

Implement of zoning in order to evaluate the establishment of the airports using integrating MCDM methods and noise pollution modeling softwares

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Abstract

Background: Finding the best location for the airport reduces the negative effects of construction and its activity on the environment. This study aimed to evaluate the establishment of the airports (Mehrabad and Imam Khomeini airports) in Tehran province through integration of multi-criteria decision making (MCDM) methods and noise pollution modeling software.

Methods: The criteria for zoning the airports were determined using Delphi method, and then, were weighed using analytic network process (ANP). One of the criteria was noise pollution. The computer aided noise abatement (CadnaA) software was used to map the noise level at the airports. The geographic information system (GIS) software and weighted overlay method were used to zone Tehran province for construction of the airports. The percentage of voice annoyance was defined according to the questionnaire provided by the International Commission on the Biological Effects of Noise (ICBEN).

Results: Prioritization between the selected criteria using ANP and TOPSIS showed that the most important criteria are the land use (0.069) and the distance from the city (0.0598), respectively. The highest percentage of highly annoyed (%HA) persons was reported at both airports at Lden levels above 70 dB.

Conclusion: According to the results of this study, the location of Mehrabad and Imam Khomeini airports is considered 60% and 18% inappropriate, respectively. The results introduce a set of criteria that determines compatibility rate of different activities around the airports based on the noise levels. Finally, it is recommended to study the correlation between aircraft noise pollution indicators in other airports of Iran and design a local model for the whole country.

Keywords: Noise, Geographic information systems, Airports, Environmental indicators, Software

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Introduction

Problems and challenges arising from the integration of the airport functions in the context of urban space are complex issues (1,2). Airports can have profound effects on land use and activities in the area, which may be economic, developmental, visual, etc (3,4). The environmental impacts of airports are considerable within the local area (5,6). During the construction of an airport, some operations like land use changes and removal of vegetation are considered as the necessary changes to create a suitable area for this kind of land use. Other environmental factors like air pollution, industrial

wastewater and domestic wastewater generated from the airports, and even the disruption of the existing environmental balance should be noticed. The share of airports in the production of noise in urban societies varies depending on the geographical location of the airports and other parameters like economic development and the presence of other means of transportation (7,8). Noise as an undesired or harmful sound has short-term effects like sleep disorders (9,10) or increased stress, fatigue, and neural stimulations. It also affects human activities such as learning, working, and sleep quality (3-6). This means that noise pollution reduces the quality of human life



(11,12). A healthy environment without undesired sounds is simply removed from the human life (13,14). Aviation industry is a dynamic and fast-paced industry that fits into the needs of today's societies (15). The aviation industry plays a key role in local and national economy (16-18). Noise pollution is considered as an important factor in any kind of project for construction and development of airports (19-21). The negative effects of airplanes include behavioral and psychological disorders such as irritability or sleep disorders (22-24). Airport authorities should also have eligible potentials for land acquisition, controlling the impacts of noise, as well as proper knowledge on noise pollution estimation methods (25-28). To confront the above-mentioned problems, a proper zoning procedure for airport developments considering all environmental criteria can be a good solution (29-31). As mentioned before, air pollution is the most important environmental problem at airports that should be considered in both development and construction procedures. The development of silent engines and modification of aviation patterns have significant effects in reducing noise pollution. Another effective strategy to reduce the pollution is to provide comprehensive plans to use the airports surrounding areas. Mahashabde et al assessed the environmental impact of aircraft noise and emissions (32). For this purpose, first, the noise effects, air and aviation in general were investigated, then, it was discussed how environmental impact assessment and its ambiguities could provide a more comprehensive assessment of aviation environmental policies (32). Kroesen et al investigated the effects of transportation noise annoyance on residential satisfaction in the Netherlands (33). They determined the correlation between target variables, sound annoyance, and residents' satisfaction using a structural model and SPSS software. Babisch examined various factors causing the residents' annoyance in the study area and reported that the effect of noise caused by aircrafts is greater than that caused by traffic, railway, and construction activities. They also found that the type of aircraft, the size, shape, and location of airport, and airport runways have created many problems for the residents. In addition, the results have shown that the effects of noise pollution depend on noise level, noise time span, runways for landing and taking off, number and type of flight operations, aviation method, the use of airport runway system accompanied with aviation plan, different timing, season and climate conditions (34).

The present study was conducted to identify and prioritize the effective criteria for the establishment of Mehrabad and Imam Khomeini airports in Tehran province, and examine the spatial desirability of the airports. For the first time, the criteria for zoning the airports were determined according to the criteria presented by the reputable International organizations. Using Delphi method and emphasizing on the analysis of sound measurement parameters, percentage of annoyance caused by noise levels was determined. On

the other hand, multi-criteria decision making (MCDM) methods and weighted overlay in geographic information system (GIS) were used to investigate the spatial status of Imam Khomeini and Mehrabad airports in Tehran province. The computer aided noise abatement (CadnaA) model was used to calculate sound levels.

Guidelines and effective criteria for zoning airports are provided by the reputable International organizations such as the Federal Aviation Administration (FAA) and International Civil Aviation Organization (ICAO), which were studied in this research. Unfortunately, there are no specific guidelines and criteria for the establishment of airports in Iran. Therefore, in the present study, the criteria and suitability of different zones for establishment of airports in Tehran province were investigated and introduced. In this study, the integration of MCDM and GIS methods along with sound field measurement and CadnaA model were used. MCDM is a mathematical model that refers to a problem-solving approach, which is used to select an option from a limited number of options. In this study, in order to achieve more efficient decisions to weight zoning criteria properly and select the best location for establishment of airports, a combined approach (ANP-TOPSIS) was used to compensate their weaknesses and strengths (35-37). Compensatory methods such as TOPSIS allow trade-offs between criteria, where a poor result in one criterion can be negated by a good result in another criterion. TOPSIS is the Technique for Order of Preference by Similarity to Ideal Solution (38-40). The analytic network process (ANP) is used in multi-criteria decision analysis. It consists of hierarchies, clusters, elements, and their relations (41-43). Therefore, in this study, in order to profit the advantages of both techniques in ranking and selecting the best option, a combined method (ANP-TOPSIS) was used. These methods are used to evaluate the suitability of different areas of Tehran province for establishment of airports.

Materials and Methods

Study area

Tehran province with an area of about 12981 km² is situated between 34 to 36.5 degrees' north latitude and 50 to 53 degrees' east longitude. The population of the province in 2016 was estimated around 13 267 637 people. The capital of this province is Tehran, which is the capital of Iran. Tehran province has two International airports, Imam Khomeini and Mehrabad airports.

Imam Khomeini International airport is located on a 14000-hectare site, 30 km far away from Tehran, in the administrative and political area of Shahr-e Rey (Fashafoyeh section), between Tehran-Qom freeway. Since June 2019, the airport has two active terminals. Mehrabad International Airport is another international airport in Tehran, which was built in 1938 in the western part of Tehran. The location of these two airports in Tehran province is shown in Figure 1 (44,45).

Using Delphi method and emphasizing on the analysis of sound measurement parameters, the percentage of annoyance caused by sound levels was determined. On the other hand, MCDM methods and weighted overlay in GIS were used to investigate the spatial status of the airports in Tehran province. The CadnaA model was used to calculate sound levels.

Guidelines and effective criteria for zoning the airports provided by the reputable international organizations such as the FAA and ICAO, were studied in this research. Unfortunately, there are no specific guidelines and criteria for establishment of airports in Iran.

In this study, first, different airport location criteria published by the reputable global organizations such as ICAO and FAA were studied. According to the criteria and using Delphi method, a set of zoning criteria was determined. The ANP was conducted using Super Decisions software. Then, ArcGIS software was used to mathematically measure the layers. At this stage, according to the weight of the criteria selected by ANP, Weighted Overlay was performed, and then, prioritization was done between suitable places for establishment of the airports using TOPSIS method. Simultaneously, sound parameters were measured around Mehrabad and Imam Khomeini airports. The CadnaA model was used to prepare the sound zoning map of the airports. Then, the questionnaire presented by the International Commission on the Biological Effects of Noise (ICBEN) was used to study the sound annoyance levels caused by the airports. The questionnaire is related to the monitoring and evaluation of environmental sounds. The results of this stage were used to determine the land uses compatibility criteria with the sound levels in the airports surrounding areas in Iran. The procedures are described in the following sections.

Data collection using Delphi method and a combined method (ANP-TOPSIS)

In this survey, firstly, different criteria published by the important international organizations like ICAO and FAA to estimate the location for establishment of the airports, were studied. The Delphi method was used to determine the criteria. The Delphi method is an approach that collects the opinions of the experts without any communication between them (46). Using the Delphi method, the criteria were introduced and evaluated in three steps by a panel of experts. In the first stage, the Delphi panel members were asked individually to introduce their criteria by giving their reasons. In the second stage, a table consisted of a set of the selected criteria, which were introduced based on the feedback reported by the panel in the first step, was sent to the experts and they were asked to rate and rank the criteria. In the third stage, a summary of the second stage questionnaires was provided as a feedback report for the Delphi panel. They were asked to rank the selected indicators for each criterion considering the opinions of other experts. At this stage, the presented model contains

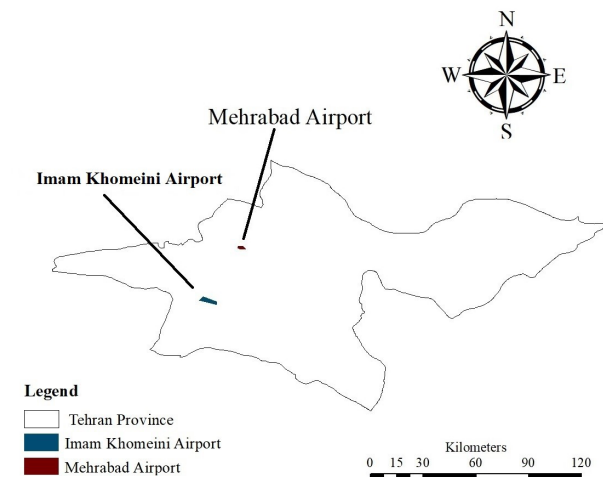


Figure 1. Location of Imam Khomeini and Mehrabad airports in Tehran province.

the standardized parameters that have been determined by the Delphi panel using consensus. Along with the model of priority of the criteria, the ANP method can be used to estimate the weight of the criteria. It is a powerful and flexible tool for the quantitative and qualitative investigation of multi-criteria problems through pairwise comparison as its main characteristic (41).

The TOPSIS method was also used to determine the weight of the criteria and prioritize the appropriate locations. The TOPSIS is a powerful technical decision-making method for prioritizing options with the shortest distance of the selected option to the ideal answer and the longest distance to the inefficient answer. In this method, double comparison matrix was used to determine the weight of the criteria. Then, this matrix entered in Expert Choice software version 11 for the final weighing of the criteria and determining adjustment coefficients. In this research, TOPSIS algorithm was capable of considering all aspects, including issues such as profit and cost, priority and weight of the criteria compared to each other, etc. It also measures the options relative to each other and sorts them in a rational way.

The ICAO has introduced the following criteria for zoning airports:

- Aviation operations
- How to develop the airports surrounding area
- Climate conditions (fog, mist, smoke, changes in climate pattern, prevailing wind, rainfall, snow, low clouds, and turbulence)
- Access to road transportation system
- Availability of land (sufficient land to expand existing airports or create new ones): To evaluate this factor, studies regarding aviation, land, roads, topographic maps, aerial photographs, etc are needed. Studying the topographic maps identifies areas with appropriate slope and drainage. Geological maps show the distribution of soil and rock types. In addition, the

availability of construction materials, the value of relevant land and their use (agricultural, industrial, residential, etc) should also be studied.

- Topography: It has an important impact on the construction costs, including drilling, embankment, drainage, and so on.
- Environment: Studying wildlife reservoirs, migration areas for wildlife and birds, noise-sensitive areas such as hospitals and schools.
- Existence of other airports and availability of airspace in the area
- Access to facilities for airport establishments (water, electricity, gas, fuel, plumbing, and telephone) (47).

The FAA has also provided an APPENDIX E added to FAA B6-5070/150 on zoning the airports. It states that a screening process is needed to locate airports. All primary locations considered for this development must be evaluated by a set of basic criteria to identify their weaknesses. Screening factors may include topography, natural or man-made barriers, airspace, accessibility, environmental impacts, and development costs. Also, one of the best references that plans for noise pollutions caused by airplanes in locating new airports is the Federal Aviation Regulations (FAR) part 150 (Sound Adaptation Program) (48). After introducing the airport locating criteria by the Delphi method, the criteria weights were determined by the ANP method and Super Decisions software version 2.10. Then, ArcGIS software version 10.4 was used for weighted overlay of criteria layers.

CadnaA model and ICBEN questionnaire

At this phase, according to the weights of the criteria selected by the ANP, weighting process was completed and the appropriate location for establishment of an airport in Tehran was studied. Along with these steps, sound parameters around Mehrabad and Imam Khomeini International airports in Tehran province were measured and the noise level of these two airports was mapped using CadnaA model.

CadnaA is a software for estimating the environmental noise assessment in the vicinity of sound generating sources such as airports and aviation sites. This program communicates with all components and elements that affect the creation and dispersion of the sound. CadnaA provides calculation and documentation of the sound level according to the national and international guidelines and regulations. It displays the results by drawing a sound domain and providing colored maps of the sound level. In other words, CadnaA produces the maps of sound distributions from their sources and evaluates them. Then, the ICBEN questionnaire was used to examine the annoyance level of the noise caused by the airports. Using the questionnaire, the environmental sounds are monitored and evaluated. The questionnaire has been designed by the ICBEN and its results can be used for the international comparisons and reviews (49,50). The

questionnaire includes some questions regarding aircraft noise assessment and a series of general questions (51,52).

Results

Super Decisions and TOPSIS software were used to determine the weight of the criteria. The weights related to the airport zoning criteria are presented in Table 1. The environmental criteria affecting airport location were co-scaled in five classes, and then, Super Decisions and TOPSIS software were used to determine the weight of the criteria. Weighted Overlay and TOPSIS methods were used to integrate the layers and MCDM methods. Figure 2 shows the output results of the weighted overlay and TOPSIS methods in locating airports in Tehran province. Based on this method, a map for establishment of an airport was obtained using the weight of layers. In this map, which is made by overlaying of 22 criteria, there was no location as the most suitable zone (5 grades) for airport establishment. All zones presented in the map were categorized into four categories including inappropriate (grade 1), weak (grade 2), moderate (grade 3), and suitable (grade 4). The results of field measurements of sound and noise zoning by CadnaA model in Imam Khomeini and Mehrabad airports are presented in Figures 3 and 4. The outputs of these maps were integrated with the results of the questionnaires distributed among residents regarding the noise annoyance levels.

Table 1. Weights for airport zoning criteria

Criteria	ANP	TOPSIS
Erodibility	0.052	0.0413
Soil fertility	0.061	0.052
Soil texture	0.055	0.0445
Climate	0.049	0.0586
Height	0.057	0.0567
Slope(%)	0.069	0.0582
Slope direction	0.042	0.03392
Parent rock	0.051	0.0401
Fault distance	0.039	0.0321
Distance from permanent rivers and permanent aqueducts	0.028	0.03588
Temperature	0.048	0.0565
Distances from the protected areas	0.039	0.0395
Distance from cities	0.057	0.0598
Distances from villages	0.057	0.0541
Land capacity	0.041	0.0498
Distance from airport	0.025	0.0415
Distances from main roads and highways	0.023	0.0201
Land uses	0.073	0.061
Population density	0.058	0.05356
Distance from water transmission lines	0.021	0.0311
Distance from power lines	0.021	0.03211
Distance from existing industries	0.022	0.0389

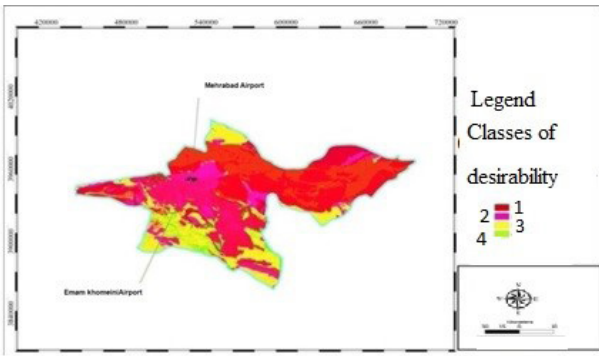


Figure 2. Zoning the airports location in Tehran province using TOPSIS and Weighted Overlay methods (Classes 1 to 4 show the desirability of the airports location, Classes 1 and 4 show the lowest and highest desirability, respectively).

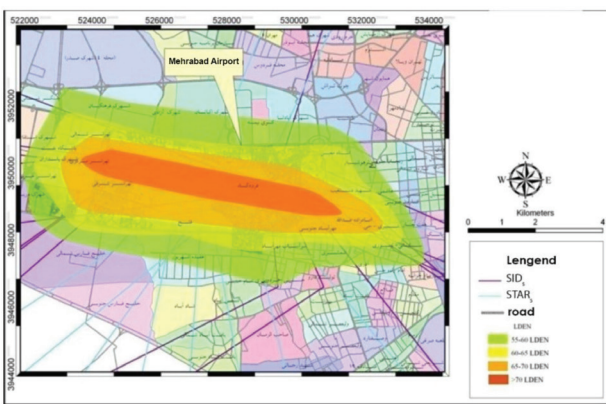


Figure 3. Strategic map of sound factor in Mehrabad Airport using CadnaA Model.

Calculation of the highest percentage of annoyance (%HA)

The basis for observation and evaluation of the noise annoyance level is determined as the percentage of

respondents highly annoyed by source (%HA). The rates of annoyance for each level of noise were measured using the ICBEN 11-point scale. Many studies have been conducted using this scale (53) and all studies performed using this method are stored in the ICBEN's studies bank and can be compared with other studies (54). The high amounts of %HA percentage as the top three numbers of this scale are considered as 8, 9, and 10 (44). The HA percentages at Imam Khomeini and Mehrabad airports are presented in Table 2. Table 3 shows the HA percentages of the respondents at Imam Khomeini and Mehrabad airports at different levels of Lden ($P < 0.0001$ and $P < 0.0003$, respectively).

The compatibility rate of different activities and land uses around Mehrabad and Imam Khomeini airports regarding sound levels was determined based on the results obtained from field measurements, CadnaA model, and the questionnaires (considering %HA in different noise levels). The results are expanded for the whole country. The results of %HA analysis at different levels of Lden in different uses are presented in Table 3.

Based on the above-mentioned results, the criteria that determine the compatibility rate of different activities regarding sound levels in the airports surrounding areas, are presented in Table 4.

Zoning of the airports location in Tehran province is summarized in 5 categories (1 to 5), from inappropriate (1) to the most appropriate (5). An area of 8897.2 km² was placed in category 1, an area of 1368.8 km² in category 2, an area of 2323.96 km² in category 3, and an area of 1095.04 km² was placed in category 4. However, there was no desirable land on the 5th category in Tehran province. Based on the final results of zoning and Map No. 2, the location of Imam Khomeini and Mehrabad airports was assessed, the results are presented in Table 5.

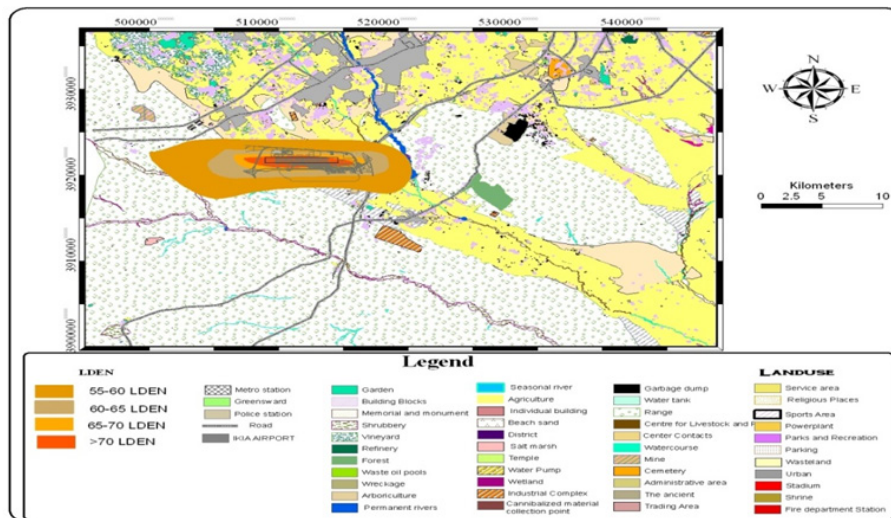


Figure 4. Strategic map of sound factor in Imam Khomeini Airport using CadnaA model.

Table 2. The %HA among the respondents in the study areas (Imam Khomeini and Mehrabad airports) at different levels of Lden (Author, 2016)

Imam Khomeini Airport		Mehrabad Airport	
Lden (dB)	%HA (%)	Lden (dB)	%HA (%)
45-50	8.2	45-50	29
50-55	25	50-55	42
55-60	39	55-60	58
60-65	57	60-65	73
65-70	71	65-70	84
>70	85	>70	96.8

Discussion

Figure 5 shows that at the airports of Imam Khomeini and Mehrabad, with increasing the amount of Lden, the %HA has a more upward trend than that at the airports studied in the United States, the Netherlands, and Korea. Also, at Lden levels of 55-70, the %HA reported in the study by Miedema (55) has a more upward trend compared with that reported at Imam Khomeini Airport. But at Mehrabad Airport, at Lden levels up to 65%, the %HA has an increasing trend compared with that reported by other studies (56). At Lden levels of 66-70, the %HA reported in a study in China (57) is higher than that reported at Mehrabad Airport. Also, at Lden levels of 55-75, the increasing trend of %HA reported in a study in China (2012) is higher than that reported at Imam Khomeini Airport. The innovation of the present study compared to other similar studies (58,59) is the introduction of criteria that determine the compatibility rate of different activities and land uses in the airports surrounding areas while emphasizing on the sound levels obtained from the field measurements, CadnaA model, and the questionnaires feedbacks (considering %HA at different noise levels). According to Table 5, the location of Mehrabad Airport is not suitable in terms of topography and hydrology,

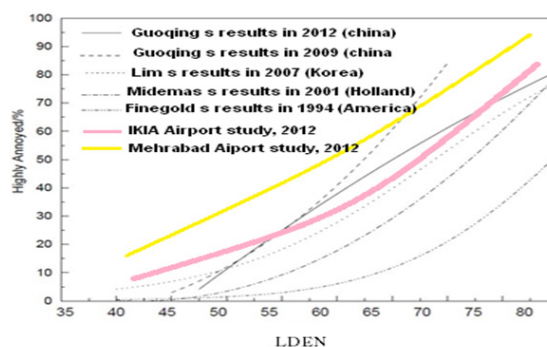


Figure 5. Comparison of the correlation curves between Lden level and %HA in five countries (Author, 2016).

soil type, and proximity to residential areas. The airport is located in an urban area that is surrounded by the residential, industrial, and commercial areas. It has put not only the residents of surrounding areas at risk, but also has led to air pollution and noise pollution in the area. One of the most important issues at Imam Khomeini airport that has not been taken into account is the passage of aqueducts through the surrounding land, especially under the runway long, which threatens their strength. In addition to the aqueducts, another significant point that should be considered is the proximity of the airport to the river that in any future development, its drainage will become an important issue.

Conclusion

According to the results of the present study, the location of Mehrabad and Imam Khomeini airports is considered 60% and 18% inappropriate, respectively. The results indicate that a large-scale zoning for airport establishment is need. The efficiency of the use of the MCDM approach with ArcGIS methods has been

Table 3. Results of HA% at different levels of Lden in different uses (Author, 2016)

	Lden 40-45	Lden 45-50	Lden 50-55	Lden 55-60	Lden 60-65	Lden 65-70	Lden >70	Lden
Residential	7	23	39	42	68	76	85	%HA
Public services	2	10	15	25	32	48	75	
Commercial	0	4	5	7	21	42	51	
Industrial and manufacturing	0	1	2	2	5	8	25	
Recreation and entertainment	0	0	3	4	7	15	32	

Table 4. Criteria of compatibility rate of land uses regarding sound level in the airports surrounding areas in Iran (Author, 2016)

Lden 40-45	Lden 45-50	Lden 50-55	Lden 55-60	Lden 60-65	Lden 65-70	Lden >70	Lden
Residential	A	A1	B	B	B	B	B
Public services	A	A	A1	B	B	B	B
Commercial	A	A	A	A	B	B	B
Industrial and manufacturing	A	A	A	A	A	B	B
Recreation and entertainment	A	A	A	A	A	B	B

A: Compatible, B: Incompatible, A1: With noise insulation and controlling the sound levels.

Table 5. Assessment of the location of Mehrabad and Imam Khomeini airports according to Map No. 2

Criteria	Mehrabad Airport	Emam Khomeini Airport
Erodibility	Inappropriate	Inappropriate
Soil fertility	Appropriate	Appropriate
Soil texture	Appropriate	Appropriate
Climate	Appropriate	Appropriate
Height (m)	Inappropriate	Inappropriate
Slope	Inappropriate	Inappropriate
Slope direction	Inappropriate	Appropriate
Parent rock	Inappropriate	Appropriate
Distance from fault	Inappropriate	Inappropriate
Distance from permanent rivers and aqueducts	Inappropriate	Inappropriate
Temperature	Appropriate	Appropriate
Distance from protected areas	Appropriate	Appropriate
Distance from cities	Inappropriate	Appropriate
Distance from villages	Appropriate	Appropriate
Distance to landfill	Appropriate	Appropriate
Distance from airport	Appropriate	Appropriate
Distance from main roads and highways	Appropriate	Appropriate
Land use	Inappropriate	Appropriate
Population density	Inappropriate	Appropriate
Distance from water transmission lines	Inappropriate	Appropriate
Distance from power transmission lines	Inappropriate	Appropriate
Distance from existing industries	Inappropriate	Appropriate

extensively confirmed in the recent zoning studies. One of the strengths of this research is the simultaneous field measurements of noise pollution and examining the level of noise annoyance among residents of Mehrabad and Imam Khomeini airports, the results of which led to the introduction of a set of criteria for determining the compatibility rate of different activities around the airports based on the noise levels. The lack of this index was quite significant in the criteria for locating airports in Iran. The indicators can be used in future studies on locating airports in Iran.

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Ethical issues

The authors hereby certify that all data collected during the research are as expressed in the manuscript, and no data from the study has been or will be published elsewhere separately.

Competing interests

The authors declare that they have no conflict of interests.

Authors' contributions

All authors have contributed in the study design, field

visits, data collection and analysis, and manuscript preparation. The final version of this manuscript was reviewed and confirmed by all authors.

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