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Original Research

Spatial modeling of site suitability assessment for apartments-based on the combined fuzzy MCDM approach

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ABSTRACT:

Due to development restrictions in different geographical aspects in the recent times, the city of Bandar Abbas in central Iran, is faced with acute shortage of suitable lands for the construction of apartments. Despite this shortage of land, the demand for housing continued to rise due to increasing urbanization and steep rise in the population of the city. One reason for this phenomenon is the availability of harbors, refineries and industrial zones around the city, which result in the migration of enormous populations into the city annually. On the other hand, there are a number of the old regions in the city, which suffer from low construction density and lack of development. As a consequence, the inhabitants of these regions move to the more developed regions of the city. As such, the development of a method for detecting sites, which are suitable for the construction of apartments, is indeed crucial. Specifically, this study aims to model the selection of suitable lands for constructing apartments in the Bandar Abbas city, which is one the most popular cities for immigration in Iran. Another goal of the study is to determine the appropriate qualitative and quantitative criteria to evaluate alternative lands. Given the fact that the selection of suitable lands among a number of alternatives is the main problem associated with Multi Criteria Decision Making (MCDM), the fuzzy logic is utilized in the current study as the natural method for obtaining the ideal solution to the MCDM mode. Specifically, the hybrid MCDM method, together with the Fuzzy Analytical Hierarchy Process (Fuzzy AHP), were used to assign weights to the criteria and sub-criteria associated with land selection. Besides, the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (Fuzzy TOPSIS) method was utilized to detect suitable alternatives based on the weights of criteria and sub-criteria. In the rest of the study sensitivity analysis results are presented.

Keywords:

Apartment, site selection, fuzzy AHP, fuzzy TOPSIS

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INTRODUCTION

Selecting suitable land for the construction of apartments is a prominent problem in all sorts of urban developments such as population distribution and service provision. Suitable site selection also improves settlement quality in urban areas, and is considered as a crucial component in the urban development. It might also be used as an important tool which positively affects urban sprawl in the old districts. It must be noted that the land selection does not merely involve selecting a land with good accessibility or landscape; it also involves effective research on population characteristics, settlement quality, market demand and competition. Also, constructors must manage the layout and construction according to the use and service type of the apartments; in addition to personal preferences of the applicant, surrounding land uses and the final cost of utilization are also taken into consideration. Also, legal ownership and urban development plans might be taken into consideration during site selection, design and implementation.

One of the most important urban development and service provision plans for settlement of citizens is the construction of the apartments based on standard regulations of urbanization and architecture. Apartments with appropriate settlement capabilities result in population concentration and provide proper service for the population. These include the provisioning of proper educational facilities, hygiene, land pricing, accessibility as well as suitable land savings. In addition, provided the standards are observed in apartment construction, urban management and planning would be easier and more disciplinary. Service quality plays a significant role in the management of apartments. This important feature not only decreases costs, but also increases profitability, investment return, market share and efficiency (Rosen and Walks 2013; Fornell *et al.,* 1996; Anderson and Fornell 2000; Hsieh 2009; Wen *et al.,* 2005; Kuo *et al.,* 2011; Kuo *et al.,* 2012).

Several other factors influence site selection of suitable lands for apartment construction. Among these are the social characteristics, including factors such as population distribution, household, population density and accessibility to official, educational and remedial services; where the factors exert varying levels of pressure on the land detection. Besides, the economic structure of individual cities is unique due to the differences in social groups, income levels, job opportunities and land price.

Moreover, accessibility of a site to other important sites, as well as its distance from other urban services might be considered as another significant criterion for evaluation. For example, districts with appropriate transport networks and urban facilities are more capable of land detection due to the various interactions between them. Land detections of this nature can be afforded using the Multi Criteria Decision Making (MCDM). The MCDM technique involves finding the evaluation criteria, assessing their importance, determining their impacts on each other and finally selecting a suitable site (Vaidya and Kumar 2006; Banai-Kashani 1989; Saaty and Vargas 1991).

In general, the MCDM technique is associated with decision making using a few criteria or objectives. The technique has been developed by careful evaluations and precise measurements. However, it is probable that some selected criteria do not have enough precision. Also, objectives are usually contradictory. Thus, selecting a suitable site completely depends on the decision maker's priorities. Hence, evaluating data regarding suitable land locations for building apartments based on different criteria and sub-criteria is subjective. The weights of criteria and sub-criteria are usually based on linguistic relations. As a result, fuzzy logic can be employed as a natural method for finding solutions. It is possible to integrate the MCDM technique into the fuzzy method in order to address the problem of uncertainties. In this study, a methodology which is based on fuzzy-

MCDM combination is proposed. The method is utilized to evaluate suitable lands for building apartments. Here, the AHP model is exploited to calculate the weights of the criteria and sub-criteria while the TOPSIS method is used to determine the priorities, and rank alternative sites.

There are several methods of calculating weights; however, the AHP method is found to be one of the most appropriate. A significant advantage of the AHP is its ability to afford pairwise comparison. The method is also suitable for calculating the inconsistency index, which defines a rate of decision maker inconsistency. Therefore, considering the objective of the study, the decision maker may perform a number of pairwise comparisons during the analysis procedure. This circumstance, particularly in Fuzzy AHP, may result in unfeasible AHP procedure. To overcome this problem, the Fuzzy TOPSIS method can be utilized to reduce pairwise comparisons and rank alternatives.

The TOPSIS method was first developed by Hawang and Yoon (1981). This method uses simple and programmable computational procedure, with consideration to both ideal and non-ideal solutions, and has the capability to use linguistic variables. For these reasons, the TOPSIS is adopted by a considerable number of researchers (Karsak, 2002). The basic concept of the TOPSIS is that all the best level of descriptions belong to the positive ideal alternative, while all the worst description levels belong to the negative ideal alternative. In Fuzzy TOPSIS, the descriptive values are identified by fuzzy numbers. In this way, the fuzzy values are allocated to criteria and sub-criteria based on their priorities, and where the procedure of opinion integration increases the reliability of decision making precision.

Review of the literature revealed that very few studies have been conducted in detecting suitable urban lands for building apartments. The performed studies have mainly focused on the structure of service quality, legal ownership, building management and accessibility. In the study by Jung and Lee (2012), the alternative evaluation model is utilized to detect suitable lands for residential development. This method is developed using the fuzzy system and the AHP model. The selection takes into consideration the environmental factors such as air quality, water resources, lands and natural ecosystems. Hsieh (2009), on the other hand, investigated the importance of economic criteria and accessibilities in ownership and management of apartments in Taiwan. This study was based on field observations, questionnaires and experts' opinion; and the result indicated that land price, proper equipment and facilities as well as optimal accessibility to urban services play a crucial role in increasing ownership and management demand of apartments. Palmas *et al.* (2012) utilized the physical and structural criteria such as Digital Elevation Model (DEM), slope, aspect and land use. Using AHP model, they also investigated renewable energies in residential development in the eastern part of a metropolitan; Cagliari, Sardinia, Italy. The result of the analysis demonstrated that land capabilities, open spaces and density play significant roles in detecting suitable lands for building apartments and future settlements development. Furthermore, consistency and lack of interference between the detected alternatives with urban development plans are introduced as the basic approach to urban management. The study by Seo *et al.* (2004) employed the fuzzy set for the evaluation of sustainable building given specific uncertainty conditions. Here, the authors argued that sustainable building evaluation is difficult in that the environmental impacts and socio-economic realities are sometimes at conflicting ends. With this in mind, the fuzzy theory and hierarchical structure analysis were employed in order to formulate the evaluation method of the building.

Diverse studies have also been carried out on construction management and service quality in countries such as US (Fishman, 1987; Bureau of the census 1994; Lees 1994; Low *et al.,* 2012), Canada (Hulchanski

1988; Preston *et al.,* 1993; Skaburskis 1998; Kern 2007, 2010 a,b; Lehrer and Wieditz 2009; Harris 2011) and China (Ji 2011; Logan *et al.,* 2009; Wang *et al.,* 2010; Zhang and Skitmore, 2012; Wang 2004); with some of these studies concentrating on the selection of suitable land for building apartments and residential settlements.

However, only a few of these works employed the MCDM technique. Despite the fact that a number of publications emerged in the evaluation and selection of suitable land for the construction of apartment in the literature, none of these works focused on the use of the AHP and TOPSIS in the Iranian scenario under a fuzzy environment. In order to fill this research gap, the current study seeks to model suitable sites for the building of various apartments across the city of Bandar Abbas in Iran. This city has been identified for the study due to its strategic nature in that it is the main port city of Iran for both export and import activities. Here, the Fuzzy TOPSIS is employed for the selection of a location alternative, while the Fuzzy AHP is employed for calculating the criteria weights. Moreover, the triangular fuzzy numbers are utilized for all the pairwise comparison matrices using the Fuzzy AHP. In this way, the criteria weights are computed as the triangular fuzzy numbers, which are then inserted into the Fuzzy TOPSIS technique for ranking the alternatives.

Study Area

The study area was Bandar Abbas County (Figure 1), which is located in the south of Iran at . It is composed of 4 sections and 2 central city, 10 rural district and 331 village with a total area of 1953 km^2, 2.87% of total land area of Hormozgan Province. The population was 435751 in the end of 2011. Population density per square kilometer was about 36.73 % in the county during 2006-2011; and in per residential unit are living average 4.7 people, that's little more than county household rate (4.3) (Iranian Statistic Center, 2012). Bandar Abbas County is a flat region with elevation descending from south to north, varying from 0 to 2261 m. Coastal

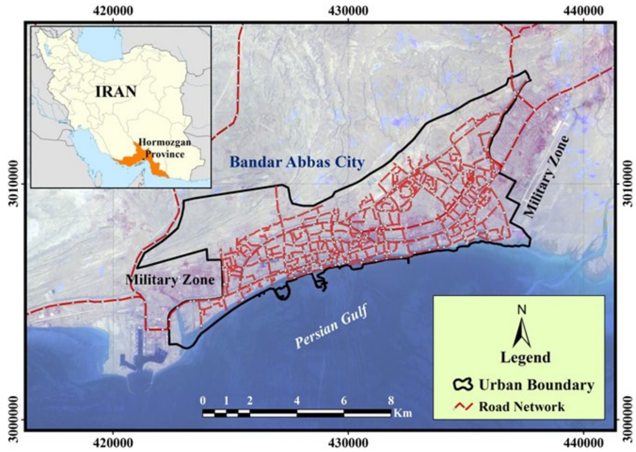

Figure 1. Location of the study area (Dadras *et al.,* 2015; Dadras *et al.,* 2014a and 2014b).

plain and hillside plains account for 68.5% of total area of Bandar Abbas. The annual rainfall is 185.5mm, which is one of low rainfall areas in Iran. The largest population settlement in Bandar Abbas County is located in south of study area (Bandar Abbas City). Commercial ports, oil and gas refineries and power stations in Bandar Abbas city are due to be turned into an important center of economic and population in Iran country. This properties has caused the city of Bandar Abbas is of high quality migrants. Possibility of horizontal expansion of cities is not available due to natural limitations of the north (rocky cliffs) and south (seashore) and land use barriers in the east (air force) and west (novel force). Thus, given the population growth is essential to identify residential area. Most practitioners due to its position near the main port of export and import related services with 72.34 percent (Dadras *et al.,* 2015; Dadras *et al.,* 2014a; Dadras *et al.,* 2014b).

METHODOLOGY

The study was conducted in two phases. The first phase consists of calculating the criteria weights by using the Fuzzy AHP; while the Fuzzy TOPSIS is applied for ranking and selecting the alternatives in the second phase. The specific details of the Fuzzy AHP as well as the Fuzzy TOPSIS are illustrated in the following subsections. Figure 2 shows the methodology used in the

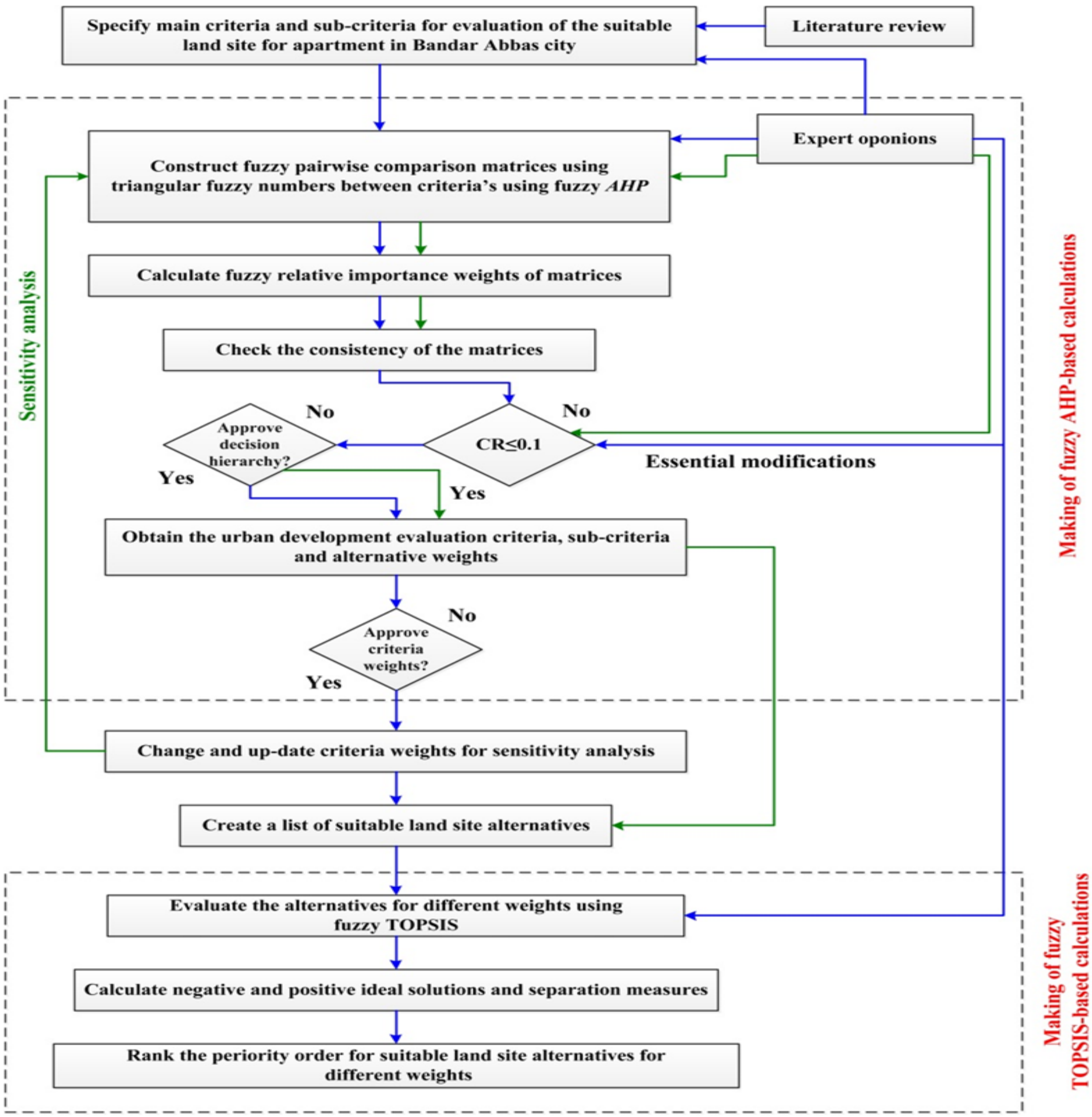

Figure 2. The methodology used in the present research

current research. Here, the suitable lands were identified by creating a geo database with data collection and geo-spatial analysis.

Fuzzy AHP

In the suggested methodology, the AHP with its fuzzy extension, i.e, Fuzzy AHP is useful to attain more conclusive judgments by making the machine tool selection criteria a priority and weighting them in the attendance of vagueness. There are various Fuzzy AHP applications in the literature that suggest systematic methods for selection of alternatives and justification of problem by using hierarchical structure analysis and fuzzy set theory. It normally suits decision makers to express interval judgments rather than fixed value judgments owing to the fuzzy nature of the comparison procedure (Bozdag˘*et al*., 2003). This research which is presented by Chang (1992) is combination with a Fuzzy AHP method, in which triangular fuzzy numbers are desired for pairwise comparison scale. Extent analysis method is chosen for the synthetic extent values of the pairwise comparisons. Some papers (Buckley, 1985; Kahraman *et al.,* 2003; Kahraman *et al.,* 2004) used the Fuzzy AHP

Table 1. Linguistic variables describing weights of the criteria and values of rating

Linguistic scale for importance	Fuzzy number for the Fuzzy AHP	Membership function	Domain	Triangular fuzzy scale (l, m, u)
Just equal	-	-	-	(1.0,1.0,1.0)
Equal importance	$\tilde{1}$	-	-	(1.0,1.0,3.0)
Weak importance of one over another	$\tilde{3}$	$\mu_M(x) = (3-x)/(3-1)$ $\mu_M(x) = (x-1)/(3-1)$	$1 \le x \le 3$ $1 \le x \le 3$	(1.0,3.0,5.0)
Essential or strong importance	$\tilde{5}$	$\mu_M(x) = (5-x)/(5-3)$ $\mu_M(x) = (x-3)/(5-3)$	$3 \le x \le 5$ $3 \le x \le 5$	(3.0,5.0,7.0)
Very strong importance	$\tilde{7}$	$\mu_M(x) = (7-x)/(7-5)$ $\mu_M(x) = (x-5)/(7-5)$	$5 \le x \le 7$ $5 \le x \le 7$	(5.0,7.0,9.0)
Extremely preferred	$\tilde{9}$	$\mu_M(x) = (9-x)/(9-7)$ $\mu_M(x) = (x-7)/(9-7)$	$7 \le x \le 9$ $7 \le x \le 9$	(7.0,9.0,9.0)
If factor *i* has one of the above numbers assigned to it when compared to factor j, then *j* has the reciprocal value when compared with *i*	-	-	-	Reciprocals of above $M_1^{-1} \approx (\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1})$

process according to extent analysis method and presented the way it can be applied to the selection problems. The scheme of the fuzzy sets and extent analysis method for the Fuzzy AHP are as follows.

A fuzzy number is a particular fuzzy set, $F = \{(x, \mu_F(x), x \in R\}$ where 'x' takes its values on the real line, $R: -\infty \le x \le \infty$ and $\mu_F(x)$ is a continuous mapping from 'R' to the closed interval [0, 1]. A Triangular Fuzzy Number (TFN) states the relative strength of each pair of features in the same hierarchy and can be indicated as , $M = (l, m, u)$ where $l \le m \le u$

The parameters l; m; u; specify the smallest possible value, the most capable value, and the largest possible value respectively in a fuzzy result. Triangular method membership function of $'M'$ fuzzy number can be explained as in Eq. (1). When $l = m = u$ it is a non-fuzzy number by convention.

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

A linguistic variable is the one with its values expressed in an artificial or natural language. The concept of a linguistic variable offers means of rough feature of phenomena that are too intricate or too inaccurate to be disposed to explanation in conventional quantitative terms (Bellman and Zadeh 1970).

In this research, the linguistic variables used in the model can be stated in positive Triangular Fuzzy

Number (TFNs) for each of the criteria as in Figure 3. The linguistic variables corresponding TFNs and the matching membership functions are given in Table 1. Suggested methodology uses a Likert Scale of fuzzy numbers starting from $\tilde{1}$ to $\tilde{9}$ symbolized with tilde $(\sim)$ for the Fuzzy AHP method (Figure 4). Table 1 displays the Fuzzy AHP comparison scale considering the linguistic variables that depict the significance of criteria and alternatives to improve the scaling scheme for the judgment matrices. By applying TFNs via pairwise comparison, the fuzzy judgment matrix $\tilde{D}(d_{ij})$ can be stated mathematically as:

$$\tilde{D} = \begin{Bmatrix} 1 & \tilde{d}_{12} & \tilde{d}_{13} & \cdots & \tilde{d}_{1(n-1)} & \tilde{d}_{1n} \\ \tilde{d}_{21} & 1 & \tilde{d}_{23} & \cdots & \tilde{d}_{2(n-1)} & \tilde{d}_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ \tilde{d}_{(n-1)1} & \tilde{d}_{(n-1)2} & \tilde{d}_{(n-1)3} & \cdots & 1 & \tilde{d}_{(n-1)n} \\ \tilde{d}_{n1} & \tilde{d}_{n2} & \tilde{d}_{n3} & \cdots & \tilde{d}_{n(n-1)} & 1 \end{Bmatrix} \quad (2)$$

The judgment matrix $\tilde{D}$ is a $n \times n$ fuzzy matrix containing fuzzy numbers d_{ij}

$$\tilde{d}_{ij} = \begin{cases} 1, & i = j \\ \tilde{1},\tilde{3},\tilde{5},\tilde{7},\tilde{9} \ or \ \cdots \tilde{1}^{-1},\tilde{3}^{-1},\tilde{5}^{-1},\tilde{7}^{-1},\tilde{9}^{-1} & i \neq j \end{cases} \quad (3$$

Let $X = \{x_1,x_2,\ldots,x_n\}$ be an object set, whereas, $U = \{u_1,u_2,\ldots,u_m\}$ is an aim set. Based on fuzzy extent analysis, the method was completed with respect to each object for each corresponding aim, , result- g_i ing in 'm' extent analysis values for each object, given as $M_{g_i}^1, M_{g_i}^2, \ldots, M_{g_i}^m, i = 1,2,\ldots,n,$ where all the $M_{g_i}^j \ (j = 1,2,\ldots,m)$ are TFNs signifying the performance of the object x_i with regard to each aim u_j. The following is the details of Chang's extent analysis steps (Chang 1992; Bozbura *et al.,* 2007; Kahraman *et al.,* 2003, Kahraman *et al.,* 2004):

Step 1: The value of fuzzy synthetic extent according to the i[th] object is specified as:

$$S_i = \sum_{j=1}^{m} M_{g_i}^j \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1} \quad (4)$$

To achieve $\sum_{j=1}^{m} M_{g_i}^j$ apply the fuzzy addition operation extent analysis values for a specific matrix such that

$$\sum_{j=1}^{m} M_g^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad (5)$$

and to obtain $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1}$ the fuzzy addition operation of $M_{g_i}^j (j = 1,2,m)$ values is are performed such as:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \quad (6)$$

and then calculate the inverse of the vector in Eq. (6) such that

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^j\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (7)$$

Step 2: As $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is specified as:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) \quad (8)$$

and can be stated as follows:

$$V(M_2 \geq M_1) = \sup_{y \geq x}[\min(\mu_{M1}(x), \quad \mu_{M2}(y))] \quad (9)$$

$$= \begin{cases} 1, \ if & m_2 \geq m_1 \\ 1, \ if & l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & Otherwise \end{cases} \quad (10)$$

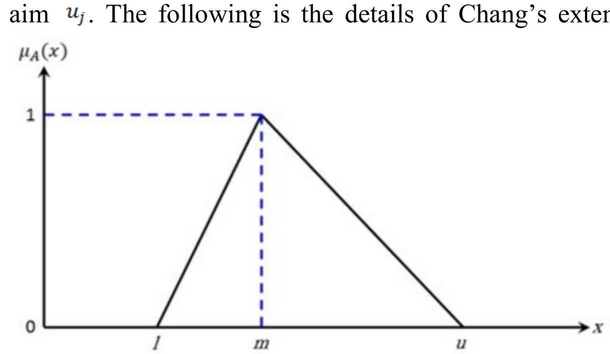

Figure 3. Schematic diagram of fuzzy triangular number A= (l, m, u)

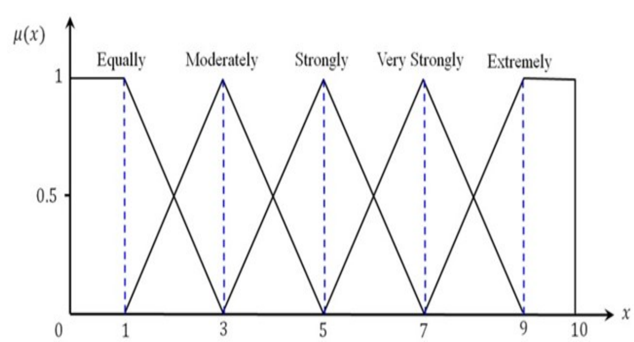

Figure 4. Linguistic variables for the importance of each criterion

Figure 4 demonstrates Eq. (6) where 'd' is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2}

To compare M_1 and M_2 we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$

Step 3: The degree possibility of a convex fuzzy number to be greater than *'k'* convex fuzzy numbers $M_i\ (i = 1,2,\ldots,k)$ was specified by

$$V(M \geq M_1, M_2, \ldots, M_k) = V[(M \geq M_1)]\ and\ V[(M \geq M_2) and\ (M \geq M_k)] = \min V\ (M \geq M_i), i = 1,2,3,\ldots,k. \quad (11)$$

Let's consider $d(A_i) = \min V(S_i \geq S_k)$ for $k = 1,2,\ldots,n; k \neq i$. then the weight vector was given by

$$W' = (d'(A_1), d'(A_2), \ldots \ldots, d'(A_n))^T \quad (12)$$

where $A_i = (i = 1, 2, \ldots n)$ are were 'n' elements.

Step 4: Via normalization, the normalized weight vectors were

$$W = (d(A_1), d(A_2), \ldots \ldots, d(A_n))^T \quad (13)$$

where W is a non-fuzzy number.

Fuzzy TOPSIS

The TOPSIS method was first suggested by Hwang and Yoon (1981). As the central notion of this method is that the selected alternative should be the closest in terms of distance from the positive ideal solution and from negative ideal solution it should have the extreme distance. Positive ideal solution is the one that through which the advantage criteria is maximized and rate criteria are minimized, while the rate criteria is maximized and the advantage criteria is minimized by negative ideal solution (Onut *et al.,* 2010; Zimmermann, 1991). In the typical TOPSIS method, the ratings of alternatives and the weights of the criteria are accurately known and in the assessment procedure crisp values were used. Though, in many situations crisp data are insufficient to model real-life decision problems. Consequently, the Fuzzy TOPSIS method is offered where ratings of alternatives and the weights of criteria are assessed by linguistic variables characterized by fuzzy numbers to tackle the absence in the traditional TOPSIS. In the current study what is considered is the extension of TOPSIS method offered by Chen (2000) and Chen *et al.* (2006). The following steps can describe algorithm of this method:

Step 1: Let $\tilde{a} = (l_1, m_1, u_1)$ and $\tilde{b} = (l_1, m_1, u_1)$ be two TFNs, then the vertex method was defined to compute the distance between them, as:

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2]} \quad (14)$$

The following sets describe the problem:

1. A set of 'J' possible candidates called $A = \{A_1, A_2, \ldots, A_j\}$.
2. A set of 'n' criteria, $C = \{C_1, C_2, \ldots, C_j\}$.
3. A set of priority ratings of $A_j\ (j = 1,2,3,\ldots,J)$ with respect to criteria $C_i\ (i = 1,2,3,\ldots,n)$ called $\tilde{X} = \{\tilde{x}_{ij}\ i = 1,2,3,\ldots,n, j = 1,2,3,\ldots,J\}$.
4. A set of importance weights of each criterion $w_i(i = 1,2,3,\ldots,n)$.
5. As expressed above, problem matrix format was expressed as follows:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{J1} & \tilde{x}_{J2} & \cdots & \tilde{x}_{Jn} \end{bmatrix} \quad (15)$$

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n] \quad (16)$$

Step 2: After the fuzzy decision matrix was constructed, it is normalized. The linear scale transformation was used instead of using complicated normalization formula of typical TOPSIS to transform different criteria scales into a comparable scale. Hence, the normalized fuzzy decision matrix was attained:

$$\tilde{V} = [\tilde{v}_{ij}]_{n \times J}\quad i = 1,2,\ldots,n, j = 1,2,\ldots,J \quad (17)$$

Where

$$\tilde{v}_{ij} = \tilde{x}_{ij}\ (.) w_i. \quad (18)$$

The outline of Fuzzy TOPSIS steps is as follows based on the above concisely summarized fuzzy theory.

Step 3: The linguistic ratings $(\tilde{x}_{ij}\ i = 1,2,3,\ldots,n, j = 1,2,3,\ldots,J)$ for alternatives according to the criteria are selected. The fuzzy linguistic rating $(\tilde{x}_{ij})$ conserved the property that the ranges of normalized TFNs depend on [0, 1]; therefore, there was no need for normalization.

Let $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}), \tilde{x}_j^- = (a_j^-, b_j^-, c_j^-)$ and $\tilde{x}_j^* = (a_j^*, \quad b_j^*, c_j^*)$

we have

$$\tilde{r}_{ij} = \begin{cases} \tilde{x}_{ij}(\div)\tilde{x}_j^* = \left(\dfrac{a_{ij}}{a_j^*}, \dfrac{b_{ij}}{b_j^*}, \dfrac{c_{ij}}{c_j^*}\right) \\ \tilde{x}_j^-(\div)\tilde{x}_{ij} = \left(\dfrac{a_j^-}{a_{ij}}, \dfrac{b_j^-}{b_{ij}}, \dfrac{c_j^-}{c_{ij}}\right) \end{cases} \quad (19)$$

Step 4: The weighted normalized fuzzy decision matrix computed. The weighted normalized value $\tilde{v}_{ij}$ is calculated by Eq. (16).

Step 5: Positive ideal (A^*) and negative ideal (A^-) solutions. The fuzzy positive ideal solution $(FPIS, A^*)$ and the fuzzy negative-ideal solution $(FNIS, A^-)$ are illustrated in the following equations:

$$A^* = \{\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_i^*\} = \left\{\left(\max_j v_{ij} | i \in I'\right)\right\}, \left\{\left(\min_j v_{ij} | i \in I''\right)\right\}, \ i = 1,2,\dots,n \ \ j = 1,2,\dots,J \quad (20)$$

$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_i^-\} = \left\{\left(\min_j v_{ij} | i \in I'\right)\right\}, \left\{\left(\max_j v_{ij} | i \in I''\right)\right\}, \ i = 1,2,\dots,n \ \ j = 1,2,\dots,J \quad (21)$$

where I' is related to advantage criteria and I'' is related to cost criteria.

Step 6: The distance of each alternative from A^* and A^- using the following equations were computed.

$$D_j^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_i^*) \quad j = 1,2,\dots,J \quad (22)$$

$$D_j^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_i^-) \quad j = 1,2,\dots,J \quad (23)$$

Step 7: Similarities to ideal solution was calculated.

$$CC_j = \frac{D_j^-}{D_j^* + D_j^-} \quad j = 1,2,\dots,J \quad (24)$$

Step 8: Rank preference order. Choose an alternative with maximum CC_j^* or rank alternatives according to CC_j^* in the descending order.

Suitable land selection for building apartments in Bandar Abbas

At the beginning of the 20th century, which coincided with rapid economic development in Iran, the city of Bandar Abbas was faced with widespread changes due to urban development projects, rising population and economic growth. The increase in the number of migrants during the last three decades has also increased the demand for settlement in Bandar Abbas city; which greatly influenced physical sprawl of the city. Due to its location, Bandar Abbas city is also restricted by urban sprawl limitations in the north (which is characterized by stone cliffs), south (characterized by a coastal zone), east (air force military zone) and west (navy force military zone). As such, the city is faced with limitations of suitable lands for residential uses; and thus, suitable construction patterns are considered as serious challenges of urban development, construction of settlements and population distribution. Also, the presence of old structures is another impediment to the availability of land for the construction of settlements in most urban districts of Bandar Abbas. Specifically, more than half of the urban areas of the city are allocated to old districts; where the construction of residential units failed to obey the standard regulations, thereby leading to the loss of suitable lands in the recent years. Nevertheless, these old districts of the city have the required capability for the construction of residential apartments due to low density and compression. After Tehran (the capital of Iran), Bandar Abbas is the second largest city in Iran, where construction of residential apartments has rapidly grown. In Bandar Abbas, the largest amount of construction patterns for residential uses is allocated for apartments. Specifically, the development of urban infrastructures and high quality settlements, have increased settlement demand in these regions. Therefore, detecting suitable lands for the building of apartments in the districts of Bandar Abbas city is quite vital in order to afford controlled population distribution and efficient land used.

Data collection

In this research, a feasibility study was the main strategy conducted to determine the suitable lands. The procedure aims to detect and select lands which are suitable for building apartments in the districts of Bandar

Table 2. Criteria, sub-criteria and source of geospatial data used in this study (Iranian Statistic Center, 2009 and 2012; Ministry of Roads and Urban Development Iran, 2008 and 2012; Sharmand Consultant Engineering, 2008 and 2010)

Main criteria	Sub-criteria	Source	Year
Cultural and Historic	Aesthetics	Master plan	2006
	Cultural and Tourism	Master plan	2006
	Historical places	Master plan	2006
	Local built environment	Master plan	2006
Ecological and Environmental	Coastal line	Geo-Eye Image Satellite	2012
	Green space	Geo-Eye Image Satellite	2012
	Noise pollution	Iran department of environment	2012
	Wastewater network	Regional water company	2012
	Water pollution	Iran department of environment	2012
Physical	Aspect	Topographic map (1:500)	2001
	Digital Elevation Model	Topographic map (1:500)	2001
	Fault	Geology map (Scale 1:50000)	2010
	Geology	Geology map (Scale 1:50000)	2010
	Hydrology	Topographic map (Scale 1:500)	2001
	Slope	Topographic map (Scale 1:500)	2001
	Soil	Soil map (Scale 1:50000)	2008
Economic	Commercial center	Master plan	2006
	Commercial and fishing ports	Ports and maritime organization	2012
	Land value	Bandar Abbas municipality	2012
Social	Administrative center	Master plan	2006
	Distribution of population	Iranian Statistic Center	2012
	Education center	Master plan	2006
	Household size	Iranian Statistic Center	2012
	Medical center	Master plan	2006
	Neighborhood community change	Master plan	2006
	Population density	Iranian Statistic Center	2012
Structural	Construction density	Master plan	2006
	Construction pattern	Master plan	2006
	Functional zoning	Master plan	2006
	Height building	Aerial photo – Ultra Cam D	2012
	Land area	Master plan	2006
	Land use	Master plan	2006
	Lifetime	Master plan	2006
	Road network	Master plan	2006
	Total residential density	Master plan	2006
Accessibility	Airport, Railway and Port for passenger	Road and Urban Development Organization	2010
	Bus way	Bandar Abbas municipality	2012
	Bus station	Bandar Abbas municipality	2012
	Fire station and hydrant	Fire department	2012
	Telecommunication line	Telecommunication Co.	2012
	Post office	Post Co.	2012
	Power distribution network	Hormozgan Electrical Distribution Co.	2012
	Road network	Master plan	2006
	Water zone area	Regional Water Co.	2012

Abbas city. Executive urban organizations and private sector investors can also select suitable lands based on the feasibility study. Here, various goals must be set before conducting a feasibility study. Detecting suitable lands and performing feasibility studies on them results in the optimization of development plans to be implemented by urban organizations or private sector investors. In order to evaluate the suitability criteria for land selection and determining the largest amount of suitable alternative lands, a comprehensive interview is carried out with 20 experts. These experts, with specialization in geography, environment, economy, social sciences, construction, architecture and urbanization; managers of execution and development sections of private construction companies as well as professional consultants and highly experienced experts in executive governmental organizations.

Furthermore, a precise questionnaire is prepared based on the collected data and according to the quantitative and qualitative criteria for selecting the appropriate model (See the appendix). At this juncture, a number of face to face interviews were conducted to achieve a geo database and develop it based on the selected criteria. Based on spatial and attribute data collection, compilation and sampling have been completed questionnaires and expert opinions. The interview lasted almost two months. Interviews were conducted with ten experts with different specialties. According to research from experts in different scenarios and criteria (including: Cultural and Historic, Ecological and Environmental, Physical, Social, Economic, Structural, Accessibility) were used.

RESULTS

In order to detect the selection criteria, a few quantitative and qualitative factors, which are efficacious on the evaluation process, must be considered. Here, there are complete and complicated indices of evaluation criteria which are derived from previous resources. After consulting the experts (mentioned above), seven criteria were selected together with 45 layers of spatial data. The data were derived from Geographic Information System (GIS) as presented in Table 2. Specifically, seven criteria were selected, including cultural and historic, environmental and ecological, economic, social, physical, structural and accessibility, which are denoted by C_1, C_2, C_3, C_4, C_5, C_6, C_7 respectively. The cultural and historic criterion demonstrates cultural and historic identity of a district. Indices of cultural and historic criterion are based on aesthetic, historical sites and touristic areas. Nowadays, a balance between development and environmental considerations is known as a crucial issue for large and developing cities. Environmental and ecological criterion includes factors which are efficacious on variations of life and environmental quality of the studied area. Along the Bandar Abbas city coastal line is the most prominent and determinant factor in assessing this criterion. Among the other important factors in determining the environmental circumstances of the area are pollution sources (water, soil and air), green space per capita as well as the sewer system. Investigating the gross population density and the needed per capita are considered as vital necessities in urban planning and management. As such, factors such as neighborhood community change, per capita and accessibilities to official, educational and remedial centers are investigated when considering the social criterion.

Similarly, the economic and urban growth is related to different aspects. For example, increase in economic growth in urban societies and the provision of budget for governmental organizations and urban centers leads to the implementation of executive and constructive plans associated with urban settlements. Also, economic growth raises cooperation of private sector investors and governmental organizations in the apartment construction projects. In this study, data associated with commercial centers, export and import harbors and land prices are utilized to investigate the economic criterion. Physical conditions of cities are important factors affecting apartment construction. These include elevation, slope, geological factors, type of soil and surface water condition. Given the fact that Bandar Abbas is a seaside city, it has expanded like a strip along the beach. The major part of the city is located in the low elevation and low slope region. Moving towards the north of the city, altitude increases and as a result, the slope is steeper. Other factors such as land hardness and type of soil are

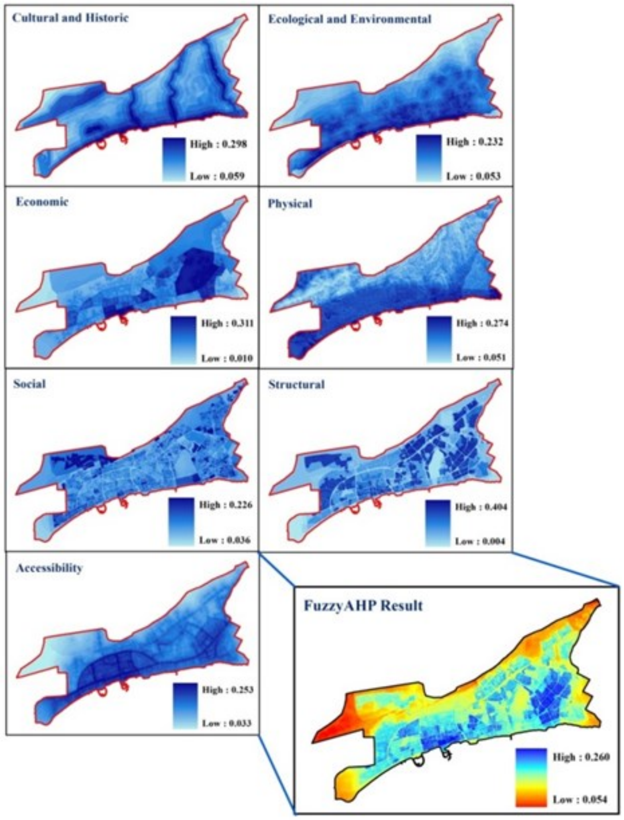

Figure 5. Prioritize the development of urban lands by using Fuzzy AHP model

highly effective on urban construction procedure and strength of buildings. The structural criterion is one of the most prominent factors in suitable land selection for building apartments. In this criterion, factors such as land use, functional zone, residential density, construction density, construction pattern, height and antiquity of the building and open space ratio are considered. Among the mentioned factors, land use, density indices and open space ratio are considered as the main advantageous lands when suitable lands are being detected. Bandar Abbas has experienced irregular and unbalanced growth during its history. Hence, inconsistence uses of land and land limitation are considered as constraints to the development of residential units. In most of the new patterns, residential lands per capita were allocated based on the comprehensive plans. Additionally, the availability of open spaces in these areas make them suitable for the growth and development of apartments.

The accessibility criterion in the current study includes the ratio of the distance from the urban infrastructures. These infrastructures consisted of road networks, power distribution networks, telecommunication lines, water zones, post offices, fire stations and transport centers (such as bus stops, railways, passenger harbors

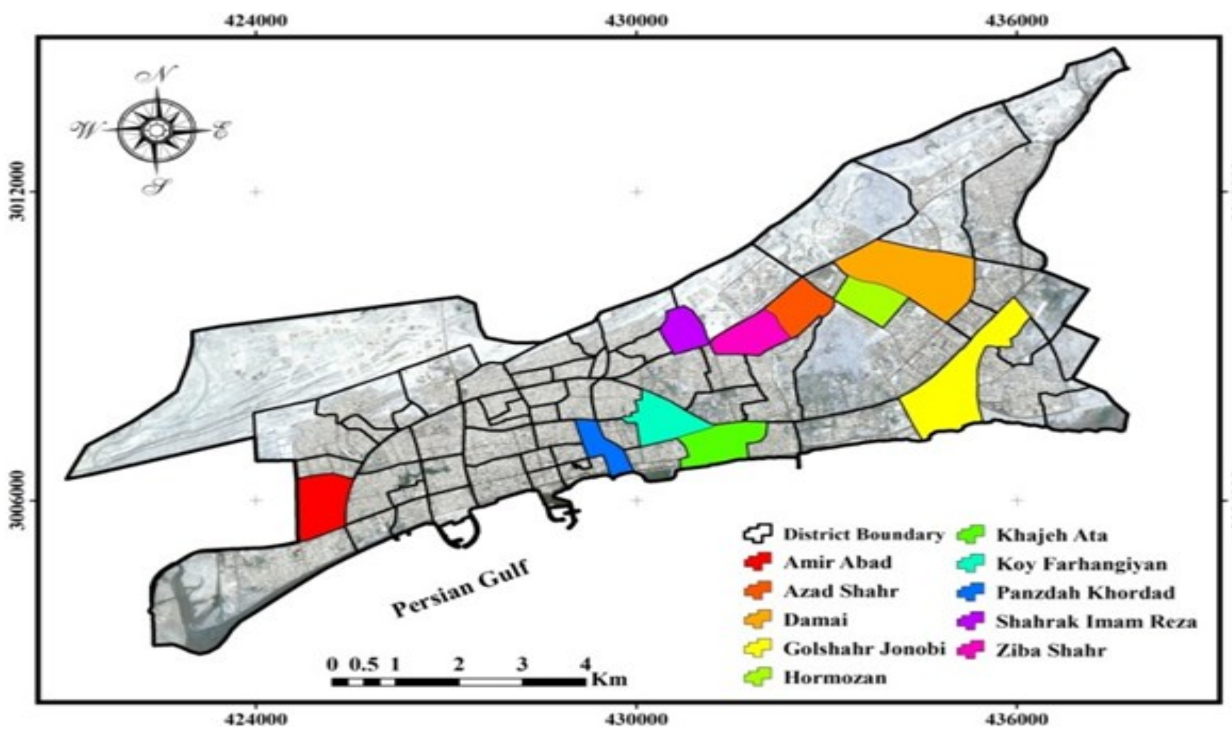

Figure 6. The potential location of suitable lands for construction of apartments

and airports). As a consequence of improper implementation of comprehensive urban plans in Bandar Abbas and its irregular development, urban infrastructures have not been perfectly transferred to some regions in the north, northeast and northwest. In the old districts of the city, shortcomings in the modification of urban infrastructures have led to consequences, which are not acceptable for urban settlement (apartment) development.

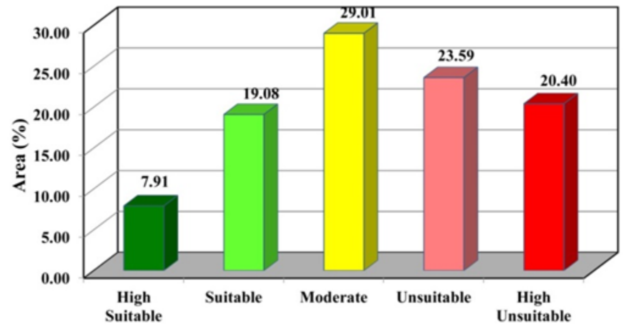

Figure 8. Percentage of the land area for urban development (Fuzzy AHP)

Finally, ten potential sites were identified in the selection of the most suitable lands for building apartments. These sites were selected based on the Fuzzy AHP analysis model depicted in Fig. 5. The potential sites are Amir Abad, Azad Shahr, Damai, Golshahr Jonobi, Hormozan, Khaje Ata, Koy Farhangiyan, Panzdah Khordad, Shahrak Imam Reza and Ziba Shahr. Amir Abad is highly capable of being allocated for apartment construction as it is newly constructed and has open spaces. Also, it is located close to the naval residential town. The Azad Shahr district is selected due to the fact that the construction density and urbanization standards were considered during its development. The Damai district is close to the largest academic center of Bandar Abbas as well as Tavanir residential town and has experienced balanced growth during the last years. Furthermore, the per capita is noticed in urban design and planning. Golshahr Jonobi is the largest area among the potential regions for building apartments. In the southern margin of this district, the Dolat Beach Park is located. This park is the largest park of Bandar Abbas with multipurpose capabilities such as amusement, sport and commercial centers. The Hormozan district is located beside the largest remedial center of Bandar Abbas city. Among its advantages is its compliance to the per capita and construction density regulations. The Khaje Ata district overlooks the beach. In addition, this area has open spaces and proper accessibilities, which makes it suitable for development of residential apartments.

The largest green space, commercial complex and theater are located in thye Koy Farhangiyan, where the constructed land uses follow urbanization principles; however, the shortage in open spaces has imposed limitations on the construction of residential structures. The largest hotel (five-star Hormoz Hotel) and the Takhti sport complex are located in the Panzdah Khordad district.

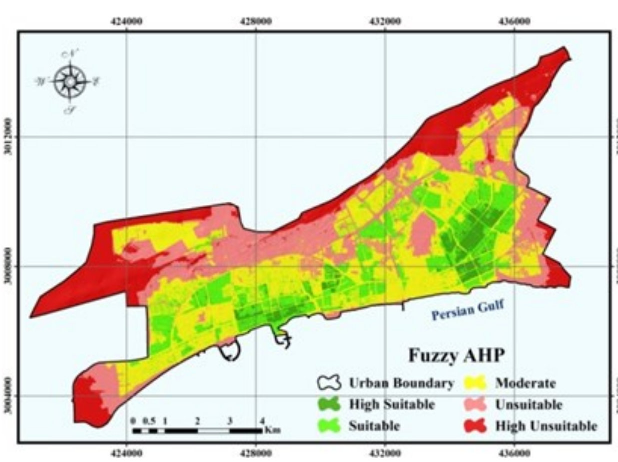

Figure 7. Classification results for the Fuzzy AHP model

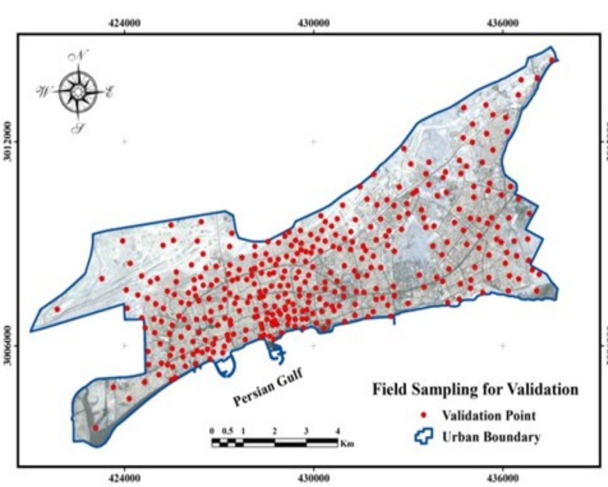

Figure 9. Field sampling for validation

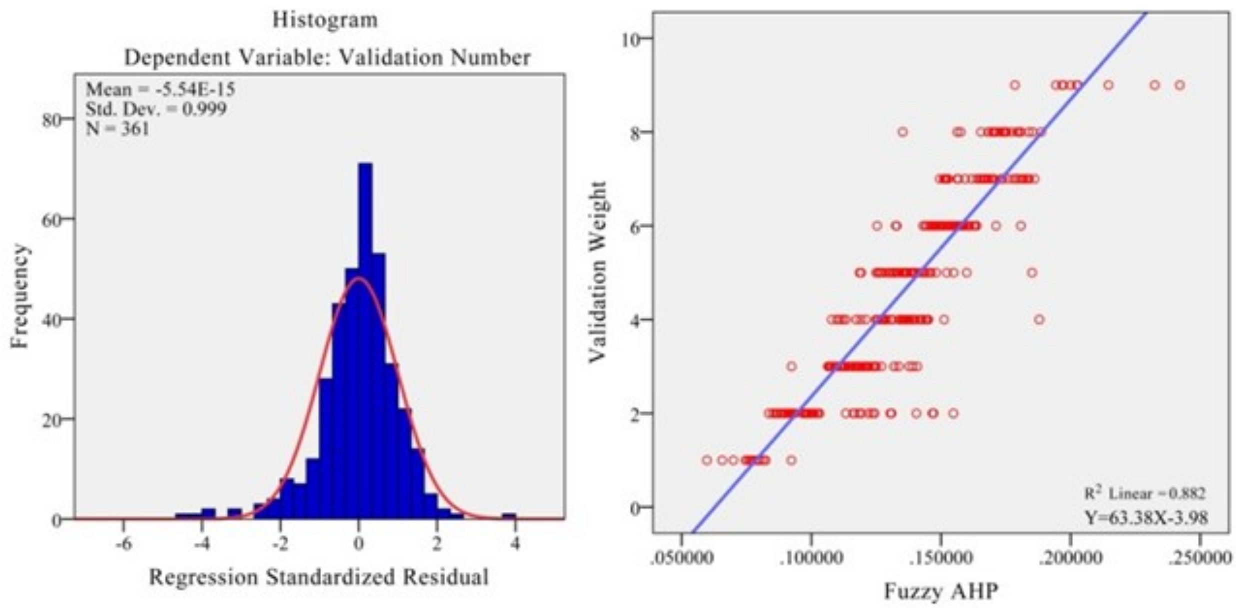

Figure 10. Standardization and correlation diagram of Fuzzy AHP model

Besides, the Shahnaz seasonal river (which is considered as one of the appropriate elements in urban design) is adjacent to the eastern boundary of the district. Additionally, the district includes open spaces. The Shahrak Imam Reza is a newly constructed district and is located in the north of the city. This district has suitable accessibility and open spaces. The Ziba Shahr district is an old district, but due to the per capita and urban density regulations, it is highly capable of apartment development. The mentioned potential sites are illustrated in Figure 6.

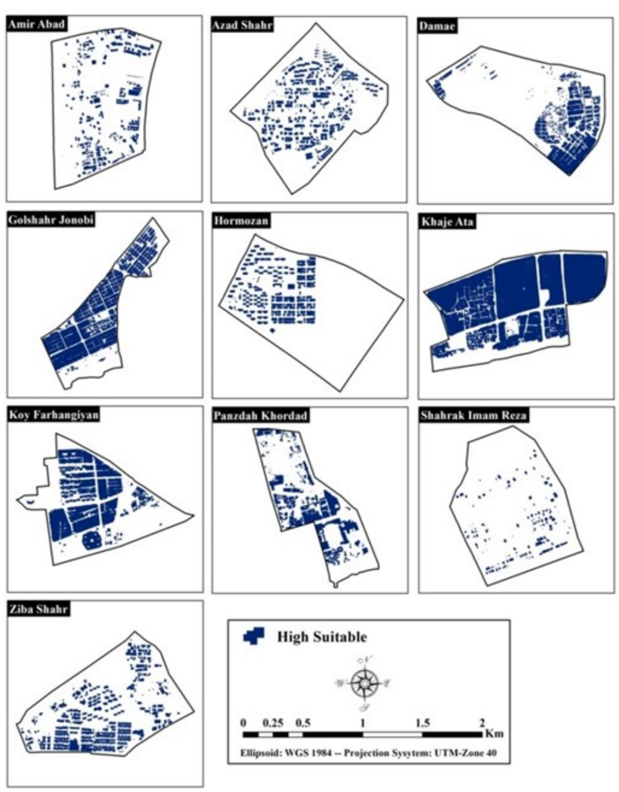

Figure 11. Districts which are the most capable and with the highest percentage of suitable lands for building apartments

Sensitivity analysis

In the first step, the Fuzzy AHP model is utilized to determine the priority and importance of the criteria. When the final map is extracted based on the importance of the land development capabilities, the output results are classified. The priority classes are very suitable, suitable, medium, unsuitable, and very unsuitable. According to the result in Figure 7, south, east and parts of northeast areas have the largest number of suitable lands for urban development. As shown in Figure 8, the largest percentage of urban lands, based on the Fuzzy AHP model, belongs to the medium class with 29.01 %, while the smallest percentage belongs to the very suitable class with 7.91%. To validate research results and determine the best outputs, field observation is utilized. Based on the observed results, 1300 points were sampled across the Bandar Abbas city (Figure 9).

In the second step, a numerical value is assigned

Table 3. Pairwise comparison of land selection criteria for urban development via TFN

	Structural	Accessibility	Economical	Social	Physical	Ecological and Environmental	Cultural and Historic	Priority Weight (W)
Structural (C_1)	(1,1,1)	(1,2,3)	(2,3,4)	(2,3,4)	(2,3,4)	(2,3,4)	(3,4,5)	0.2867
Accessibility(C_2)	(0.33, 0.5,1)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(1,2,3)	(2,3,4)	0.1886
Economical(C_3)	(0.25,0.33,0.5)	(0.33, 0.5,1)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(2,3,4)	0.1635
Social(C_4)	(0.25,0.33,0.5)	(0.33, 0.5,1)	(0.33, 0.5,1)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	0.1257
Physical(C_5)	(0.25,0.33,0.5)	(0.33, 0.5,1)	(0.33, 0.5,1)	(0.33, 0.5,1)	(1,1,1)	(1,2,3)	(1,2,3)	0.1031
Ecological and Environmental(C_6)	(0.25,0.33,0.5)	(0.33, 0.5,1)	(0.33, 0.5,1)	(0.33, 0.5,1)	(0.33, 0.5,1)	(1,1,1)	(1,2,3)	0.0805
Cultural and Historic(C_7)	(0.2,0.25,0.33)	(0.25,0.33,0.5)	(0.25,0.33,0.5)	(0.33, 0.5,1)	(0.33, 0.5,1)	(0.33, 0.5,1)	(1,1,1)	0.0515

$V(S_{R_1} \geq S_{R_2}, S_{R_3}, S_{R_4}, S_{R_5}, S_{R_6}, S_{R_7}) = 1.000$ $\quad V(S_{R_2} \geq S_{R_1}, S_{R_3}, S_{R_4}, S_{R_5}, S_{R_6}, S_{R_7}) = 0.714$

$V(S_{R_3} \geq S_{R_1}, S_{R_2}, S_{R_4}, S_{R_5}, S_{R_6}, S_{R_7}) = 0.686$ $\quad V(S_{R_4} \geq S_{R_1}, S_{R_2}, S_{R_3}, S_{R_5}, S_{R_6}, S_{R_7}) = 0.611$

$V(S_{R_5} \geq S_{R_1}, S_{R_2}, S_{R_3}, S_{R_4}, S_{R_6}, S_{R_7}) = 0.508$ $\quad V(S_{R_6} \geq S_{R_1}, S_{R_2}, S_{R_3}, S_{R_4}, S_{R_5}, S_{R_7}) = 0.374$

to each sampled point. The using linear regression model is then used to determine the correlation and significance of the Fuzzy AHP model results. When the values are standardized (Figure 10), the linear regression model is then applied on the sample points of the Fuzzy AHP model. As evident in Fig. 10, the Fuzzy AHP model with R^2=0.882 is highly significant. Thus, when this model is used for detecting the suitable lands, the derived results are precise and accurate. Finally, the districts which have the maximum percentage of suitable lands for apartment construction are selected. As demonstrated in Figure 11, the districts of Amir Abad ($L_{SA}1$), Azad Shahr ($L_{SA}2$), Damai ($L_{SA}3$), Golshahr Jonobi($L_{SA}4$), Hormozan($L_{SA}5$, Khaje Ata ($L_{SA}6$), Koy Farhangiyan ($L_{SA}7$,) Panzdah Khordad($L_{SA}8$), Shahrak Imam Reza($L_{SA}9$) and Ziba Shahr ($L_{SA}10$) are selected as the districts with the most potential capabilities for apartments building. Then by using the Fuzzy TOPSIS model, the selected districts are prioritized based on their importance to the research criteria.

In order to undertake the ambiguities that exist in the linguistic valuation of the data as a process, the TFNs is used to perform a pairwise comparison. Again, the above mentioned questionnaires were used again for carrying out the face-to-face interviews with the experts. The Fuzzy AHP procedure is then applied in order to determine the importance weights of the criteria which are vital for the Fuzzy TOPSIS technique. Table 3 shows the pairwise comparison matrix of the TFNs. The fuzzy values of aired comparison are then transformed in order to afford Chang's extent analysis. Here, the fuzzy synthetic extent computation was afforded using Eq. (4). The Eqs. (5) - (7). Eqs. (7), (8) and (9) were utilized to determine the degree of synthetic extent values. In order

Table 4. The comparison of alternatives in accordance with criteria

	$L_{SA}1$	$L_{SA}2$	$L_{SA}3$	$L_{SA}4$	$L_{SA}5$	$L_{SA}6$	$L_{SA}7$	$L_{SA}8$	$L_{SA}9$	$L_{SA}10$
C_1	(8,9,10)	(6,7,8)	(4,5,6)	(6,7,8)	(5,6,7)	(3,4,5)	(4,5,6)	(2,3,4)	(7,8,9)	(7,8,9)
C_2	(2,3,4)	(4,5,6)	(4,5,6)	(7,8,9)	(3,4,5)	(5,6,7)	(6,7,8)	(8,9,10)	(3,4,5)	(4,5,6)
C_3	(5,6,7)	(4,5,6)	(8,9,10)	(6,7,8)	(8,9,10)	(3,4,5)	(7,8,9)	(2,3,4)	(5,6,7)	(6,7,8)
C_4	(4,5,6)	(5,6,7)	(6,7,8)	(8,9,10)	(7,8,9)	(3,4,5)	(7,8,9)	(2,3,4)	(2,3,4)	(4,5,6)
C_5	(6,7,8)	(2,3,4)	(4,5,6)	(5,6,7)	(2,3,4)	(8,9,10)	(8,9,10)	(7,8,9)	(2,3,4)	(2,3,4)
C_6	(5,6,7)	(4,5,6)	(5,6,7)	(6,7,8)	(6,7,8)	(7,8,9)	(7,8,9)	(8,9,10)	(2,3,4)	(3,4,5)
C_7	(2,3,4)	(4,5,6)	(3,4,5)	(7,8,9)	(2,3,4)	(7,8,9)	(6,7,8)	(8,9,10)	(3,4,5)	(5,6,7)

Table 5. Weighted normalized decision matrix

	$L_{SA}1$	$L_{SA}2$	$L_{SA}3$	$L_{SA}4$	$L_{SA}5$
C_1	(1,1,1)	(0.75,0.77,0.8)	(0.5,0.55,0.6)	(0.75,0.77,0.8)	(0.62,0.66,0.7)
C_2	(0.25,0.33,0.4)	(0.5,0.55,0.6)	(0.5,0.55,0.6)	(0.87,0.88,0.9)	(0.37,0.44,0.5)
C_3	(0.62,0.66,0.7)	(0.5,0.55,0.6)	(1,1,1)	(0.75,0.77,0.8)	(1,1,1)
C_4	(0.5,0.55,0.6)	(0.62,0.66,0.7)	(0.75,0.77,0.8)	(1,1,1)	(0.87,0.88,0.9)
C_5	(0.75,0.77,0.8)	(0.25,0.33,0.4)	(0.5,0.55,0.6)	(0.62,0.66,0.7)	(0.25,0.33,0.4)
C_6	(0.62,0.66,0.7)	(0.5,0.55,0.6)	(0.62,0.66,0.7)	(0.75,0.77,0.8)	(0.75,0.77,0.8)
C_7	(0.25,0.33,0.4)	(0.5,0.55,0.6)	(0.37,0.44,0.5)	(0.87,0.88,0.9)	(0.25,0.33,0.4)
	$L_{SA}6$	**$L_{SA}7$**	**$L_{SA}8$**	**$L_{SA}9$**	**$L_{SA}10$**
C_1	(0.37,0.44,0.5)	(0.5,0.55,0.6)	(0.25,0.33,0.4)	(0.87,0.88,0.9)	(0.87,0.88,0.9)
C_2	(0.62,0.66,0.7)	(0.75,0.77,0.8)	(1,1,1)	(0.37,0.44,0.5)	(0.5,0.55,0.6)
C_3	(0.37,0.44,0.5)	(0.87,0.88,0.9)	(0.25,0.33,0.4)	(0.62,0.66,0.7)	(0.75,0.77,0.8)
C_4	(0.37,0.44,0.5)	(0.87,0.88,0.9)	(0.25,0.33,0.4)	(0.25,0.33,0.4)	(0.5,0.55,0.6)
C_5	(1,1,1)	(1,1,1)	(0.87,0.88,0.9)	(0.25,0.33,0.4)	(0.25,0.33,0.4)
C_6	(0.87,0.88,0.9)	(0.87,0.88,0.9)	(1,1,1)	(0.25,0.33,0.4)	(0.37,0.44,0.5)
C_7	(0.87,0.88,0.9)	(0.75,0.77,0.8)	(1,1,1)	(0.37,0.44,0.5)	(0.62,0.66,0.7)

to determine the weight vector, Eqs. (12), Eqs. (10) and (11) were utilized to compare the fuzzy numbers. By using Eq. (13), the weight vector is normalized in order to afford the priority weight vector as depicted in Table 3. From the table, the 'structural' and 'accessibility criteria are found to be the two most significant criteria which influence the land selection procedure for constructing apartments. In the decision matrix, the importance degree relevant to the criteria is described through the preference weight vector. Following the attainment of the importance degree of criteria, the alternative locations are evaluated using the Fuzzy TOPSIS method. At this juncture, the fuzzy assessments of the alternative locations is established ($L_{SA}1$, $L_{SA}2$, $L_{SA}3$, $L_{SA}4$, $L_{SA}5$, $L_{SA}6$, $L_{SA}7$, $L_{SA}8$, $L_{SA}9$ and $L_{SA}10$) using the Fuzzy TOPSIS, which is based on the criteria by reuse of the TFNs. The result is the decision matrix for ranking the alternatives which mirrors the efficiency ratings of the alternatives.

Table 6. Fuzzy TOPSIS results

Alternatives	D_j^*	D_j^-	CC_j
$L_{SA}1$	0.075	0.089	0.4573
$L_{SA}2$	0.072	0.064	0.5316
$L_{SA}3$	0.075	0.066	0.5318
$L_{SA}4$	0.038	0.094	0.2862
$L_{SA}5$	0.076	0.073	0.5100
$L_{SA}6$	0.090	0.054	0.6269
$L_{SA}7$	0.059	0.081	0.4205
$L_{SA}8$	0.102	0.073	0.5808
$L_{SA}9$	0.082	0.072	0.5322
$L_{SA}10$	0.066	0.078	0.4585

The linguistic scales and their associated fuzzy values are expressed as: (1,1,1)-very poor, (2,3,4)-poor, (4,5,6)-fair, (6,7,8)-good, (8,9,10)-very good. Table 4 illustrates the comparison of the alternatives with regard to the criteria. Following the creation of the decision matrix, calculation of the normalized decision matrix begins. To obtain the normalized decision matrix, Eq. (19) is used. Here, the third and the fifth criterion are referred to as the coast criteria, while the other criteria are referred to as the benefit criteria. As a case in point, given the benefit criterion $'C_1'$ the maximum value of the criterion is $'C_1'$ with fuzzy numbers (8,9,10) on alternative $L_{SA}2$. The computation of the normalization for the alternative $L_{SA}4$ becomes:

(6,7,8)/(8,9,10) = (6/8, 7/9, 8/10) = 0.75,0.77,0.8.

Another parameter the cost criterion is given on Table 4. Given that the minimum scores of the criterion $'C_3'$ are fuzzy scores (2,3,4) on alternative $L_{SA}5$. The computation of the normalization for the alternative $L_{SA}8$ is:

(2,3,4) / (8,9,10) = (2/8,3/9,4/10) = (0.25,0.33,0.4).

As illustrated in the Table 4, the weighted normalized fuzzy decision matrix is generated by multiplying the normalized decision matrix by the weights of the criteria matrix (Table 3), which is attained through the Fuzzy AHP procedure. Table 5 illustrates the weighted

Table 7. The sensitivity analysis result

	$L_{SA}1$	$L_{SA}2$	$L_{SA}3$	$L_{SA}4$	$L_{SA}5$	$L_{SA}6$	$L_{SA}7$	$L_{SA}8$	$L_{SA}9$	$L_{SA}10$
CC_{12}^{*}	0.61	0.69	0.72	0.50	0.68	0.82	0.59	0.76	0.74	0.63
CC_{13}^{*}	0.63	0.71	0.74	0.53	0.68	0.84	0.62	0.80	0.76	0.71
CC_{14}^{*}	0.68	0.73	0.79	0.59	0.75	0.88	0.67	0.84	0.81	0.73
CC_{15}^{*}	0.71	0.81	0.82	0.73	0.78	0.91	0.70	0.87	0.84	0.77
CC_{16}^{*}	0.75	0.85	0.85	0.68	0.81	0.93	0.74	0.90	0.87	0.75
CC_{17}^{*}	0.80	0.88	0.89	0.74	0.85	0.95	0.79	0.94	0.91	0.89
CC_{23}^{*}	0.63	0.74	0.74	0.53	0.68	0.82	0.62	0.80	0.76	0.68
CC_{24}^{*}	0.68	0.78	0.79	0.59	0.78	0.86	0.67	0.84	0.81	0.76
CC_{25}^{*}	0.71	0.81	0.82	0.63	0.78	0.88	0.70	0.87	0.84	0.74
CC_{26}^{*}	0.75	0.84	0.85	0.68	0.81	0.91	0.74	0.90	0.87	0.80
CC_{27}^{*}	0.80	0.88	0.89	0.74	0.85	0.95	0.79	0.94	0.91	0.84
CC_{34}^{*}	0.68	0.78	0.79	0.59	0.70	0.86	0.67	0.84	0.81	0.73
CC_{35}^{*}	0.71	0.81	0.82	0.63	0.78	0.88	0.70	0.87	0.84	0.76
CC_{36}^{*}	0.75	0.84	0.85	0.68	0.79	0.91	0.74	0.90	0.87	0.80
CC_{37}^{*}	0.80	0.88	0.90	0.74	0.88	0.95	0.79	0.94	0.91	0.84
CC_{45}^{*}	0.71	0.81	0.83	0.63	0.80	0.88	0.70	0.87	0.84	0.76
CC_{46}^{*}	0.75	0.84	0.86	0.68	0.81	0.91	0.74	0.90	0.87	0.80
CC_{47}^{*}	0.80	0.88	0.90	0.74	0.85	0.95	0.79	0.94	0.91	0.84
CC_{56}^{*}	0.75	0.84	0.85	0.68	0.79	0.91	0.74	0.90	0.87	0.80
CC_{57}^{*}	0.80	0.88	0.78	0.74	0.85	0.95	0.79	0.94	0.91	0.82
CC_{67}^{*}	0.80	0.88	0.78	0.74	0.88	0.95	0.79	0.94	0.91	0.86

normalized decision matrix.

The weighted normalized values can also be used to define whether the solution is a negative ideal solution (A^-) or positive ideal solution (A^*). Specifically, the Eqs. (20) and (21) are used to determine the positive and negative ideal solutions respectively. Here, the positive TFNs occur in the range [0, 1]. As such, the fuzzy positive ideal reference point $(FPIS, A^*)$ is denoted by (1,1,1), while the fuzzy negative ideal reference point $(FNIS, A^-)$ is denoted by (0,0,0). Finally, the relative closeness of the ideal solution is calculated using the Eqs. (22) and (23), through Eq. (14). The final result is summed up in Table 6. Given the fact that the higher the closeness, the better is the rank; the ideal solution of the alternatives may be ranked thus: $CC_6 > CC_8 > CC_9 > CC_3 > CC_2 > CC_5 > CC_{10} > CC_1 > CC_7 > CC_4$ where $L_{SA}6$ was found to depict the best location alternative.

A sensitivity analysis was also implemented in order to assess the accuracy of the final result. Sensitivity analysis involves the replacement of different criteria's weights in the place of one another. This resulted in 21 different calculations. For every calculation, the values of CC^* are found. A case in point is CC_{13}^* which means the weights of criterion 1 and 3 have been altered, while

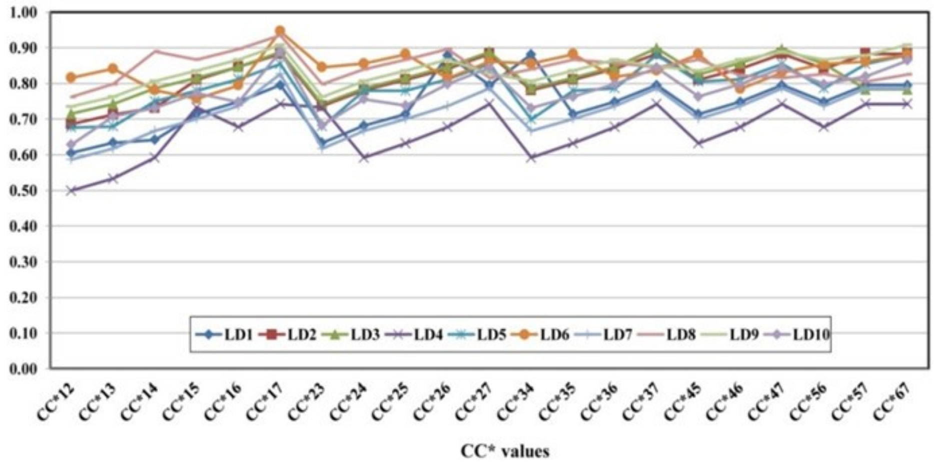

Figure 12. New *CC value of the alternatives**

CC^*_{45} shows a change in criterion 4 and criterion 5's weights.

Fig. 12 summarizes the new CC^* values of the alternatives using graphical representation. Like Fig. 12, Table 7 also illustrates the new CC^* values. It is obvious from Fig.12 and Table 7 that the $L_{SA}6$ is also the best alternative in the 4th, 5th, 6th, 11th, 11th, 14th, 15th, and 21st calculations. The best alternative in the rest of the calculations is $L_{SA}8$. Thus, the decision maker can choose one of these, based on criteria importance.

SUMMARY

Nowadays, population growth, political stability and economic growth have resulted in urban growth, thus claiming substantial quantities of land in the urban. With these occurrences, further existence of suitable lands in the cities are considered as an essential necessity for development. Therefore, detecting suitable lands for building apartments, especially in the urban areas is a difficult task for governmental organizations, for implementing construction projects as well as governmental and private sector investment activities. In this paper, a hybrid approach based on Fuzzy AHP and Fuzzy TOPSIS models is proposed. The study is conducted to explicate the proposed hybrid model in the real world, using seven criteria and 44 sub-criteria. In the employment of the proposed method, the Fuzzy AHP model was utilized for determining the weights of the criteria and sub-criteria.

Subsequently, the Fuzzy TOPSIS model is used to prioritize the detected alternative sites. To determine the accuracy of the achieved results, the correlation between the sampled points and the priority map of the Fuzzy AHP model was exploited, and the R2 index was found to be 0.882. This value is indicative of a high significance between the result and the reality.

CONCLUSION

The obtained result revealed that the Khaje Ata district has the highest priority regarding apartment construction.

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APPENDIX

Research Questionnaire

The aim of this study was to identify land suitable for apartments -based on the combined fuzzy MCDM approach and to provide a model for planning and sustainable urban development based on reality. In this study, two scenarios of land development, seven criteria (Cultural and Historic, Ecological and Environmental, Physical, Social, Economic, Structural, Accessibility) and 45 sub-criteria are considered.

After the analysis of hierarchical models and Fuzzy TOPSIS, the prioritize lands and sites identified are normalized. The remainder of the priority areas of smart growth model based on the smart code for the planning of land development in identifying areas is used. The 1300 points to analyze and validate the results obtained have been used.

Table A1. Pairwise comparison matrix for classes

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9	Class 10	Class 11	Class 12	Class 13	Class 14	Class 15
Class 1	1														
Class 2	1/C2	1													
Class 3	1/C3	1/C3	1												
Class 4	1/C4	1/C4	1/C4	1											
Class 5	1/C5	1/C5	1/C5	1/C5	1										
Class 6	1/C6	1/C6	1/C6	1/C6	1/C6	1									
Class 7	1/C7	1/C7	1/C7	1/C7	1/C7	1/C7	1								
Class 8	1/C8	1/C8	1/C8	1/C8	1/C8	1/C8	1/C8	1							
Class 9	1/C9	1/C9	1/C9	1/C9	1/C9	1/C9	1/C9	1/C9	1						
Class 10	1/C10	1/C10	1/C10	1/C10	1/C10	1/C10	1/C10	1/C10	1/C10	1					
Class 11	1/C11	1/C11	1/C11	1/C11	1/C11	1/C11	1/C11	1/C11	1/C11	1/C11	1				
Class 12	1/C12	1/C12	1/C12	1/C12	1/C12	1/C12	1/C12	1/C12	1/C12	1/C12	1/C12	1			
Class 13	1/C13	1/C13	1/C13	1/C13	1/C13	1/C13	1/C13	1/C13	1/C13	1/C13	1/C13	1/C13	1		
Class 14	1/C14	1/C14	1/C14	1/C14	1/C14	1/C14	1/C14	1/C14	1/C14	1/C14	1/C14	1/C14	1/C14	1	
Class 15	1/C15	1/C15	1/C15	1/C15	1/C15	1/C15	1/C15	1/C15	1/C15	1/C15	1/C15	1/C15	1/C15	1/C15	1

Table A2. Pairwise comparison matrix for each sub-criterion

	Sub-Criterion									
Sub-Criterion	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1									
2	1/SC2	1								
3	1/SC3	1/SC3	1							
4	1/SC4	1/SC4	1/SC4	1						
5	1/SC5	1/SC5	1/SC5	1/SC5	1					
6	1/SC6	1/SC6	1/SC6	1/SC6	1/SC6	1				
7	1/SC7	1/SC7	1/SC7	1/SC7	1/SC7	1/SC7	1			
8	1/SC8	1/SC8	1/SC8	1/SC8	1/SC8	1/SC8	1/SC8	1		
9	1/SC9	1/SC9	1/SC9	1/SC9	1/SC9	1/SC9	1/SC9	1/SC9	1	
10	1/SC10	1/SC10	1/SC10	1/SC10	1/SC10	1/SC10	1/SC10	1/SC10	1/SC10	1

Table A3. Pairwise comparison matrix for each criterion

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7
Criterion 1	1						
Criterion 2	1/CR2	1					
Criterion 3	1/CR3	1/CR3	1				
Criterion 4	1/CR4	1/CR4	1/CR3	1			
Criterion 5	1/CR5	1/CR5	1/CR4	1/CR3	1		
Criterion 6	1/CR6	1/CR6	1/CR5	1/CR4	1/CR3	1	
Criterion 7	1/CR7	1/CR7	1/CR6	1/CR5	1/CR4	1/CR7	1

Table A4.Vehicular lane dimensions: assigned lane widths to transect zones

Name of District		**Area (Ha)**	**Total Residential Density**	**Height Density**	**Open Space Area (%)**	**Green Space (%)**	**Functional Zone**	**Roads (%)**	**Popula-tion Density**	**Household Size (Average)**
According to the transect zone, what is the character of each T-zone in this district?										
T1	T2	T3	T4	T5	T6					
What is the proportions of Transect Zones within each Community Type?										
	O1	O2	G1		G2		G3		G4	
			CLD		CLD	TND	TND	RCD	TND	RCD
T1										
T2										
T3										
T4										
T5										
T6										
Specific requirements for truck and transit bus routes and truck loading shall be decided by Warrant.										

Design Speed	**Travel Lane Width**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
Below 20 mph	8 feet						
20-25 mph	9 feet						
25-35 mph	10 feet						
25-35 mph	11 feet						
Above 35 mph	12 feet						

Design Speed	**Parking Lane Width**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
20-25 mph	Angle (18 feet)						
25-35 mph	Parallel (7 feet)						
25-35 mph	Parallel (8 feet)						
Above 35 mph	Parallel (9 feet)						

Design Speed	**Effective Turning Radius**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
Below 20 mph	5-10 feet						
20-25 mph	10-15 feet						
25-35 mph	15-20 feet						
Above 35 mph	20-30 feet						

Table A5. The projected design speeds determine the dimensions of the vehicular lanes and Turning Radii assembled for Thoroughfares.

No Parking	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T1	T2
Yield Parking	T3	T4	T3	T4									
Parking One Side Parallel	T3	T4	T3	T4	T5	T4	T5	T4	T5	T6	T5	T6	
Parking Both Side Parallel	T4	T4	T5	T6	T4	T5	T6	T5	T6	T5	T6		
Parking Both Side Diagonal	T5	T6	T5	T6	T5	T6	T5	T6	T5	T6			
Parking Access	T3	T4	T5	T6									

Table A6. Public Frontages - General. The Public Frontage is the area between the private Lot line and the edge of the vehicular lanes.

(HW) for Highway			**(RD) for Road**			**(ST) for Street**			**(DR) for Drive**				**(AV) for Avenue**				**(CS) (AV) for Commer-cial Street or Avenue**		**(BV) for Boulevard**			
T1	T2	T3	T1	T2	T3	T3	T4	T5	T3	T4	T5	T6	T3	T4	T5	T6	T5	T6	T3	T4	T5	T6

Table A7. Public Frontages - Specific. This table assembles prescriptions and dimensions for the Public Frontage elements - Curbs, walkways and Planters – relative to specific Thoroughfare types within Transect Zones. What is the type of Public Frontages is suitable for this district?

	T1	T2	T3	T1	T2	T3	T3	T4	T4	T5	T5	T6	T5	T6
Assembly														
Curb														
Walkway														
Planter														
Landscape														
Lighting														

Table A8. Lighting varies in brightness and also in the character of the fixture according to the Transect. What is the type of Public Lighting is suitable for this district?

	T1	T2	T3	T4	T5	T6	SD	Specifications
Cobra Head								
Pipe								
Post								
Column								
Double Column								

Table A9. This table shows six common types of street tree shapes and their appropriateness within the Transect Zones. The local planning office selects species appropriate for the bioregion. What is the type of Public Planting is suitable for this district?

	T1	T2	T3	T4	T5	T6	SD	Specifications
Pole								
Oval								
Ball								
Pyramid								
Umbrella								
Vase								

Table A10. This table categorizes Building Functions within Transect Zones. Parking requirements are correlated to functional intensity. For Specific Function and Use permitted By Right or by Warrant, see Appendix 11-12. What is the type of Building Function is suitable for this district?

	T2 T3	T4	T5 T6
Residential			
Lodging			
Office			
Retail			
Civic			
Other			

Table A11. The Private Frontage is the area between the building Facades and the Lot lines. What is the type of Private Frontage is suitable for this district?

	Section	Plan	
Common Yard			T2 T3
Porch & Fence			T3 T4
Terrace or Lightwell			T4 T5
Forecourt			T4 T5 T6
Stoop			T4 T5 T6
Shopfront			T4 T5 T6
Gallery			T4 T5 T6
Arcade			T5 T6

Table A12. This table shows the Configurations for different building heights for each Transect Zone. It must be modified to show actual calibrated heights for local conditions. Recess Lines and Expression Lines shall occur on higher buildings as shown. N = maximum height. What is the type of Building Configuration is suitable for this district?

T2	T3	T4	T5	T6

T6	T6	T6

Stepbaks / Arecade Heights. The diagram below show the arcade Frontages. Diagram above apply to all frontages.

T6	T6	T6	T6

Table A13. This table approximates the location of the structure relative to the boundaries of each individual Lot, establishing suitable basic building types for each Transect Zone. What is the type of Building Disposition is suitable for this district?

Edgeyard	**T2** **T3** **T4**
Sideyard	**T4** **T5**
Rearyard	**T4** **T5** **T6**
Courtyard	**T5** **T6**
Specialized	**SD**

Table A14. What is the type of Green Space and Commercial zone is suitable for this district?

Park	T1
	T2
	T3
Green	T3
	T4
	T5
Square	T4
	T5
	T6
Plaza	T5
	T6
Playground	T1
	T2
	T3
	T4
	T5
	T6