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Identification and Assessment of Fire Risk Factors Using the Delphi Technique and Multiple-Criteria Decision Analysis A Case Study: Forest Parks in the Southern Slopes of Alborz, Iran

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ABSTRACT

Background: The present research was conducted to achieve sustainable development and optimal use of environmental resources for identifying and prioritizing fire risk factors and fire management in Vesiye forest park located on the southern slopes of Alborz, Iran, to control and reduce the resultant destruction.
Methods: The three-round Delphi questionnaire and previous information were used to identify the most important fire risk factors in the studied forest park, which were subsequently ranked and weighted using Analytic Hierarchy Process (AHP).
Results: The effective factors in the fire were identified to be vegetation type, slope, slope direction, distance to roads, distance to settlements, presence of tourists, altitude changes in the region, annual temperature changes, vegetation density, land use, atmospheric humidity percentage, wind speed, direction and the presence of hunters, and animal husbandry, respectively. According to the analyzed data, the highest ranks were assigned to vegetation type (0.2785), slope (0.1875), slope direction (0.1495), distance to roads (0.1075), and distance to settlements (0.0665), and the lowest weight to height (0.055).
Conclusion: The results revealed that the vegetation type has provided suitable conditions for fire in Vesiye Forest Park due to its high flammability factor as a fuel for the fire and the distance to roads as the factor of easy access for tourists to the forest park.

1. Introduction

Sustainable development depends on the optimal use and preservation of natural resources. Currently, one of the threats to natural resources is fires that destroy and alter the ecosystem in an unwanted and uncontrolled way. Knowing the phenomenon of fire and the factors affecting these incidents can be used as a strategic study in controlling and reducing fire damage [1]. Natural resource areas are subjected to several destructive factors and unexpected events such as fire which is among the most common of these factors [2]. Fire is one of the most common environmental disasters, which causes numerous and irreparable damages with profound environmental, social, and economic impacts [3]. Fire hazards potentially affect human life and health. Other adverse effects of fires include reducing biodiversity, soil erosion, increasing sediments downstream of rivers and affecting the quality of water resources, destroying land cover and disrupting the relationship between rainfall and runoff, increasing the risk of flooding, especially in mountainous areas, disturbing the ecosystem landscape composition, and increasing disease outbreak and pest invasion in forested areas [4, 5]. Forests are one of the most essential natural resources to achieve environmental balance [6]. However, the forest area is rapidly decreasing due to various reasons, including the

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constant occurrence of fires [7, 8]. Uncontrolled fire in forests also causes many ecological damages, including increasing the rate of soil erosion and river sedimentation, releasing a large amount of CO_2 into the atmosphere, and sudden changes in soil properties [9-14]. In addition to the environmental damage, the economic loss caused by fire is high only by estimating tangible outputs such as wood, water, resin, and ecotourism [15, 16]. The ecological role of fire is to influence several factors including plant community development, water conservation, soil nutrient recycling, plant succession, and biodiversity [17]. A combination of different technologies including remote sensing and geographic information system (GIS) with statistical methods or approaches such as the Analytic Hierarchy Process (AHP) can provide accurate and useful data on fire. Multi-criteria analysis (MCA) is a decision-making tool developed for complex multi-criteria problems involving qualitative and quantitative aspects in the decision-making process [18]. The MCA can be implemented using the AHP method. In this method, decision-making is done by arranging important components in a hierarchical structure (pairwise comparison) [19]. AHP is one of the most comprehensive systems designed for multi-criteria decision-making. The first step in AHP is to establish a hierarchical structure of the subject under study, focusing on objectives, criteria, options, and the relationship between them [12]. In a research, Behzadi et al. (2018) investigated the zoning of fire risk in rangelands and forests using GIS and AHP; since most of the previous fires occurred in high-risk areas, the validity of the generated models has been proven [1]. The most effective way to reduce damage to vegetation is the timely detection of fires [20]. Huyen and Tuan (2008) used the combined method of spatial analysis and multi-criteria evaluation to classify fire risks in northwestern Vietnam. They found that the high temperature in the dry season was the most important cause of fire in the region [21]. Arianoutsou et al. (2011) conducted a study in Cape Sounion National Park, Greece. They used a multi-criteria decision-making approach to analyze bio- (woody cover and legume cover) and geo- (fire history, parent material, and slope inclination) indicators to rank landscape components, and finally combined the judgments of each factor with the weight coefficients and then with the multi-criteria rule to provide a map of the risk index in detecting high-risk points of fire [22]. Mohammadi et al. (2010) used the AHP method to identify the effective factors in the occurrence and spread of fire and showed that the obtained map was highly compatible with the actual fire locations [23]. Moreover, Babaie Kafaki et al. (2021) carried out research on fire risk zoning and risk assessment in the Zab-Sardasht forests (Iran). They analyzed data by GIS and Hierarchical analysis and assessed the fire risks by a linear method. Their findings showed that vegetation and climatic conditions were the most significant environmental factors influencing fire development in the forest ecosystem [2]. Similarly, the results of Salamati et al.′s study (2011) demonstrated that about 40% of the forest fire risk map of Golestan province in Iran is a high-risk area. They used AHP and GIS in the evaluation and zoning of the area [24]. Mahdavi et al. (2012) mapped fire risk areas in the forests of Ilam, Iran, using GIS and AHP. The variables used in association with the occurrence of fire in this study included land use, roads, rivers and climatic characteristics, physiography, and anthropogenic themes. The results showed that 50% of the past fires were located in very high-risk areas and 40% in high-risk areas, which shows the high reliability of the built model [25]. The forest park area in the watershed of Vesiye valley in Alborz province, Iran, is of special importance due to the geographical location and accessibility of local communities in Tehran and Alborz provinces. Due to the ever-increasing population growth, the role of the forests of the southern slopes of Alborz in the west of Tehran province and the east of Alborz province in reducing the level of air pollution and maintaining the quality of the environment has been emphasized. Therefore, it seems necessary to conserve green space and forest parks in such big cities. Since preserving the forest along with its appropriate species and preventing them from catching fire is effective in preserving the environment and the health of the community, this research was conducted to provide a management plan for the control and prevention of fires in Vesiye Forest Park.

2. Materials and Methods

The forest park on the southern slope of Alborz with a cold and dry climate according to Dumartin's method, is located in the watershed of the Vesiye valley region with an area of 2516 hectares in the northern part of Iran and on the heights of the southern slope of Alborz in the western area of Tehran province and eastern Alborz province at the geographical coordinates of 35.8111° N, 51.0486 ° E (Fig.1). At first, to determine the validity and reliability, eight experts evaluated the questionnaire and the CVI (Content Validity Ratio) was determined to be 0.75. Considering the minimum acceptable value for the CVI index (0.79), the validity and reliability of the questionnaire were confirmed. At this stage, the three-round Delphi questionnaire was sent to 33 experts and professors who had scientific and experimental records in the field of study. Then, the responses were analyzed and common criteria were extracted and scored. In the end, the criteria with the highest scores were extracted. The questionnaires of each round were distributed and collected in person or online. In the first round, a list of factors and criteria affecting fire, extracted from previous successful research, was provided to Delphi panel members to determine their degree of significance. In addition, they were asked to provide their ideas about criteria outside of this list. In the second round, the set of criteria proposed in the first round along with the primary factors extracted from the subject literature was received. The Delphi method was completed after the third round and reached a favorable consensus. In all stages, the degree of significance was determined for all factors based on a 5-point Likert scale, including "very low impact = 1", "low impact = 2", "moderate impact = 3", "high impact = 4", and "very high impact = 5".

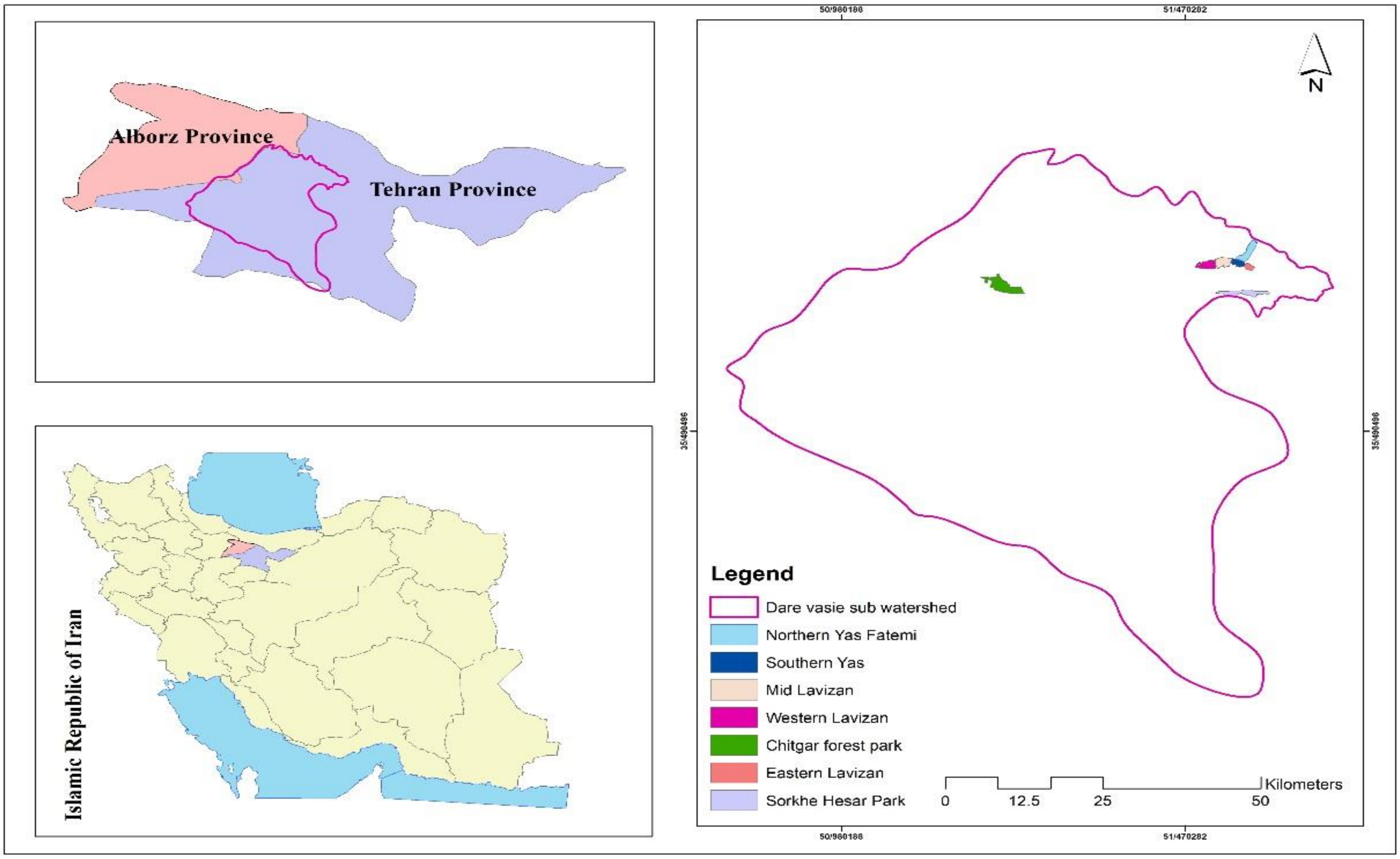

Figure 1: The geographical location of the forests of the Vesiye Valley watershed at the heights of the southern slopes of Alborz, Iran

In each round, in front of each factor, the average response score of the panel members in the previous rounds and the previous response of each person were also informed separately to the respondents. In this research, the criteria were weighted based on the opinions of experienced experts using the AHP method and Expert Choice software. Correspondingly, 33 questionnaires were prepared using the Delphi method to score the AHP model. The consistency ratio (CR) was used to ensure the accuracy of the relative weighting so that if the value of this index was higher than 0.1, the judgments were inconsistent and the weighting should be re-performed [19]. It is worth mentioning that the CR ratio in this research was 0.07, which indicates the acceptability of the result. In the AHP method, the final goal of the problem was placed at the first level, the criteria (sub-objectives of the problem) at the second level, sub-criteria of the problem in the third level (which are layers in spatial discussions). Paired matrices in the second and third levels were formed separately and their weighting process was done separately in the following steps [26-29]:

1. Creation of a hierarchical structure: In this step, effective criteria in decision-making are identified and placed as the second level of the structure. If the identified criteria have sub-criteria, they are also added to the structure.

2. Forming the matrix of paired comparisons: In this step, the elements of each level are compared to other related elements at a higher level in a pairwise manner, and matrices of paired comparisons are formed. In order to determine the importance and preference in pairwise comparisons, the range 1 to 9 of Thomas L. Saati was used [26]. Table 1 shows the expressions corresponding to each number.

3. Calculation of CR: Eigenvectors are used for this purpose. The concept of compatibility is that if criterion A has n importance equal to B and criterion B has m importance equal to C. If this relationship exists in paired matrices, the matrix is consistent, and otherwise, the matrix is inconsistent. In most cases, the judgment of analysts is inconsistent; the inconsistency is acceptable up to the normal limit, which is determined by CR calculated through equations (1) and (2):

$$CR = \frac{CI}{RI} \quad \text{Eq. (1)}$$

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

Where, λ_{max} stands for the largest eigenvalue of the paired comparison matrix, and n for the dimensions of the matrix.

The value of the randomness index (RI) is obtained by matrices whose numbers are chosen completely randomly.

Table 1: AHP expressions and equivalent numerical values

Preferences	Numerical values
Absolutely in priority	9
Very high priority	7
High priority	5
Moderate priority	3
Low priority	1
Intermediate priority	2, 4, 6, 8

3. Results and Discussion

3.1 The results from the analysis of Delphi rounds

To identify the factors affecting fire in the forest parks of the southern slopes of Alborz, a questionnaire and three-round Delphi method were used as described below.

3.1.1 The first round

panel members identified many factors extracted from previous successful research that had a very high and high impact on the model design. In addition, the respondents suggested a total of 50 factors to design a model of factors influencing effective participation in the field of environment. Kendall rank correlation coefficient for members' responses regarding the order of 50 factors with very high and high impact in this round was 0.187.

3.1.2 The second round

after evaluating the opinion of the panel experts on the factors raised and extracted from the theoretical foundations, and also receiving the suggestions of the panel members on other effective factors, be careful, all the factors extracted from the theoretical foundations as well as the factors suggested by the panel members regarding other effective factors in the design of the model along with the average score of the members' opinion in the first round and the previous opinion of the same member were again available to all the panelists. The panel members identified 20 out of the 50 factors presented in the second round as having a very high impact (with an average score of > 3) on fire in the forest parks of the southern slopes of Alborz. Kendall's rank correlation coefficient for members' responses regarding the order of the 50 factors that had a high and very high impact in this round was 0.414.

3.1.3 Third round

Based on the average score of experts' opinions, since there was no factor with moderate or low impact (having an average impact of ≤ 3), so no factor was eliminated. The list of 20 factors, which were identified in the second round of Delphi by the experts of the panel as having a high and very high impact (with an average score of > 3) in the design of the model, along with the average score of the members' opinion in the second round and the previous opinion of the same member was made available to all panelists. In this round, the members expressed their opinion about the impact of each of the 13 selected factors. In addition, they had to determine the order of significance of the factors from their point of view. Kendall rank correlation coefficient for members' responses about the order of 13 factors that had a high and very high impact in this round was 0.579. Table 2 summarizes the results of the three Delphi rounds, including the increase of consensus indices.

Table 2: Comparison of the results of the consensus indices of three Delphi rounds

No.	Parameters	Kendall rank correlation coefficient		
		Delphi R-1	Delphi R-2	Delphi R-3
1	height	0.275	0.587	0.787
2	slope	0.225	0.504	0.731
3	slope direction	0.347	0.497	0.767
4	temperature	0.272	0.536	0.827
5	Atmospheric humidity percentage	0.213	0.500	0.722
6	wind speed and direction	0.084	0.628	0.787
7	vegetation density	0.438	0.606	0.818
8	vegetation type	0.227	0.612	0.832
9	distance to roads	0.108	0.697	0.909
10	land use	0.300	0.496	0.973
11	distance to settlements	0.238	0.559	0.817
12	the presence of hunters and animal husbandry	0.310	0.663	0.874
13	The presence of tourists	0.207	0.638	0.833

3.2 The results of the AHP model

In weighting to calculate the final weight, the quantity of sub-criteria of each criterion was multiplied by the weight of the criterion to obtain the final weight. Finally, the simple weighted sum was obtained from the sum of the final weights. Based on the results of the AHP method (Table 3), the most important environmental factors affecting the occurrence and spread of fire in forest ecosystems, in order of priority, were vegetation type, the slope of the land, slope direction of the land, distance to roads, distance to settlements, the presence of tourists, the height of the ground, temperature, vegetation density, land use, atmospheric humidity percentage, wind speed, and direction and finally the presence of hunters and animal husbandry.

Table 3: Calculated weights for factors affecting fire in Vesiye Forest Park located on the southern slopes of Alborz, Iran, using the AHP method

Main criteria	Relative weight	Sub-criteria	Relative weight	Ranking
Topography	0.08	Height	0.055	7
		Slope	0.1875	2
		Slope direction	0.1495	3
Climatic conditions	0.033	Temperature	0.0285	8
		Humidity	0.0185	11
Physiography	0.434	Wind speed and direction	0.0095	12
Anthropogenic themes	0.290	Distance to road	0.1075	4
		Land use	0.0205	10
		Distance to settlement	0.0665	5
		The presence of hunters and animal husbandry	0.0095	13
		The presence of tourists	0.0425	6
Biologic agents	0.163	Vegetation density	0.0265	9
		Vegetation type	0.2785	1

Fire is one of the most critical concerns that every year causes much damage in the fields of environment, wildlife, economy, and human life safety. One of the control measures is the identification of fire critical areas, which is of great importance in reducing the frequency of fires and preventing the destruction of forest areas [30]. As in Table 2, the highest weight (0.2785) was assigned to vegetation type, because this variable as a fuel for fire has a strong role in forest fire due to its high combustion coefficient. Behzadi et al. (2018) concluded that the vegetation density in Bamu National Park, Iran, could be considered the main criterion based on GIS and AHP findings. Since the density of annual gramineae (a family of grasses including cereals, reeds, sugar cane, bamboo) had resulted in an increase in the density of vegetation and the supply of combustible materials effective in surface fires, thus the impact of human activities had aggravated the fire in the region due to the increase in temperature and dryness of vegetation in the summer season and after that, following the results of the present research Ajin et al. (2016) and Chavan et al. (2012) who announced that areas with dense forest cover had high risk and were prone to fire [1, 31, 32]. In the next category, the highest weights were assigned to the slope (0.1875), slope direction (0.1495), distance to roads (0.1075) and distance to settlements (0.0665), and the lowest weight to height (0.055). Since humidity is higher and temperature is lower at high altitudes, the probability of fire occurrence is inversely related to the increase in altitude [33]. Therefore, in this research, the lowest coefficient was assigned to this variable. The slope and slope direction had a high weight because the slope direction is exposed to direct sunlight and makes the fuel required for fire (plants and debris) dry and more flammable [34, 35]. Dong et al. (2006) considered the southern directions as high-fire risk areas.

Fataei (2020) points out that higher ranges help heat and ignite easily and spread the fire. In addition, on steep slopes, dry biomass is close to the flames and causes the fire to spread faster [36, 37]. Spatial analysis of the variables showed that the rate of fire spread on the slope of 36% is twice that of the fire on the slope of 18%. In the research of Bagherabadi et al. (2022), the highest slope had the greatest risk of fire [34]. It is also consistent with the results of Hong et al. (2017) and Kumari and Pandey (2020) so that most fires occurred on slopes above 15% and in the south direction [38, 39]. The results of the survey also showed that the role of the road is a factor in increasing the risk of fire, and on the other hand, it is effective as a useful factor for speeding up access and fire extinguishing. Importantly, the type of roads in terms of density and volume of traffic is influential in determining the positive or negative impact of the road on the risk of fire. The number of fires near the first-class roads was higher than the second-and third-class roads, probably due to more traffic of tourists on the main roads. The results of this section were consistent with the results of Zarekar et al. (2013) and Eskandari et al. (2013) conducted in the northern regions of the country. Since the most important way for tourists and forest dwellers to access the forests of the region are forest roads, these people are one of the most important factors in causing fires in the forests of the region. [40, 41].

4. Conclusion

Fires in forests destroy forests an important part of the environment, air pollution, and the loss of wealth and many facilities, and pose serious risks to the lives of people living in the vicinity of the forest. In this study, risk factors with high potential were identified using multi-criteria decision analysis and the Delphi method. According to the results, most of the fire-sensitive areas were located in areas that were at risk for exposure to fire in terms of natural characteristics, including vegetation type, slope, and slope direction, as well as the anthropogenic factor of distance to the road. The vegetation type due to the high combustion coefficient to supply fire fuel, the slope and slope direction due to exposure to direct sunlight, and the distance to roads as a factor for easy access of tourists to Vesiye Forest Park on the southern slope of Alborz provided suitable conditions for fire. The preparation of fire risk zoning maps is highly effective to control and reduce the harmful impacts of forest fires. Based on the prioritization of fire risk factors in the studied forest park, it is suggested to prepare a fire risk zoning map for optimal conservation of the region.

Authors' Contributions

Behzad Bozorgmer: preparation of the introduction sections, data collection and analysis, and the completion of the discussion section of the article. Mina Macki Aleagha: writing the research method of the article. Azita Behbahani: data analysis and research conclusions.

Conflicts of Interest

The authors declare no conflicts of interest.

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