparations, considering limitations in a shape of buffering, standardizing the layers by applying fuzzy and Boolean logics, combination massive data including factors, constrains and D-ANP-driven weights via WLC model and reclassifying and analyzing the final suitability map. Regarding the study findings, this comprehensive approach is considerably able to assist the decision makers due to the integration of 5 models, namely, Delphi, Cochrane and Morgan, Fuzzy and Boolean, DEMATEL, ANP, and WLC to consider all the aspects, completely.

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