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COMBINING FUZZY-ANALYTIC HIERARCHY PROCESS TO IDENTIFY SUITABLE LANDS FOR RESIDENTIAL DEVELOPMENT BASED ON LANDFORM IMPACTS

Mohsen Dadras*[a,c], HelmiZulhaidiMohdShafri[a,b], NoordinAhmad[a], BiswajeetPradhan[a], SahabehSafarpour[d]
[a] Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, Serdang, Selangor, Malaysia
[b]Geospatial Information Science Research Centre (GISRC), Faculty of engineering
[c]Faculty of Engineering, Department of Civil Engineering, Islamic Azad University, Bandar Abbas, Iran
[d]School of Physics, UniversitiSains Malaysia, 11800 Penang, Malaysia
*Corresponding author. Tel: +60 17 354 2063
E-mail addresses: mohsen.sci@gmail.com or m.dadras@iauba.ac.ir

Abstract

Understanding the morphological characteristics of urban land is necessary in urban planning. Identify the morphological characteristics of unbalanced is very essential in determining and controlling of land use. Environmental planners are usually faced with difficult decisions, such as selecting the location of a new facility subject to multiple conflicting criteria. Unbalanced environmental morphology is necessary for targeted and controlled land use. Morphologically unbalanced environments are not safe for human activities. New methods and tools for urban planning and development are important in decision making and public management. The main problems in the development of Bandar Abbas City include natural barriers, lack of planning, and asymmetric development of urban land. The objective of this study is to identify suitable lands for residential development based on landform impacts. Hence, this study identifies lands suitable for residential development by using geospatial information system (GIS) and fuzzy analytic hierarchy process (FAHP) based multi-criteria decision making. GIS is applied for visualization, classification (criteria and sub-criteria), and calculation, whereas fuzzy AHP is utilized for assigning weights of criteria and preferences of candidate lands. The fuzzy approaches used in this study are fuzzy extent analysis, centroid defuzzification, and the alpha level cut method. The usefulness of the new suitable site for residential development is evaluated by computing adaptability index for each pixel in the GIS environment. Results show that approximately 8% of the study area is suitable for residential development because of its good landform properties.

Keywords Residential area, MCDA, AHP, FAHP, Bandar Abbas City

Introduction

Population growth and land development have a causal relationship. Hence, understanding the different factors involved in residential development is indispensable. Criteria for developing new settlements in urban regions with natural features and morphology were established. Morphological factors that may be more important in geographical studies, capabilities and bottleneck of human activities on the ground that it's formed [15, 26]. This concept, identifies landform as a subset of geomorphology in geography [32]. Landform pertains to the shape and structure of the earth, which includes mountains, flats, boreholes, soil properties, faults, surface waters, and ground waters [1]. The identification of lands suitable for residential development is affected by the uncertainty in describing and ranking available alternatives based on landform parameters (quantitative criteria).

Various studies applied geospatial information systems (GIS) and quantitative model to identify lands suitable for urban development. However, these studies only considered a few parameters [7, 11, 13]. These studies also focused on urban land development [20]. For example, Dai et al. (2001) used GIS technology for the geo-environmental evaluation of urban land use planning in Lanzhou City and its neighborhood in Northwest China. This evaluation includes topography, surficial and bedrock geology, ground water conditions, and historic geologic hazards. Park et al. (2011) and Malczewski (2004) combined GIS and land suitability index to forecast and deliver land uses for regional planning.

Multiple MCDA has been used in literature to identify suitable lands. Various approaches such as artificial neural network (ANN), TOPSIS, ELECTRE, FR, and LR were also used to rank alternative lands, especially those in natural and environmental problems [17, 3, 38, 1]. The analytic hierarchy process (AHP) developed by Saaty (1980) is a structured technique used to analyze decisions and identify optimized alternatives [10]. AHP is a partial form of the analytic network process and compares the tangibles and intangibles [36]. AHP can be combined with the fuzzy set theory of Zadeh (1965) to facilitate flexible judgment and decision making. FAHP is a synthetic extension of classical AHP when the fuzziness of the decision maker is considered. Despite the convenience of AHP in investigating quantitative and qualitative criteria of multi-criteria decision-making problems based on decision maker judgments, the presence of fuzziness and vagueness in many decision-making problems may contribute to the ambiguous judgment of decision makers in conventional AHP [2].

Many researchers used FAHP to solve or find problems from different aspects, such as site selection [29, 23], land use and land cover [39, 24], monitoring potential landfill site [41], supplier selection [21], and new construction areas [31].

The present study identifies lands suitable for residential development using GIS and fuzzy analytic hierarchy process (FAHP). The inherent uncertainty in these decisions is also considered. Appropriate lands for residential development are identified based on morphological characteristics and landform impacts. Settlements that are far from natural and environmental crisis centers are prioritized. Therefore, multi-criteria decision analysis (MCDA) is appropriate for evaluating the alternatives.

The first statistics released by Iran census in 1956 indicates that the number of Iranian cities was 199 with a 31% proportion of urban population. The number of cities increased to 1200 in 2011 and the proportion of urban population exceeded by 75% of the total [6, 19]. Large urban centers, such as Tehran [6], Mashahd[16], and Isfahan [14], are experiencing transitional residential area growth processes from compact to outspread forms. This phenomenon results in the development of a residential area around urban centers. Bandar Abbas City is limited by natural and structural barriers because of urban growth boundaries. Natural barriers to development include rocky cliffs and mountain in the north and coastline in the south. Structural barriers to residential area growth can be cited to military land use in the east (air force) and west (novel force). The recent increase in the population growth of Bandar Abbas City has resulted in the demands for the construction of new residential lands. The identification of lands suitable for residential development is essential for such purposes.

Study Area

Bandar Abbas city is located in South of Iran and beside the Persian Gulf and it is capital of Hormozgan province (Figure 1). It is one of the most important southern ports of Iran and it used to be named Bandar Gambroun. It is located in a hot and humid region. Summer continues almost nine months in this city. The temperature fluctuates between 44 and 2 Celsius degrees during the hottest and coldest day of the year, respectively. The average precipitation in Bandar Abbas is almost 200 mm. Bandar Abbas is surrounded by mountains and high altitude regions from North and sea from South. Hence, general slope of the city is from North to South. A considerable area of the city including Sourou district in South West of the city, southern side of Imam Khomeini street between ShilatKhor and GourSouzanKhor and South of Nakhl-e-Nakhoda district are smooth land with altitude between 0.6 to 5 meters higher than sea level. Starting Iran-Iraq war while prominent commercial ports of Iran such as Khoramshahr and Abadan were destroyed, ShahidRajaee commercial port in Bandar Abbas became the main and most strategic commercial port of Iran. In the beginning of 90s, when the war finished, economic growth of Iran increased drastically. It changed form -1.2 percent in 1975 to 2.5 percent in 1990. The aforementioned factors as well as establishment of refinery, steel and aluminum industries, increased migration of job seeking population to Bandar Abbas. Tourist attraction is another functionality of this city as it has several commercial centers, it is seaside, and it consists of coral islands and lots of natural landscapes. Annually more than 5 million people visit Bandar Abbas and its nearby islands.

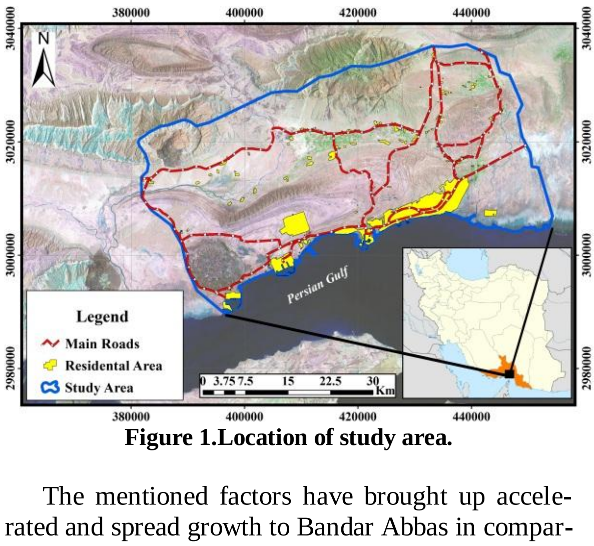

Figure 1.Location of study area.

The mentioned factors have brought up accelerated and spread growth to Bandar Abbas in comparison with other cities of the country. According to census of Iranian Statistics Center the population of Bandar Abbas was about 520000 in 2012. Considering 2.3% growth rate it will be 820000 by 2030.

Thus, Bandar Abbas will be considered as one of the large cities of Iran.

Material and Methods

Figure 2 shows the methodology used in this study. Suitable lands were identified by creating a geodatabase with data collection and geospatial analysis. Site assessment includes AHP consistency verification and disparate FAHP. A geospatial database of geomorphology, geology, fault, soil, land use, digital elevation model, slope, and hydrology was constructed. A geomorphology layer was first created using aerial photo (1:25000) and geology data. The border of geomorphological units was established, and the final map was prepared with field visits. The geologic and fault maps used were provided by the Geological and Survey of Iran. The soil map (1:100000) of the study area was obtained based on the spatial and attribute data of Food and Agriculture Organization. Field survey and soil classes were identified using the soil Manson table. The Aster image satellite, topography data (1:25000), and field visits were used to prepare land use map. The digital elevation model (DEM) was extracted by contour line and spot height of topography map. The slope layer was created by interpolation with the DEM layer. Topographic data were used to provide distance from the river map. The data were used to identify lands suitable for the construction of residential areas.

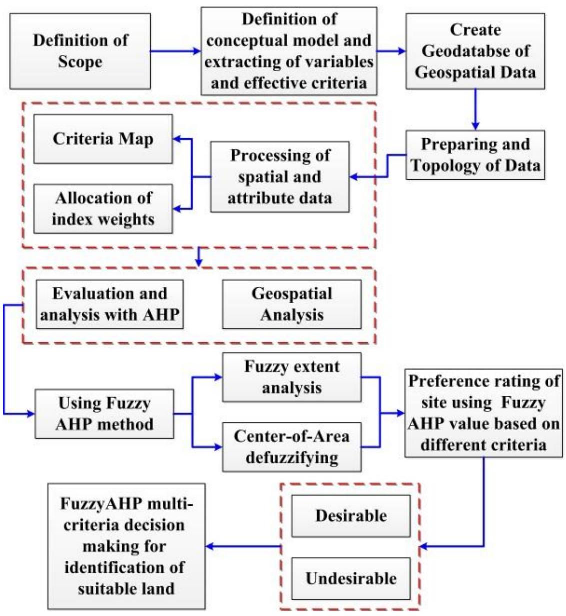

Figure 2. The methodology used in this study.

Analytical Hierarchy Process (AHP)

AHP, which was developed by Saaty (1995), is used to organize and analyze a problem by breaking it down into smaller constituent parts that can be calculated to prioritize each hierarchic level of criterion using pairwise comparison judgment. This method is efficient in solving complex decision-making problems with a few alternatives and numerous criteria. The relative importance or priority of criteria to other criteria is compared based on pairwise comparison. In pairwise comparison, the weights for identifying the priority of criteria and the advantage of AHP over other decision-making methods are assigned arbitrarily. AHP can be used to transfer intellectual evaluation of relative weights (significance and preference) to a set of priority ratio scale and overall score [37]. The hierarchical model for solving a problem creates different criteria of a main scenario and specifies the weight of each criterion through simplification and prioritization of criteria based on pairwise comparison. The first step of each hierarchy is a goal or objective, whereas the last level is an evaluation of alternatives [37].

Saaty (1980) introduced pairwise comparisons at each hierarchical level using a reciprocal matrix. A set of matrices is generated in Eq. (1), where Ã is the reciprocal matrix and each entry (a_{ij}) of Ã indicates the relative importance of a factor i compared with factor j using a scale of 1 to 9 (Table 1) [34].

$$\tilde{A} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

The pairwise comparison index a_{ij} of the first parameter of matrix triangle should be defined by the decision maker. The last parameter of the matrix triangle is derived because it represents the reciprocal $\left(a_{ij} = \frac{1}{a_{ij}}\right)$ for all diagonal entries for $(i = j), a_{ij} = 1$. Several mathematical techniques, such as eigenvector, geometric mean, and arithmetic mean, can be used to calculate the vector of priorities (weights) from the reciprocal matrix. No significant difference exists between the vectors of priorities. Normalization based on geometric means of the row was suggested because it provides an easy method to obtain approximate priorities (weights). This stage requires normalization for each column of the matrix. Averaging is conducted over each row. The structure of the pairwise comparison matrix is not consistent; that is, $(i, j{:}\ a_{ij} \neq w_i/w_j)$. A consistency value is recommended to ensure consistency in the pairwise comparisons and related weight estimation.

Saaty (1980) discovered a suitable measurement scale for pairwise comparisons. The verbal judgments in this scale are expressed as a degree of preferred reciprocal to express the inverse relationship (Table 1). The consistency index (CI) is calculated as

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (2)$$

where λ_{max} is the principal eigenvalue of the pairwise comparison matrix and n is the dimension of the comparison matrix. The final inconsistency in the pairwise comparison is computed using the consistency ratio (CR).

$$CR = \frac{CI}{RI} \quad (3)$$

The ratio index (RI) is the average of the CI of 500 randomly generated matrices. The comparison must be modified to reduce the inconsistency if the CR is higher than 10%. The priorities are available, and they aggregate with a weighted sum to obtain the global priorities of the alternatives.

FAHP

FAHP is used to verify judgment by prioritizing the machine tool selection criterion and weighing them in the proximity of vagueness. The identification of alternatives and explanation of problems are conducted by hierarchical structure analysis and fuzzy set theory. These approaches allow the decision maker to express conveniently the approximate or flexible preferences using fuzzy numbers, which add fuzziness to the input and comparison judgment process [4]. Fuzzy set theory [40] is designed to model the fuzziness of human reasoning [25]. This study uses the FAHP approach illustrated by Cheng (1992). FAHP prefers triangular fuzzy numbers (TFNs) based on linguistic variables for pairwise comparison. The extended analysis method derives systematic extent value for fuzzy comparison matrices. FAHP technique based on extent analysis can be applied to identify problems [21]. The descriptions of the fuzzy set and extent analysis method for FAHP are provided below.

The membership function $\mu_A(x)$ of a fuzzy set operation is a special fuzzy set, where x takes its values on the genuine line, $R: -\infty \leq x \leq \infty$ and $\mu_F(x)$ is a member function from R to the range of real numbers, which is generally scaled to the interval [0,1]. A TFN represents the relative importance of each pair of criteria in the same hierarchy and can be marked as M= (l, m, u), where $l \leq m \leq u$. Parameters l, m, and u represent the lowest possible values in a fuzzy event. The triangular fuzzy membership function of M fuzzy number is illustrated in specified in Eq. (4).
When l=m=u, it is a non-fuzzy number by convention [9].

$$\mu_M(x) = f(x) = \begin{cases} 0 & x < 1 \\ (x-l)/(m-l) & l \leq x \leq m \\ (u-x)/(u-m) & m \leq x \leq u \\ 0 & x > u \end{cases} \quad (4)$$

A linguistic number is a variable, wherein the value is illustrated in linguistic intervals. The concept of a linguistic variable is very efficient in comparison matrices; the linguistic scale can express the fuzzy uncertainty when the decision maker is making a decision [22, 40].

Fuzzy extent analysis

Linguistic variables were defined for several levels of priority to perform a pairwise comparison among fuzzy parameters (Table 1). A Likert scale of fuzzy number from $\tilde{1}$ to $\tilde{9}$ is employed. The tilde (~) indicates that the scale is for FAHP. Table 1 depicts the AHP and FAHP comparison scale that specifies the linguistic variables that propose the importance of criteria and the alternatives to modify the scaling scheme for judgment matrices.

Table 1. Triangular fuzzy number of linguistic used in this study.

Linguistic variable	Triangular fuzzy number	Reciprocal triangular fuzzy numbers
Equally important	$\tilde{1} = (1,1,1)$	(1,1,1)
Judgment value between equally and moderately	$\tilde{2} = (1,2,3)$	(1/3,1/2,1)
Moderately more important	$\tilde{3} = (2,3,4)$	(1/4,1/3,1/2)
Judgment values between moderately and strongly	$\tilde{4} = (3,4,5)$	(1/5,1/4,1/3)
Strongly more important	$\tilde{5} = (4,5,6)$	(1/6,1/5,1/4)
Judgment value between strongly and very strongly	$\tilde{6} = (5,6,7)$	(1/7,1/6,1/5)
Very strongly more important	$\tilde{7} = (6,7,8)$	(1/8,1/7,1/6)
Judgment values between very strongly and extremely	$\tilde{8} = (7,8,9)$	(1/9,1/8,1/7)
Extremely more important	$\tilde{9} = (9,9,9)$	(1/9,1/9,1/9)

Fuzzy judgment matrix $\tilde{A}(a_{ij})$ can be expressed mathematically by TFN via pairwise comparison.

$$\tilde{A} = (\tilde{a}_{ij})_{n\times n} = \begin{pmatrix} 1 & \tilde{a}_{12} & \tilde{a}_{13} & \cdots & \tilde{a}_{1(n-1)} & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \tilde{a}_{23} & \cdots & \tilde{a}_{2(n-1)} & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ \tilde{a}_{(n-1)1} & \tilde{a}_{(n-1)2} & \tilde{a}_{(n-1)3} & \cdots & 1 & \tilde{a}_{(n-1)n} \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \tilde{a}_{n3} & \cdots & \tilde{a}_{n(n-1)} & 1 \end{pmatrix} \quad (5)$$

Judgment matrix $\tilde{A}$ is a $n \times n$ fuzzy matrix including number $\tilde{a}_{ij}$.

$$\tilde{a}_{ij} = \begin{cases} 1, & i = j \\ \tilde{1}, \tilde{3}, \tilde{5}, \tilde{9} \text{ or} \ldots\ \tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1}, & i \neq j \end{cases} \quad (6)$$

Let $X = \{x_1, x_2, \ldots, x_n\}$ be an object set and $U = \{u_1, u_2, \ldots, u_m\}$ a goal set. The method can be implemented based on fuzzy extent analysis with respect to each object for each corresponding goal, g_i, which results in m extent analysis values for each object, given as $M_{k_i}^1, M_{k_j}^2, \ldots, M_{k_i}^n, i = 1,2, \ldots, n$. All $M_{k_i}^j\ (j = 1,2, \ldots, m)$ are TNFs that represent the performance of the object x_i with regard to each goal u_j[29].The various steps of fuzzy extent analysis [8] are as follows [3]:

Step 1: The fuzzy synthetic extent value is specified in the following equation using the proportion to the ith object:

$$S_i = \sum_{j=1}^{m} M_{k_i}^j \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{k_i}^j\right]^{-1} \quad (7)$$

To obtain $\sum_{j=1}^{m} M_{k_i}^j$, the fuzzy sum operation m extent analysis values is performed for a special matrix such that

$$\sum_{j=1}^{m} M_k^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_i\right) \quad (8)$$

To receive $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{k_i}^j\right]^{-1}$, the fuzzy sum operation of $M_{k_i}^j\ (j = |1,2, \ldots, m)$ values is implemented such that

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{k_i}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \quad (9)$$

The inverse of the vector in Eq. (9) is calculated such that

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{k_i}^j\right] = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (10)$$

Step 2: The degree of possibility of $M_i \geq M_j$ is specified as

$$V(M_i \geq M_j) = \sup_{y \geq c}\left[\min\left(\mu_{M_j}(x), \mu_{M_i}(y)\right)\right] \quad (11)$$

This formal is illustrated in Eq.(12) for two fuzzy numbers. This formula can be equivalently expressed as follows:

$$V(M_i \geq M_j) = hgt(M_i \cap M_j) = \mu_{M_j}(d) = \begin{cases} 1, & m_i \geq m_j \\ \frac{u_i - l_j}{(u_i - m_i) + (m_j - l_j)}, & l_j \geq u_i i, j = 1, n; j \neq i \\ 0, & Otherwise \end{cases} \quad (12)$$

where d is the ordinate of the greatest intersection point D between $\mu_{m_{l_j}}$ and μ_{m_i}. The values of $V(M_j \geq M_i)$ and $V(M_i \geq M_j)$ are required to facilitate the comparison of $M_j$and M_i.

Step 3: The degree possibility of a convex fuzzy number to be greater than Z convex fuzzy number $M_i (i = 1,2, \ldots, z)$ can be specified by

$$V(M \geq M_i, M_j, \ldots, M_z) = V[(M \geq M_j) \text{and } V[(M \geq M_i) \text{ and } (M \geq M_z)] = \min V(M \geq M_i), i = 1,2,3, \ldots, z. \quad (13)$$

Assume that

$$d'(A_i) = \min V(S_i \geq S_z) \quad (14)$$

The weight vector for z=1,2,…,n; z≠i is given by

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_n))^T \quad (15)$$

where$A_i (i = 1,2, \ldots, n)$ has n elements.

Step 4: The normalization priority vectors are specified as

$$W = (d(A_1), d(A_2), \ldots, d(A_n))^T \quad (16)$$

where W is a non-fuzzy number.

Centroid defuzzification

Ross (1995) proposed the centroid defuzzification method of transforming fuzzy triangular number into real numbers. This method can be used to identify actual alternative priorities and overall score. A real number z^* that corresponds to the center of area of $\tilde{C}$ can be calculated for a convex fuzzy number $\tilde{C}$.

$$z^* = \frac{\int \mu_{\tilde{c}}(z) z dz}{\int \mu_{\tilde{c}}(z) dz} \quad (17)$$

Alpha level cut (α-cut) method

Fuzzy α-cut is used to resolve fuzzy numbers into crisp numbers. Fuzzy extent analysis is applied in this method to calculate the fuzzy weight and performance matrices for both alternatives under each criterion content and criterion. Then, a fuzzy weighted sum performance matrix (P) for alternatives can be derived by multiplying the fuzzy weight vector relevant to the criteria with the decision matrix for alternative under each criteria and summing up the acquired vector $\tilde{p} = \tilde{x}_i \times \tilde{w}^T$

$$\tilde{p} = \begin{pmatrix} (l_1, m_1, u_1) \\ (l_2, m_2, u_2) \\ \vdots \\ (l_n, m_n, u_n) \end{pmatrix} \quad (18)$$

where n is the number of alternatives.

According to Pan (2008), α-cut based method checks and measures the fuzzy number. The α-cut method measures fuzzy numbers (A and B) in the interval of their α-cuts $A_\alpha = [a_\alpha^-, a_\alpha^+]$ and $B_\alpha = [b_\alpha^-, b_\alpha^+]$. A is smaller than B for all $a \in (0,1]$, which is denoted by $A \leq B$, if $a_\alpha^- < b_\alpha^-$ and $a_\alpha^+ < b_\alpha^+$. Accounts of α-cut method are selected for uncertainty in the fuzzy intervals. The α-cut analysis can be used to transform the total weighted performance matrices into interval performance matrices, which prepare α-Left and α-Right for each alternative as follows:

$$\tilde{p} = \begin{pmatrix} (\alpha Left_1, \alpha Right_1) \\ (\alpha Left_2, \alpha Right_2) \\ \vdots \\ (\alpha Left_n, \alpha Right_n) \end{pmatrix} \quad (19)$$

$\alpha Left = \alpha \times (m - l) + l,$

$\alpha Right = u - \alpha \times (u - m)$

Lambda function (λ) and crisp value normalization

After the application of α-cut analysis, α-Right (maximum range) and α-Left (minimum range) are derived and converted into a crisp value by applying the λ function, which represents the optimistic, moderate, or pessimistic attributes of the decision maker. An optimistic decision maker would prefer the maximum λ of fuzzy estimates, a moderate decision maker will take the medium λ, and a pessimistic decision maker would take the minimum λ in the range of [0 , 1].

$$C_\lambda = \begin{pmatrix} \lambda_1 \\ \lambda_2 \\ \vdots \\ \lambda_n \end{pmatrix}, \quad (20)$$

$$C_\lambda = \lambda \times \alpha Right = (1 - \lambda) \times \alpha Left \quad (21)$$

C_λ is the crisp value relevant to λ. Finally, the crisp values should be normalized because the elements of the pairwise comparison matrix have different scales [18].

$$C_{\lambda n} = \frac{C_{\lambda n}}{\sum C_{\lambda n}} \quad (22)$$

Result and Dissuasion

A residential area should be located in an open plain. The degree of geomorphological layer is depicted in Figure 3-A. Table 3 shows that the land located on a plain (fine material) is the highest in this criterion. Figure 3-B and Table 3 show land use layer with different classes. Candidate lands located in low density were assigned higher scores. DEM with a scale of 1:25000 (produced by survey organization) was used to create the height layer. Figure 3-C shows that the land located between 0 and 40 m above sea level scored the highest in this criterion. The slope layer was derived from DEM. The land with the highest score belonged to the 0% to 3% class in this criterion. Other effective geologic parameters (Figure 3 and Table 3) were included in the geological organization data. The stiffness and strength of the earth are essential in building residential area. Alluvium formation obtained the highest score for land location. Soil pattern is an important factor for the construction of surface and subsurface in a residential area. The lands in the study area that are located in semi-deep to deep soil with gravel were assigned with higher scores (Figure 3-F and Table 3).

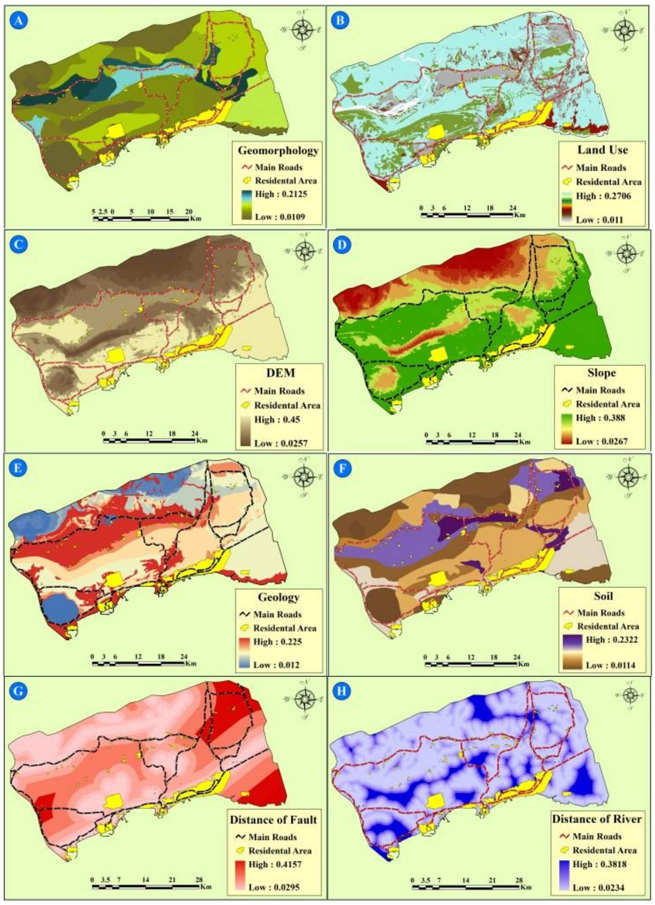

Figure 3. Thematic maps of study area: (A) Geomorphology, (B) Land Use, (C) Height, (D) Slope, (E) Geology, (F) Soil, (G) Distance of Fault, (H) Distance of River.

Active faults in Bandar Abbas County are approximately 112 km. The distance from the faults is important in determining residential area. Lands located more than 1200 m away from the faults scored the highest in this criterion (Figure 3-G and Table 3). The last essential factor considered in this study is the distance of rivers. The lands were scored based on their distance from the river and flood way. The lands close to the river were avoided, whereas lands located more than 4000 m away from the river scored the highest in this criterion (Figure 3-G and Table 3). The eight thematic maps were visualized and calculated using the Envi 4.8 and ESRI Arc GIS® software environment.

Therefore, FAHP for sub-criteria and criteria was applied to investigate the consistency of MCDM. Figure 4 shows the results of FAHP for the eight criteria. Five locations with lands suitable for the construction of residential areas were selected. Approximately 8% of the study area is suitable for residential development (Figure 5).

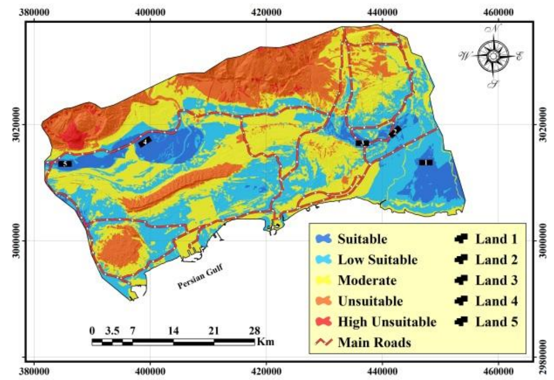

Figure 4.Classification of priorities and new land for building residential area.

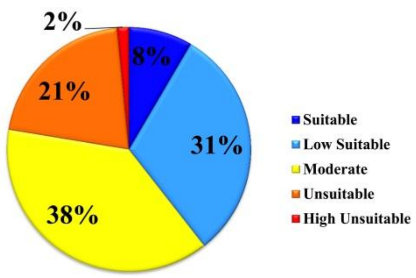

Figure 5.Percentage of classification priority.

Table 3. Pairwise comparison of land selection sub criteria and criteria for residential area, CR and computed fuzzy synthetic extend.

Geomorphology (GEOM)		Geology (GEO)		Soil (SO)	
Class	Fuzzy synthetic extent	Class	Fuzzy synthetic extent	Class	Fuzzy synthetic extent
PLf	(0.1116,0.1686,0.2573)	Qal	(0.1174,0.1733,0.2576)	A	(0.1195,0.1763,0.2599)
PLg	(0.0968,0.1505,0.2353)	Plc	(0.1010,0.1544,0.2342)	B	(0.1103,0.1626,0.2408)
Af	(0.0800,0.1273,0.2023)	Mn	(0.0866,0.1335,0.2057)	C	(0.0935,0.1393,0.2083)
Saf	(0.0669,0.1086,0.1752)	Aj	(0.0785,0.1210,0.1868)	D	(0.0791,0.1218,0.1866)
Gf	(0.0557,0.0923,0.1511)	Qt	(0.0618,0.0979,0.1541)	E	(0.0671,0.1044,0.1611)
Pf	(0.0485,0.0811,0.1338)	Gs	(0.0514,0.0826,0.1315)	F	(0.0553,0.0871,0.1363)
H	(0.0354,0.0623,0.1064)	Grm	(0.0391,0.0649,0.1059)	G	(0.0433,0.0695,0.1105)
Hk	(0.0302,0.0537,0.0936)	Rz	(0.0330,0.0549,0.0900)	H	(0.0288,0.0488,0.0809)
Hq	(0.0223,0.0411,0.0723)	As-Ja	(0.0227,0.0397,0.4463)	I	(0.0189,0.0336,0.05750)
BR	(0.0189,0.0346,0.0613)	Bgp	(0.0165,0.0296,0.0514)	J	(0.0164,0.0275,0.0458)
TD	(0.0176,0.0310,0.0551)	Kgp	(0.0126,0.0222,0.0388)	K	(0.0121,0.0197,0.0340)
M	(0.0125,0.0225,0.0424)	Gu	(0.0105,0.0169,0.0285)	L	(0.0065,0.0088,0.0128)
U	(0.0103,0.0170,0.0299)	Sp	(0.00649,0.0092,0.0144)		
Sd	(0.0060,0.0086,0.0136)				
PLf: Plain (fine material), PLg: Plain (gravelly material), Af: Alluvial fan, SAf: Salt Alluvial fan, G: Glacis (fine material, Pe: Pediment (fine material), H: Hills, Hk: Hills (karstic), Hq: Hills (quaternary deposition), BR: Bed River, TZ: Tidal Zone, M: Mountain, U: Urban Area, Sd: Salt dome		Qal:Alluvium,Qt:Alluvial-Terraces-Gravel-Fan, As-Ja: Limestone,DolomaticLimestone,Plc:Conglomerate-BakhtiaryFm.,Grm:Guri Limestone member, Kgp:Limestone-Shale-Dolomite-Khami Group, Bgp: Limestone-Shale,Bangestan Group, Rz:Sandstone-Marl-Razak Fm., Aj:Red Marl-Sandstone-Aghajari Fm., Gs: Anhydrite-Marl-GachsaranFm.,Gu:Grey Marl-GurpiFm.,Mn: Gray Marl, Mishan Fm., Sp: Hormoz Salt Plug		A: Deep to very deep soil, B: Semi-deep to deep soil, C: Semi-deep to deep soil with gravel, D:Very deep soil with moderate to heavy texture, E:Shallow to deep soil with gravel, F: Soiless or Soil is too shallow, G: Semi-deep to shallow soil with gravel, H: Shallow to semi-deep soil with salinity and gypsum, I: Soil is too shallow to shallow gravel, J: Very deep soils with small texture, K: Soilless or Shallow soil with gravel, L: Shallow soil with high salinity and gypsum	
λ_{max} =15.1622, CI=0.0894, RI=1.57, CR=0.0569		λ_{max} =14.2968, CI=0.1080, RI=1.56, CR=0.0692		λ_{max} =12.9562, CI=0.0869, RI=1.48, CR=0.0553	
Land Use (LU)		Height (H)		Slope (SL)	
Class	Fuzzy synthetic extent	Class	Fuzzy synthetic extent	Class	Fuzzy synthetic extent
R	(0.1463,0.1937,0.2500)	0-40	(0.2726,0.3617,0.4830)	0-3	(0.2579,0.2703,0.4522)
BL	(0.1252,0.1618,0.2108)	40-80	(0.1998,0.2777,0.3851)	3-5	(0.1793,0.2582,0.3680)
SL	(0.0972,0.1344,0.1847)	80-160	(0.1261,0.1812,0.2578)	5-10	(0.1064,0.1626,0.2401)
SHL	(0.0824,0.1173,0.1649)	160-320	(0.0706,0.1057,0.1549)	10-15	(0.0704,0.1111,0.1677)
F	(0.0675,0.0975,0.1386)	320-640	(0.0343,0.0526,0.0791)	15-30	(0.0420,0.0689,0.1070)
PF	(0.0591,0.0852,0.1212)	>640	(0.0165,0.0209,0.0283)	30-60	(0.0210,0.0353,0.0563)
Cu-G	(0.0530,0.0756,0.1072)			>60	(0.0161,0.0222,0.0353)
RA	(0.0420,0.0600,0.0846)				
M	(0.0201,0.0318,0.0479)				
RB	(0.0139,0.0222,0.0344)				
WL	(0.0076,0.0124,0.0199)				
Mn	(0.0057,0.0077,0.0116)				
R: Range, BL: Bare Land, SL: Sand Land, SHL: Shrub Land, F: Forest, PF: Planting Forest, Cu-G: Cultivation and Garden, RA: Residential Area, M: Morass, RB: River Bed, WL: Water Level, Mn: Mangrove Forest					
λ_{max} =13.6012, CI=0.1455, RI=1.48, CR=0.0983		λ_{max} =6.5130, CI=0.1026, RI=1.24, CR=0.0827		λ_{max} =7.1500, CI=0.0250, RI=1.32, CR=0.0189	
Distance of Fault (DF)		Distance of River (DR)		Criteria	
Class	Fuzzy synthetic extent	Class	Fuzzy synthetic extent	Layer	Fuzzy synthetic extent
>12000	(0.2591,0.3672,0.5082)	>4000	(0.2296,0.3179,0.4415)	GEOM	(0.1934,0.2808,0.6135)
8000-12000	(0.1827,0.2754,0.4035)	3000-4000	(0.1674,0.2449,0.3574)	LU	(0.1284,0.2019,0.4671)
4000-8000	(0.1041,0.1662,0.2516)	2000-3000	(0.1258,0.1868,0.2768)	H	(0.0994,0.1594,0.3741)
2000-4000	(0.0653,0.1187,0.1636)	1500-2000	(0.0831,0.1267,0.1895)	SL	(0.0772,0.1262,0.3044)
1000-2000	(0.0369,0.0596,0.0923)	1000-1500	(0.0410,0.0678,0.1072)	GEO	(0.0656,0.1043,0.2451)
0-1000	(0.0184,0.0249,0.0352)	500-1000	(0.0208,0.0359,0.0614)	SO	(0.0430,0.0698,0.1684)
		0-500	(0.0145,0.0197,0.0310)	DF	(0.0248,0.0403,0.0952)
				DR	(0.0129,0.0175,0.0387)
GEOM: Geomorphology, LU: Land Use, H: Height, SL: Slope, GEO: Geology, SO: Soil, F: Distance of Fault, R: Distance of River					
λ_{max} =6.3549, CI=0.0709, RI=1.24, CR=0.0572		λ_{max} =7.0991, CI=0.0165, RI=1.32, CR=0.0125		λ_{max} =8.7306, CI=0.1043, RI=1.41, CR=0.0740	

Figure 6 represents the hierarchical structure of MCDM, which is the possible relationship between alternatives (candidate land, numbered 1 to 5) and objectives (criteria). The overall goal is to identify lands for residential development. The attributes contained in the maps (geomorphology class, land use, height of see level, slope percent, geology formation, distance from fault, and distance from river) specify the objectives.

Alternatives were compared based on each criterion, and criteria with respect to the overall goal with pairwise comparison matrices were created. An expert was evaluated the principle of the comparison matrices. This assessment was based on the obtained results of the geospatial analysis at the alternative level and on the experience of the expert at the criterion level. The calculation of CR of each judgment matrix was derived by the pairwise comparison matrices (Tables 3 and 4).

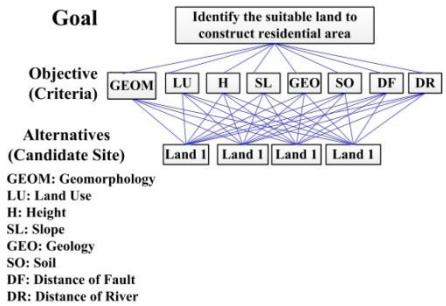

Figure 6. The hierarchical structure of multi criteria decision making (MCDM).

Table 4.FAHP priority in pairwise comparison matrices, Conventional AHP, Consistency Ratio (CR) and fuzzy synthetic extent.

Geomorphology (GEOM)λ_{max} =5.1204, CI=0.0158, RI= 1.12, CR= 0.0141						
	Land 1	Land 2	Land 3	Land 4	Land 5	Fuzzy synthetic extent
Land 1	(1,1,1)	(1,2,3)	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/3,1/2,1/1)	(0.0542,0.1045,0.2069)
Land 2	(4,5,6)	(1,1,1)	(2,3,4)	(1,1,1)	(2,3,4)	(0.1948,0.3326,0.5674)
Land 3	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1/1)	(1,2,3)	(0.0893,0.1748,0.3369)
Land 4	(3,4,5)	(1,1,1)	(1,2,3)	(1,1,1)	(2,3,4)	(0.1558,0.2815,0.4965)
Land 5	(1,2,3)	(1/4,1/3,1/2)	(1/3,1/2,1/1)	(1/4,1/3,1/2)	(1,1,1)	(0.0552,0.1066,0.2128)
Land Use (LU)λ_{max} =5.4629, CI=0.0544, RI= 1.12, CR= 0.0486						
Land 1	(1,1,1)	(4,5,6)	(6,7,8)	(1/3,1/2,1/1)	(1/4,1/3,1/2)	(0.1764,0.2502,0.3607)
Land 2	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(1/7,1/6,1/5)	(1/8,1/7,1/6)	(0.0371,0.0454,0.0572)
Land 3	(1/8,1/7,1/6)	(1,1,1)	(1,1,1)	(1/8,1/7,1/6)	(1/7,1/6,1/5)	(0.0364,0.0443,0.0554)
Land 4	(1,2,3)	(5,6,7)	(6,7,8)	(1,1,1)	(1,2,3)	(0.2132,0.3255,0.4809)
Land 5	(3,4,5)	(6,7,8)	(5,6,7)	(1/3,1/2,1/1)	(1,1,1)	(0.2336,0.3346,0.4809)
Height (H)λ_{max} =5.2891, CI=0.0496, RI= 1.12, CR= 0.0443						
Land 1	(1,1,1)	(1/3,1/2,1/1)	(1,1,1)	(2,3,4)	(1,2,3)	(0.1212,.2406,0.4800)
Land 2	(1,2,3)	(1,1,1)	(1/3,1/2,1/1)	(1,2,3)	(1,2,3)	(0.0985,0.2406,0.5280)
Land 3	(1,1,1)	(1,2,3)	(1,1,1)	(2,3,4)	(1,2,3)	(0.1364,0.2888,0.5760)
Land 4	(1/4,1/3,1/2)	(1/3,1/2,1/1)	(1/4,1/3,1/2)	(1,1,1)	(1/3,1/2,1/1)	(0.0492,0.0856,0.1920)
Land 5	(1/3,1/2,1/1)	(1/3,1/2,1/1)	(1/3,1/2,1/1)	(1,2,3)	(1,1,1)	(0.0682,0.1444,0.3360)
Slope (SL)λ_{max} =5.1968, CI=0.0384, RI= 1.12, CR= 0.0343						
Land 1	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)	(2,3,4)	(0.1481,0.2581,0.4332)
Land 2	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)	(2,3,4)	(0.1481,0.2581,0.4332)
Land 3	(1,1,1)	(1,1,1)	(1,1,1)	(1,2,3)	(2,3,4)	(0.1481,0.2581,0.4332)
Land 4	(1/3,1/2,1/1)	(1/3,1/2,1/1)	(1/3,1/2,1/1)	(1,1,1)	(1/3,1/2,1/1)	(0.0576,0.0968,0.2166)
Land 5	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,2,3)	(1,1,1)	(0.0679,0.1290,0.2383)
Geology (GEO)λ_{max} =5.3959, CI=0.0052, RI= 1.12, CR= 0.0047						
Land 1	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(0.0295,0.0390,0.0562)
Land 2	(3,4,5)	(1,1,1)	(2,3,4)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(0.1087,0.1729,0.2686)
Land 3	(2,3,4))	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(0.0608,0.0963,0.1511)
Land 4	(5,6,7)	(3,4,5)	(4,5,6)	(1,1,1)	(1,1,1)	(0.2376,0.3459,0.5035)
Land 5	(5,6,7)	(3,4,5)	(4,5,6)	(1,1,1)	(1,1,1)	(0.2376,0.3459,0.5035)
Soil (SO)λ_{max} =5.0424, CI=0.0158, RI= 1.12, CR= 0.0141						
Land 1	(1,1,1)	(1/6,1/5,1/4)	(1/7,1/6,1/5)	(1/3,1/2,1/1)	(1/3,1/2,1/1)	(0.0400,0.0631,0.1256)
Land 2	(4,5,6)	(1,1,1)	(1/3,1/2,1/1)	(1,2,3)	(1,2,3)	(0.1483,0.2798,0.5095)
Land 3	(5,6,7)	(1,2,3)	(1,1,1)	(2,3,4)	(2,3,4)	(0.2224,0.3996,0.6915)
Land 4	(1,2,3)	(1/3,1/2,1/1)	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)	(0.0725,0.1288,0.2366)
Land 5	(1,2,3)	(1/3,1/2,1/1)	(1/4,1/3,1/2)	(1,1,1)	(1,1,1)	(0.0725,0.1288,0.2366)
Distance of Fault (DF)λ_{max} =5.0601, CI=0.0098, RI= 1.12, CR= 0.0088						
Land 1	(1,1,1)	(2,3,4)	(1,1,1)	(1,2,3)	(3,4,5)	(0.1714,0.3173,0.5699)
Land 2	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1,2,3)	(0.0607,0.1202,0.2442)
Land 3	(1,1,1)	(2,3,4)	(1,1,1)	(1,2,3)	(3,4,5)	(0.1714,0.3173,0.5699)
Land 4	(1/3,1/2,1)	(1,2,3)	(1/3,1/2,1)	(1,1,1)	(1,2,3)	(0.0786,0.1731,0.3664)
Land 5	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1,1,1)	(0.0443,0.0721,0.1493)
Distance of River (DR)λ_{max} =5.0942, CI=0.0163, RI= 1.12, CR= 0.0145						
Land 1	(1,1,1)	(2,3,4)	(3,4,5)	(1,2,3)	(4,5,6)	(0.2160,0.3961,0.7107)
Land 2	(1/4,1/3,1/2)	(1,1,1)	(1,2,3)	(1/3,1/2,1)	(1,2,3)	(0.0704,0.1540,0.3180)
Land 3	(1/5,1/4,1/3)	(1/3,1/2,1)	(1,1,1)	(1/4,1/3,1/2)	(1,2,3)	(0.0547,0.1078,0.2182)
Land 4	(1/3,1/2,1)	(1,2,3)	(2,3,4)	(1,1,1)	(3,4,5)	(0.1440,0.2773,0.5237)
Land 5	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1,1,1)	(0.0399,0.0647,0.1340)

Table 5. Fuzzy weighted sum of each alternatives land under each criterion

Fuzzy weighted sum	Land 1	Land 2	Land 3
	(0.1196,0.2086,0.3679)	(0.1083,0.2005,0.3658)	(0.1150,0.2109,0.3790)
	Land 4	Land 5	
	(0.1261,0.2143,0.3770)	(0.1024,0.1658,0.2864)	

When the consistency ratio of the expert's decision-making analysis was verified, the expert evaluated the criteria and various candidate lands using the prevalent linguistic variable of Table 1 and their equivalent triangular fuzzy numbers. New pairwise comparison matrices that conform to FAHP were formed (Table 4).

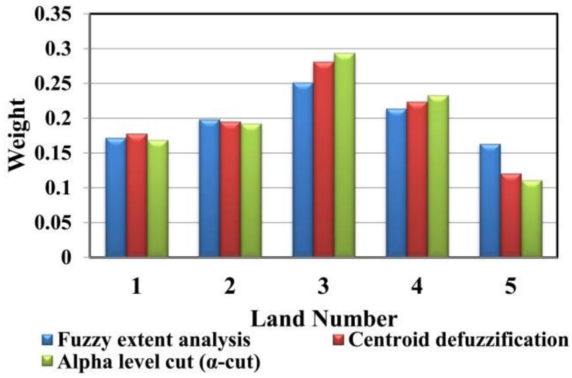

Figure 7. Comparison of the total weights obtained from each of the three defuzzification methods.

Table 6. Land preferences & weights from FAHP methods: fuzzy extent analysis, centroid defuzzification& alpha level cut (α-cut) model.

Fuzzy extent analysis			
$V(\tilde{S}_i \geq \tilde{S}_j)$		Normalized weight (w)	Preference
Land 1	0.7843	0.1721	4
Land 2	0.8912	0.1986	3
Land 3	0.9954	0.2517	1
Land 4	0.8977	0.2141	2
Land 5	0.7135	0.1635	5
Centroid defuzzification			
	x^*	Normalized	Preference
Land 1	0.2946	0.1781	4
Land 2	0.3412	0.1955	3
Land 3	0.5052	0.2815	1
Land 4	0.4136	0.2241	2
Land 5	0.2474	0.1208	5
Alpha level cut (α-cut)			
	C_λ	Normalized	Preference
Land 1	0.1831	0.168923	4
Land 2	0.2018	0.192581	3
Land 3	0.2704	0.294185	1
Land 4	0.2218	0.233238	2
Land 5	0.1162	0.111073	5

The extent of fuzzy synthetic of each alternative with regard to a given criterion and the extent of fuzzy synthetic extent of a criterion with regard to the overall goal were determined. The weighted sum of TFNs was calculated to achieve the total fuzzy weight of each land (Table 5). Finally, the total fuzzy weights were converted to real number using one of the three methods (fuzzy extent analysis, centroid defuzzification, or α-cut model) discussed in Section 2. Table 6 shows the total fuzzy weights and preferences of all candidate lands. A comparison of the three defuzzification methods is depicted in Figure 7.

Conclusion

The recent increase in population and construction necessitated the identification of lands suitable for residential development in different locations. Identifying a location suitable for residential area based on morphologic properties is a difficult task for a planner. This paper proposed a combined fuzzy MCDM approach based on FAHP to identify lands for residential development. Bandar Abbas City was depicted as the case study to explain the combined approach. FAHP was applied to determine the priority of the criteria and lands specified.

Results show that Land 3 had the highest relative score and Land 5 had the lowest relative score. Figure 7 shows that the three FAHP methods slightly differ in specifying land preferences because their determined weights vary slightly. The centroid defuzzification and α-cut methods showed better efficiency in identifying suitable lands than the fuzzy extent method. Three reliable sets of preferences can draw a consistent conclusion about the alternatives. If the three methods assigned different preferences, then the total weight could be averaged to specify a final score for each land. This average is significant only if the weight obtained from fuzzy extent analysis excludes zero values. In such case, fuzzy extent analysis does not provide the valid relative weights of the alternatives.

The fuzzy extent method can properly specify the preferences if the TFNs in each criterion and land have overlapping rates. The α-cut method is less argumentative and can be used to calculate the uncertainty under various decision-making conditions. However, this method is time-consuming. Different α and λ values should be chosen to indicate constant decision-maker approaches. This study examined six α-cut values (0, 0.2, 0.4, 0.6, 0.8, and 1). Results show that the concluding fuzzy ranking was equivalent in each case. The sum of absolute difference values between each pair of numbers at the 0.8 level was lower than at the other α-cut levels. The 0.8 level was selected because it involved minimum risk. The λ value was set to 1 because of the mostly optimistic conditions of the chosen expert.

Future study should apply new scenario and criteria and examine the compatibility of other MCDM methods and fuzzy techniques in identifying suitable lands. Similar approaches are recommended for the development of a high-efficiency application for identifying residential area using the multi-criteria decision-making process described in this paper.

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Biography

Mr. Mohsen Dadras has received his B. degree (Natural Resource and Environmental Engineering) form Islamic Azad University, Bandar Abbas Branch, Iran and Ms.c degree (GIS and Geomatic Engineering) from University Putra Malaysia (UPM), Serdang Selangor, Malaysia. And currently he is candidate PHD degree (GIS and Geomatic Engineering) from University Putra Malaysia (UPM), Serdang Selangor, Malaysia. His research interest includes Remote Sensing and GIS, Urban Planning and Modeling, and Environmental Management. Author may be reached at mohsen.sci@gmail.com