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Using forest fire experts' opinions and GIS/remote sensing techniques in locating forest fire lookout towers

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Abstract
Timely detection of fire and early warning to fire stations are crucial functions in fire-suppression and controlling efforts. The most effective way for early detection of forest fires is monitoring from fire lookout towers. This study aimed to develop a geographical information system (GIS) method to determine proper points for installing fire lookout towers based on using forest fire experts' opinions to determine effective criteria and sub-criteria on locating fire lookout towers and to weigh them via analytical hierarchy process (AHP) technique. The study area, including four sub-catchments with an area of 32,446 ha, is located in Sardasht, NW Iran, in which no tower has been constructed so far. The results revealed that the most effective criteria in order of priorities are elevation, distance from roads, distance from previous burned areas, slope, and distance from residential areas. This method proposed 4 points for erecting fire lookout towers together covering about 60% of the total study area, while this coverage was more than 75% in sub-catchment number four. Based on the results, the use of forest fire experts' opinions can lead to good results in determining and weighing (i.e., via AHP) the effective criteria on fire lookout towers locating and a GIS based method to determine optimal points for establishing fire lookout towers.

Keywords Analytical hierarchy process · Fire observation tower · Forest fire · Sardasht

Introduction

Forest fire is one of the main factors in changing vegetation within hot and dry climates (Hessl 2011; Williams et al. 2010). Forest fires are among the events that lead to drastic changes in forest ecosystems, threatening their stability, as well as agricultural land, infrastructure, and communities (Garbolino et al. 2016). Forest fires are increasing worldwide resulting in larger extents of burned areas (Eugenio et al. 2016).

Fire detection is an important part of an effective fire management program. It can be accomplished in various ways: satellite imagery, fire observation towers, aerial surveillance, lightning detection systems, or monitoring and reporting of fires by the local population. Timely detection of fire and early warning to fire stations are crucial in fire-suppression and controlling efforts (Küçük et al. 2017; Yavuz et al. 2015; FAO 2006).

In most countries, in addition to using remote sensors and aerial detectors, various measures have been taken to protect forests, mainly based on human monitoring (i.e., traditional fire lookout towers). This monitoring requires 24-h surveillance on the forest areas (Yavari 2014). Thus, the presence of fire lookout towers is important, especially in hilly and mountainous areas (Singh et al. 2014). Today, hundreds of towers are still in service in many countries where they have become an effective tool for detecting forest fires (Rego and Catry 2006). The maintenance and operation of these towers impose costs on governments and private sectors. In fire

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Table 1 List of spatial predictors in Sardasht

Input variable	References for input factors
Elevation	Nogueira et al. (2002), Akbulak and Özdemir (2008), Singh et al. (2014), Eugenio et al. (2016), Amiri and Beygi Heidarlou (2019), and Akay (2021)
Land use	Nogueira et al. (2002), Eugenio et al. (2016), and Amiri and Beygi Heidarlou (2019)
Road network	Singh et al. (2014), Nogueira et al. (2002), Eugenio et al. (2016), Amiri and Beygi Heidarlou (2019), and Ogfuz Çoban and Bereket (2020)
Water resources	Nogueira et al. (2002) and Singh et al. (2014)
Slope	Singh et al. (2014)
Near to fire-prone areas	Singh et al. (2014)

seasons, for example, the annual budget for maintaining a permanent forest fire monitoring network including 237 surveillance towers in Portugal is € 2.5 million (Rego and Catry 2006; Galante 2001). Hence, proper determination of points for constructing observation towers is important. On the other hand, in many countries, including Iran, there is no surveillance tower. Iran has been witnessing fires in its forests for a long time, and unfortunately, the number of fires and the area of burned forests are increasing every year. Iran ranks fourth in North Africa and the Middle East in terms of fire frequency. According to FAO statistics, an average of 130 fires occur annually in Iran's forests burning 5400 hectares of forest which more than 90% of them are being caused by human (Goldammer 2001; Akbulak and Özdemir 2008). Thus, building and operating a surveillance tower to detect fire quickly are essential.

Many studies have been conducted on developing a suitable method for determining the appropriate points of surveillance for fire towers based on GIS techniques and remote sensing. The inputs of those studies have included some variables (Table 1) that were used to select suitable sites for erecting watch towers in forest areas.

In this regard, Nogueira et al. (2002) used land use, water resources, road network, and elevation factors to determine the optimal number of towers in Minas Gerais, Brazil. Akbulak and Özdemir (2008), after producing visible and not-visible maps of the existing towers in the Strait of Çanakkale (Dardanelles, NW Turkey), proposed five new towers based on two factors: elevation (higher points) and visibility. Also, in the Jaunpur forest in India, Singh et al. (2014) provided a technique to choose the most suitable locations for lookout towers considering elevation (locations with an altitude of 1480 to 1840 m), road network (within 150 m of roads), drainage network (within 500 m of river), slope (less than 20 degree), and near fire-prone areas (1000 to 2000 m distance). Eugenio et al. (2016) assessed locating fire lookout towers in the state of Espírito Santo in the southeast of Brazil using GIS. They evaluated nine different methods, based on following factors: elevation (ridges with highest altitude), land use, and road networks (buffer distances of 100, 300, and 500 m). Their proposed method had a 67% coverage of the area with 140 towers. Also, Küçük et al. (2017), based on visibility analysis, showed that currently operating lookout towers had not been functioning correctly, and their suggested new towers enhanced the percentage of visible areas from 73 to 81% of the total area in the Boyabat State Forest Enterprise in Turkey. Heyns et al. (2019) used a tower site-selection optimization framework to optimize the locations of forest fire watchtowers with the aim of maximizing system visibility of fire smoke in South Africa. They used two raster-based layers to select suitable sites for locating towers: the Earth's surface and geospatial information as uniformly distributed sampling locations throughout the landscape. They extracted 72 locations for two zones, which increased the coverage of the region by 15.4%. In another study, visibility capabilities of lookout towers were evaluated using the GIS-based visibility and suitability analysis in Turkey (Akay et al. 2020). The use of these analyses and consideration of some spatial criteria (distance to roads, elevation, ground slope, topographic features) increased visibility of forest areas up to 81.47% (from the initial value of 77.12%) by locating new towers.

The above studies can be divided into two categories: (1) those that seek to suggest a method to determine the most suitable points for the installation of lookout towers and (2) studies aimed at modifying or optimizing the pre-installed system of lookout towers in an area. In both types of research, the effective criteria for determining the most appropriate locations for lookout towers are determined by the researchers who conduct the research. The disadvantages of these methods in our opinion are as follows: (1) The criteria are determined by the researchers who are conducting the study, while it is better to use a combination of opinions of researchers and experts as the experts are present in the area and are closely acquainted with the topographic conditions along with the vegetation of the area and have extensive experience in forest firefighting operations. In the research of Heyns et al. (2019), once the criteria were determined by the study researchers, the optimized points for the installation of lookout towers were extracted, and finally, firefighting experts' opinions were used to control the accuracy of these points. It seems that this procedure made a huge number of reworks. The criteria chosen by the researchers are almost the same for all regions. The criteria either have no sub-criteria or a very small number of them, and by placing criteria and sub-criteria separately in the model, appropriate points for construction of tower are estimated and compared across different scenarios. These methods complicate and increase the workload. (3) Also, the weight and importance of the criteria and sub-criteria are assumed to be the same as the Boolean scale (usually 1 or 0). This means only one or zero values are assigned to each pixel and unit area (e.g., suitable/unsuitable elevation class), specifying whether it is satisfactory or unsatisfactory (Bhowmick, et al. 2014). In other words, land characteristics may have equal importance and weight (Elaalem, et al. 2010). It is usually not appropriate to give equal importance to each criterion, but it is better to weigh the criteria based on their relative importance and then include them in the model. In this case, the relative weight and importance of each unit (pixels) can be determined by considering the total relative importance of the criteria and sub-criteria.

Thus, we sought to determine and score the criteria and sub-criteria by experts who are familiar with forest fire fighting, as well as familiar with the type of forest and vegetation specific to the region, instead of researcher(s). Secondly, allocation of scores to the criteria and sub-criteria should be relative, instead of zero or one to better represent the realities of the natural environment.

GIS is an important tool in identifying optimal location for points (Brail and Klosterman 2001). Combining GIS with multi-criteria decision-making methods (MCDM) potentially provides a powerful tool for locating fire towers. In this method, a set of criteria, which is appropriate to the purpose, is determined by experts and used for locating points after weighting as well as prioritization (Yue-Ju, et al. 2007).

The analytical hierarchy process (AHP) technique is one of the most powerful tools in applying MCDM (Carrión et al. 2008; Al Garni and Awasthi 2018). It is a flexible decision-making tool for multi-criteria problems and has been used in this study to determine the relative importance/weight of fire lookout towers criteria by forest fire experts in the region.

Accordingly, this research seeks to develop a method that can select criteria and sub-criteria in a different way. Also, their prioritization and weighting should be done by relevant experts using the AHP technique to determine the most optimal points for construction of the lookout towers considering the existing facilities (i.e., existing roads in the area instead of building new ones). In general, the main objectives of this research are (1) providing a practical solution for locating forest lookout towers using AHP method and (2) introducing effective indicators on locating forest fire lookout towers and determining their weight/importance. The procedures followed in this study can be used as a guide for selecting and prioritizing the best locations for forest fires lookout tower construction.

Materials and methods

Description of study area

Zagros forests with an area of 4,749,000 ha cover 11 provinces of Iran and make up 40% of Iran's forests (3.5% of Iran) (Roozitalab et al. 2018; Beygi Heidarlou et al. 2020a, b). Over the past decades, this forest ecosystem is being threatened by increasing numbers of forest fires (Pourreza, et al. 2014). During these years, aridity has increased due to a 2.6 °C rise in mean temperature and a 35% precipitation decline (Daneshvar et al. 2019; Eskandari et al. 2020). Thus, the number of fires and burned areas have also increased (Amiri et al. 2018). The area of natural forests in Iran's West Azerbaijan province has been estimated 91,117 ha, with about 90% of its forest being located in Sardasht City (i.e., Northern Zagros forests) (Beygi Heidarlou, et al. 2020a, b). These forests have lost 550 hectares of tree cover within a 10-year period due to forest fire (2002 to 2011) (Beygi Heidarlou, et al. 2015). The study area with an area of 32,446 ha is located northeast of Sardasht, West Azerbaijan province, NW Iran, between 36°11′5″ to 36°24′11″ N latitude and 45°26′55″ to 45°40′48″ E longitude. The altitude range is 1000 to 2371 masl (Fig. 1). This area covers 38 villages and one city (Rabat) ((Beygi Heidarlou, et al. 2019). The main tree species of the region are oaks (include *Quercus persica*, *Q. libani*, and *Q. infectoria*), all of which grow in coppice form with oak sprout clumps occupying forested lands (Amiri and Beygi Heidarlou 2019).

Identification of effective criteria in lookout towers allocation

In this research, a structured communication technique among forest fire experts was used to find reliable ideas and collect effective criteria on locating forest fire lookout towers (Dalkey 2015). For this purpose, in the first step, a group of 115 individuals who are expert in the field of forest fire was listed using the following criteria: experience in forest firefighting, recommended by related distinguished forest experts and/or consultation with directors of Iran's Forests, Range and Watershed management Organization (FRWO). Then, 27 out of 115 experts agreed to participate in our survey. They were asked to make a list of important criteria employed for locating forest fire lookout towers (Fig. 2). After collecting the opinions of experts and combining them,

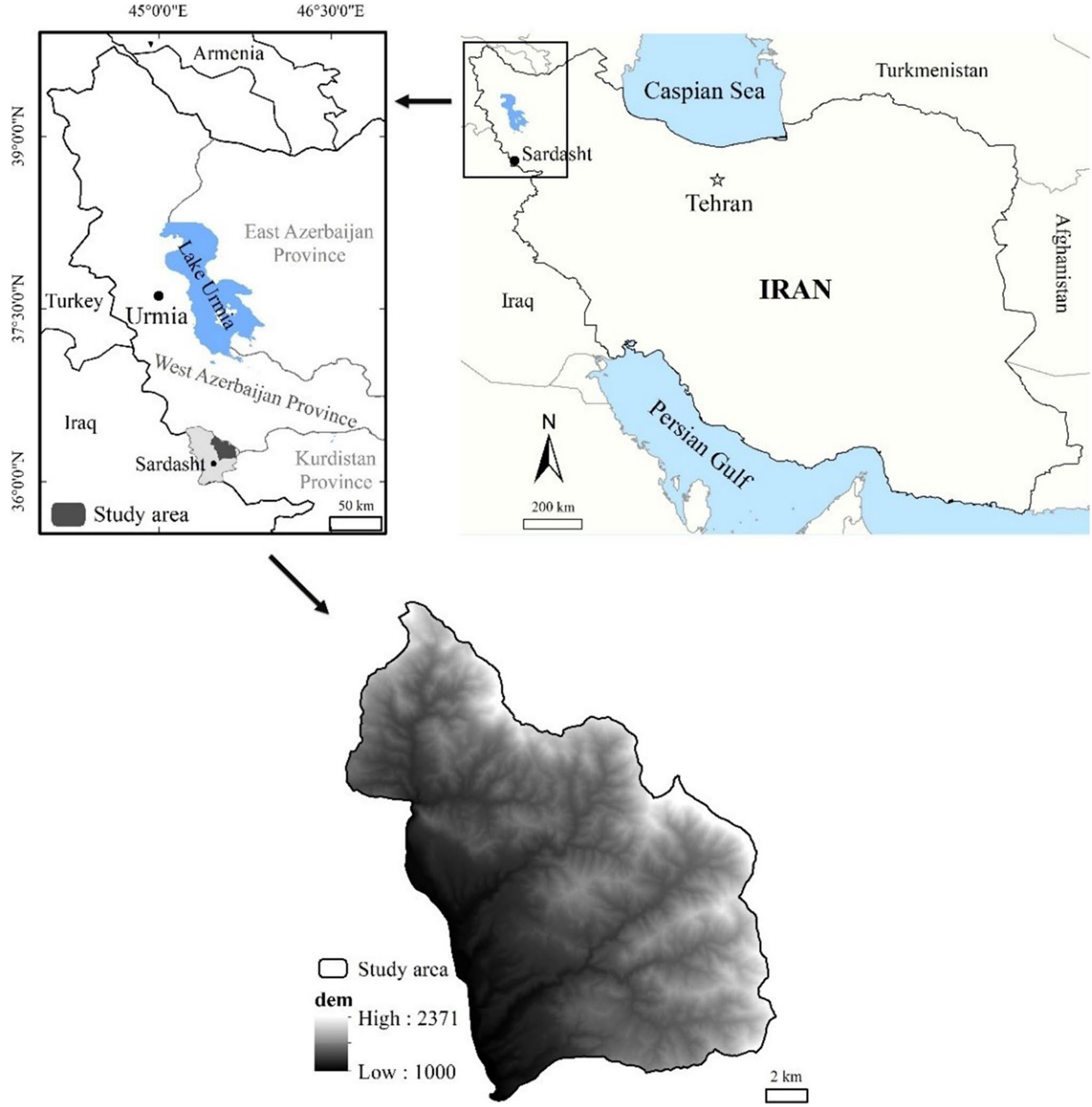
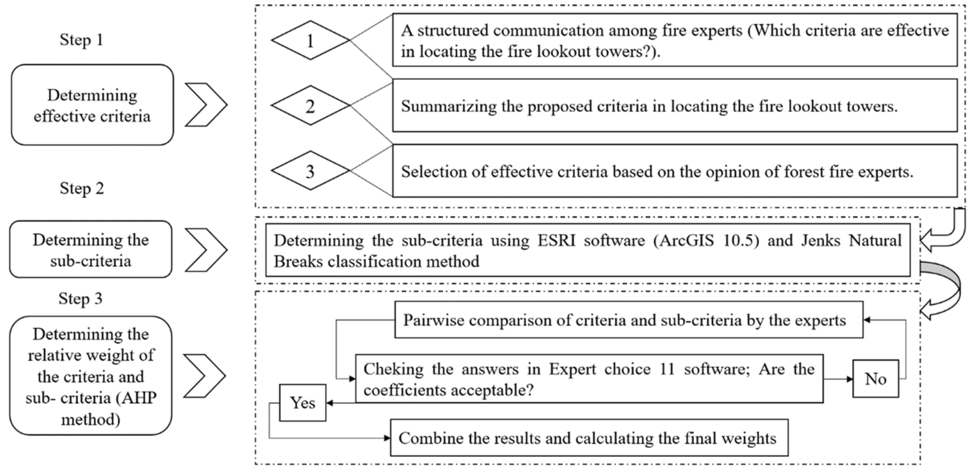


Fig. 1 The geographical location of the study area

the criteria that were homogeneous throughout the study area (such as temperature and precipitation) as well as the criteria that could not be mapped due to lack of information (such as firefighting facilities and number of firefighters) were removed. Then, according to the remaining criteria, the experts were again asked to submit their final opinions based on the remaining criteria. This step was repeated twice so that all experts would have the same opinion about the final criteria. Ultimately, the following criteria were chosen based on 27 experts knowledge on forest fires and the study area conditions: elevation (capability to see large forest lands), slope (for proper construction), distance from roads (for easy access), distance from previously burned area (for more monitoring of high fire risk areas), and distance from residential areas (due to the impact of demographic factors). The Jenks Natural Breaks classification method in ESRI software (ArcGIS 10.5) was used for determining the sub-criteria categories of each criterion according to the conditions of

Fig. 2 Phases of identification of effective criteria in locating forest fire lookout towers (FFLT) and analytical hierarchy process (AHP)



the region. This clustering method is used to determine the best arrangement of values into different classes (Chen et al. 2013; Jenks and Caspall 1971).

Data sources

The digital elevation model (DEM) consists of a grid of cells with spatial resolution of 30 m and was prepared using the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite data (Abrams 2000). Slope (%) was calculated from the DEM using the Spatial Analyst tool in ESRI software. Burned areas used in this study were obtained from Beygi Heidarlou et al. (2014). The map of residential areas, for 2013, was obtained through reclassification supervised by the maximum likelihood method provided by Beygi Heidarlou et al. (2014). The linear layer of roads was also extracted from the topographic map of the study area. Then, raster maps of distance from the roads, previously burned areas, and residential areas were also prepared using the Euclidian Distance tool in ESRI software (ArcGIS 10.5).

Application of AHP

In the second step, the AHP approach was used to prioritize the identified criteria and their respective categories (sub-criteria). In this study, the key aim has been to prioritize the forest fire lookout towers criteria; thus, the AHP approach is best suited to analyze the data collected using the survey method. The steps of criteria selection and applying the AHP approach are presented in Fig. 2.

Determining the relative weight of the criteria and sub-criteria

We conducted the pairwise comparison of the identified criteria and sub-criteria in order to determine the relative importance of each criterion (Akbar et al. 2020). Each criterion was ranked pairwise against the other criteria by experts. The sub-criteria of each criterion were also compared with each other (see Saart (2008)). The rankings were made using a scale ranging from 1 to 9, where 1 means the two criteria are equally important and 9 in the position (e.g., criterion 1, criterion 2) meaning that importance of criterion 1 is 9 times more than criterion 2. For this position, 1/9 is used if the importance of criterion 2 is 9 times more than criterion 1. A respondent always enters the entire number in its appropriate position and automatically enters its reciprocal in the transpose position (Saaty 2008, 1988). These rankings are used to determine the weights assigned to each criterion and sub-criterion. The percentage change in the weight of the criteria that led to the first change in priority was also reported for the sensitivity analysis (Triantaphyllou and Sánchez 1997). Using the Expert choice 11 software,[1] sensitivity analysis, a key step in the decision-making process with AHP (Ishizaka and Labib 2009), was carried out in this study.

Pairwise comparison between criteria and sub-criteria was done by experts who had already participated in determining the criteria and sub-criteria. Among the 27 questionnaires that were distributed among the experts for weighting the criteria, 13 questionnaires were completed and returned. One of the major advantages of the AHP is that the analysis does not always require a statistically significant sample size. The simplicity of the AHP approach is that, unlike other conjoint methods, the qualities (or levels) of different attributes are not directly compared. The AHP approach thus removes the need for complex survey designs and can even

[1] Expert Choice is a decision-making software and created by Thomas Saaty and Ernest Forman in 1983; the software is supplied by Expert Choice Inc.

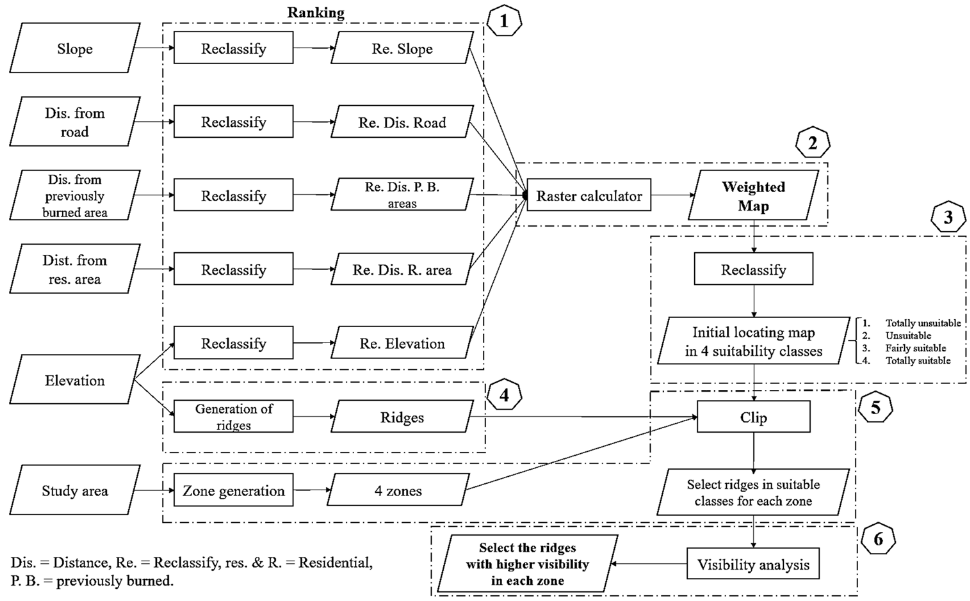


Fig. 3 Methodological steps for development of the model to locate of forest fire lookout towers (FFLT)

be applied (in an extreme case) with only a single respondent (Baby 2013; Dutta et al. 2007).

The weight and importance of the criteria and sub-criteria were determined using Expert choice 11 software. All calculations related to AHP are based on the initial judgment of the respondent and in the form of a pairwise comparison matrix, so any errors and inconsistencies in the comparison would distort the final result of the calculations. Thus, the final stage is to calculate a consistency ratio (CR) to measure how consistent the judgments have been relative to purely random judgments. If the CR is much in excess of 0.1, the judgments are untrustworthy as they are too close for comfort to randomness, and the exercise is valueless or must be repeated. Saati stated that the acceptable value of consistency should be less than 0.1, but even less than 0.2 is also acceptable (Wedley 1993). The CR of all questionnaires of this study was less than 0.1. The consistency of the pairwise comparison matrices can be calculated using the method described by Shameem et al. (2018).

Fire lookout tower sites selection

The following steps were performed to select suitable locations for forest fire lookout towers in the study area (Fig. 3):

(1) After calculating the weight and significance of the criteria plus sub-criteria, the digital maps for each criterion were generated and ranked by the Reclassify tool in ESRI software. Reclassification is the process of reassigning one or more values in a dataset to new output. Reclassify tool is available in the Spatial Analyst extension in ArcGIS 10.5. Class breaks of categories in each criterion were performed based on region conditions and Jenks method.

(2) The weighted map was obtained using the Raster Calculator tool multiplying each criterion weight by scored map separately and the weighted linear combination (WLC). The score of each pixel was calculated multiplying the weight of each sub-criterion by 100. In other words, the score of pixel i in the criterion j would be between 0 and 100.

(3) The obtained map from the previous step was then categorized (reclassified) into four classes based on Jenks classification method (i.e., the initial locating map): (1) totally unsuitable, (2) unsuitable, (3) fairly suitable, and (4) totally suitable using the Jenks method (Jenks 1977).

(4) For the analysis of elevation, the pointed ridges layer was prepared using DEM map (Eugenio, et al. 2016).

(5) Then, we extracted those ridge points that had already been placed in fairly suitable and totally suitable categories to select the best sites using clip tool in the ArcGIS software. To have a proper distribution of lookout towers across the entire area and provide a good position for the towers due to the mountainous nature of the area and the limited visibility, we divided the study area into four sub-catchments where the best points were selected based on visibility. On the other hand, due to economic issues and the high cost of building a fire lookout tower, we were looking for the minimum number of lookout towers, with the most visibility.

(6) In the last step, by performing visibility analysis for the selected ridges in each sub-catchment considering 10 and 15 m height for the towers and 10 km visibility range, the suitable ridges map in each sub-

Table 2 The weight and consistency ratio (CR) of the criteria and sub-criteria using AHP method

Criteria	Weight	Sensitivity (%)	CR	Categories (sub-criteria)	Weight	CR
Elevation (m)	0.45	16	0.01	989–1200	0.06	0.03
				1200–1400	0.09	
				1400–1600	0.16	
				1600–1900	0.27	
				1900–2371	0.43	
Slope (%)	0.13	55		0–5	0.42	0.01
				5–10	0.27	
				10–15	0.18	
				15–20	0.14	
Distance from road (m)	0.17	51		0–100	0.4	0.0001
				100–300	0.33	
				300–500	0.28	
Distance from previous burned areas (m)	0.16	53		0–2000	0.29	0.004
				2000–4000	0.24	
				4000–6000	0.19	
				6000–8000	0.15	
				8000–10,597	0.13	
Distance from residential areas (m)	0.09	61		0–1000	0.3	0.003
				1000–2000	0.27	
				2000–3000	0.24	
				3000–6273	0.2	

catchment were extracted ((Küçük et al. 2017; Göltaş et al. 2017). A horizontal 10 km visibility range is the widely accepted distance for scanning the fire signs (i.e., smoke) under optimal weather conditions (Küçük et al. 2017; Akay et al. 2020). Our study area is located in Iranian Northern Zagros forests, where mountain ridges are hewn with deep valleys (Beygi Heidarlou et al. 2020a, b). As a rule, the effective visibility ranges of 10 and 20 km are used for rough terrain and flat areas, respectively (Ruiz 2000; Rego and Catry 2006).

Finally, ridges with high visibility inside each sub-catchment were selected as suitable points for the best tower allocations. The methodological flowchart containing all steps necessary for the development of this work is displayed in Fig. 3.

Results

The results of the paired comparison and the final weight of the criteria indicated that the criterion of elevation with 0.45 weight was the most important among the other effective criteria. It was followed by the distance from road (0.17), distance from the previous fires (0.16), slope (0.13), and distance from residential areas (0.09). The results of paired comparisons and weighing of sub-criteria within each criteria revealed that the highest altitude (1900–2371 m), lowest distance from the road (< 100 m), least distance from the previous fire (< 2000 m), low slope (< 5%), and least distance from residential areas (< 1000 m) were more critical among the sub-criteria of each criterion in determining the location of forest fire lookout towers (Table 2). Also, the consistency ratio (CR) of the judgments was less than 0.1, suggesting the acceptable consistency between the views of experts and specialists about the relative importance of criteria and sub-criteria (Table 2).

The sensitivity analysis's findings revealed that for all criteria except elevation, the change in weight that led to the reordering of priorities was greater than 50% (Table 2). Therefore, it can be concluded that the sensitivity of the priorities to the elevation was higher than the other four criteria.

The maps of elevation, distance from roads, distance from previously burned areas, slope, and distance from residential areas are presented in Fig. 4. As it is not suitable for watchman to move on foot long distances, areas further than 500 m from roads were excluded from the analysis.

The initial locating map for erecting lookout towers was classified into four classes using Jenks classification method: (1) totally unsuitable, (2) unsuitable, (3) fairly suitable, and

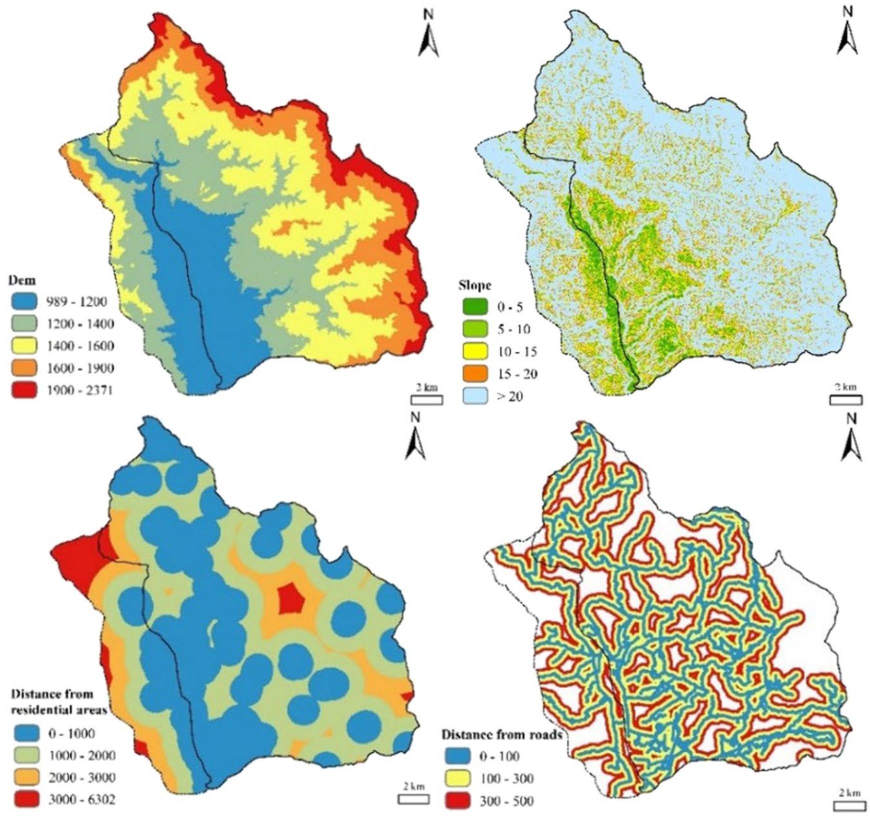


Fig. 4 Produced maps of the five criteria and their sub-criteria which used as input in locating forest fire lookout towers (FFLT)

(4) totally suitable (Fig. 5). These classes account for 11%, 12%, 4%, and 0.5% of the entire area, respectively.

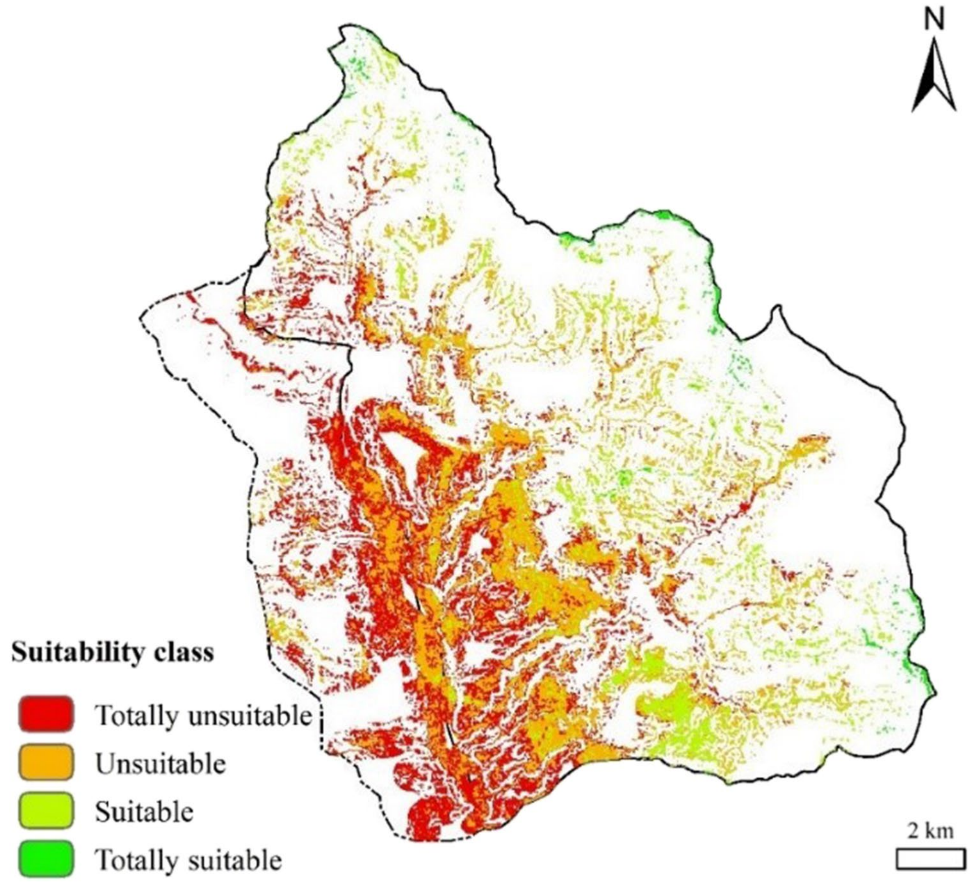
Figure 6 a indicates all ridge points of the region (includes 17,585 points) obtained from the digital elevation model (DEM), and Fig. 6b depicts the highest ridge points (includes 1775 points) which are located in fairly and totally suitable classes of initial locating map. These points are scattered in four sub-catchments; according to the weight of criteria and sub-criteria; one point was selected and proposed as the optimal point of installation of forest fire lookout towers in each sub-catchment. Thus, a total of 4 points were selected for the entire study area whose specifications are presented in Table 3.

The results of Table 3 show that the proposed point for the construction of the tower in sub-catchment 1 can cover 31.96% and 35.05% of the surface of that sub-catchment with tower heights of 10 and 15 m, respectively. The proposed point under sub-catchment 2, with tower heights of 10 and 15 m, has 38.31% and 38.99% of its area in its field of vision, respectively. In sub-catchment 3, the proposed point with a tower height of 10 m covers 38.24% and with a tower height of 15 m covers 41.05% of its surface, which is the highest rate among the 4 sub-catchments. For the 4 sub-catchments, the proposed point can cover 21.68% and 22.91% of the sub-catchment surface with tower heights of 10 and 15 m, respectively. As seen in Fig. 7, the proposed points, in addition to the area of their sub-catchment, also surround the parts of other sub-catchments. Table 4 reports the visible areas of each sub-catchment from the four proposed points with two heights of 10 and 15 m and without overlapping. Accordingly, the total visible areas in sub-catchments 1, 2, 3, and 4 with a tower height of 10 m are 48.15%, 46.50%, 61.12%, and 72.28%, respectively, and with a tower height of 15 m are 51.45%, 47.29%, 67.07%, and 75.96%, respectively. In total, 57.25% and 60.13% of the study area are visible with tower heights of 10 and 15 m, respectively.

Also, visible areas resulting from overlapping the point of the tower in sub-catchments 2 and 3 showed that the spatial coverage of these points (visible to both) had been 858.42 and 941.94 ha with the tower height of 10 m and 15 m, respectively. Also, the ridges in the sub-catchments 1, 2, and 3 together covered 108.36 and 112.32 ha of the entire area with tower heights of 10 m and 15 m, respectively (Fig. 8; Table 5).

Results from overlapping visibility maps with the fire risk map of the study area which had been produced by Beygi Heidarlou et al. (2014) revealed that in total, 12,677.7 (46.42%) and 13,182.9 (48.27%) hectares of moderate to very high fire risk classes had been covered by selected

Fig. 5 Produced initial locating map (suitability map) of forest fire lookout towers FFLT establishment



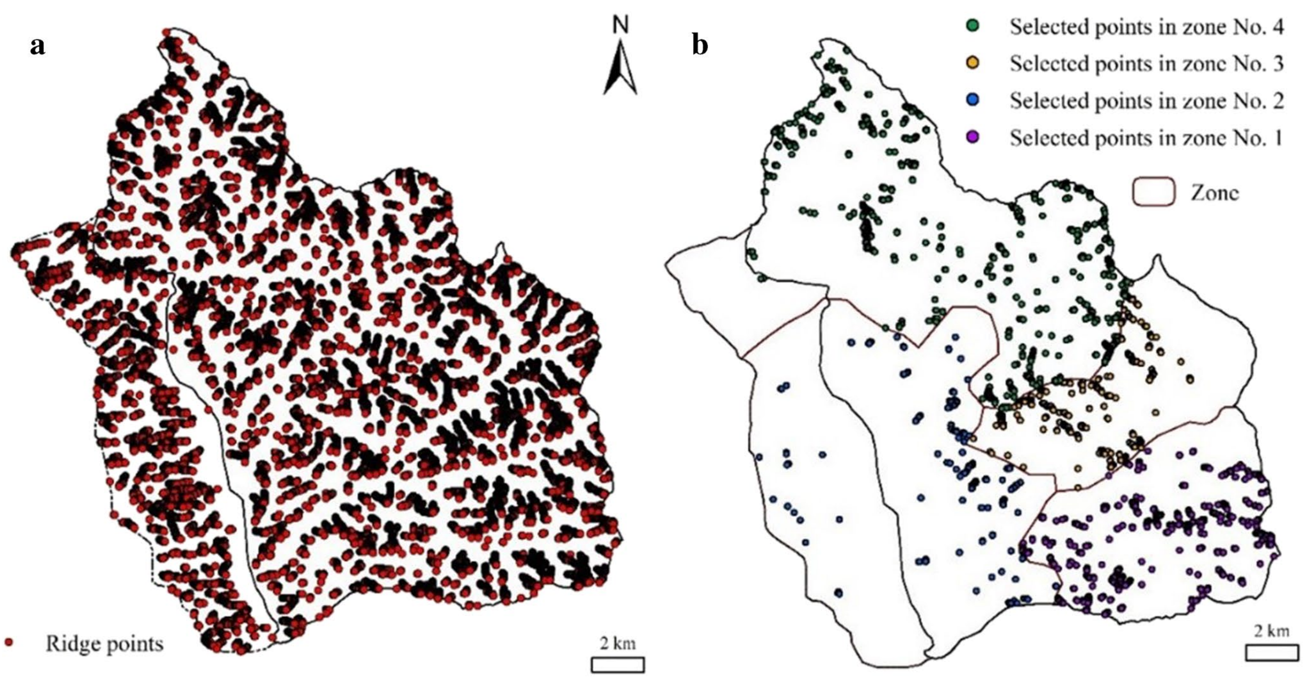


Fig. 6 Ridges point map of the study area (**a**) and the ridges point located in fairly and totally suitable classes in each zone (**b**)

Table 3 Characteristics of selected ridges based on the highest visibility in each sub-catchment

No. of sub-catchment	Area (ha)	Visible area ha (%)		Distance from road (m)	Distance from previous burned areas (m)	Distance from residential areas (m)	Elevation (m)	Slope (%)
		Tower height						
		10 m	15 m					
1	5459.63	1745.01 (19.65)	1913.58 (21.54)	489.49	8882	2135.1	2138	10.07
2	11,820	4528.47 (38.31)	4608.34 (38.99)	454.04	2315	644.13	1419	7.75
3	4586.7	1753.74 (38.19)	1882.89 (41.01)	117.64	4592	1198.9	2049	16.97
4	10,580.5	2247.75 (31.70)	2339.01 (32.99)	385.07	7090	0	2163	14.55

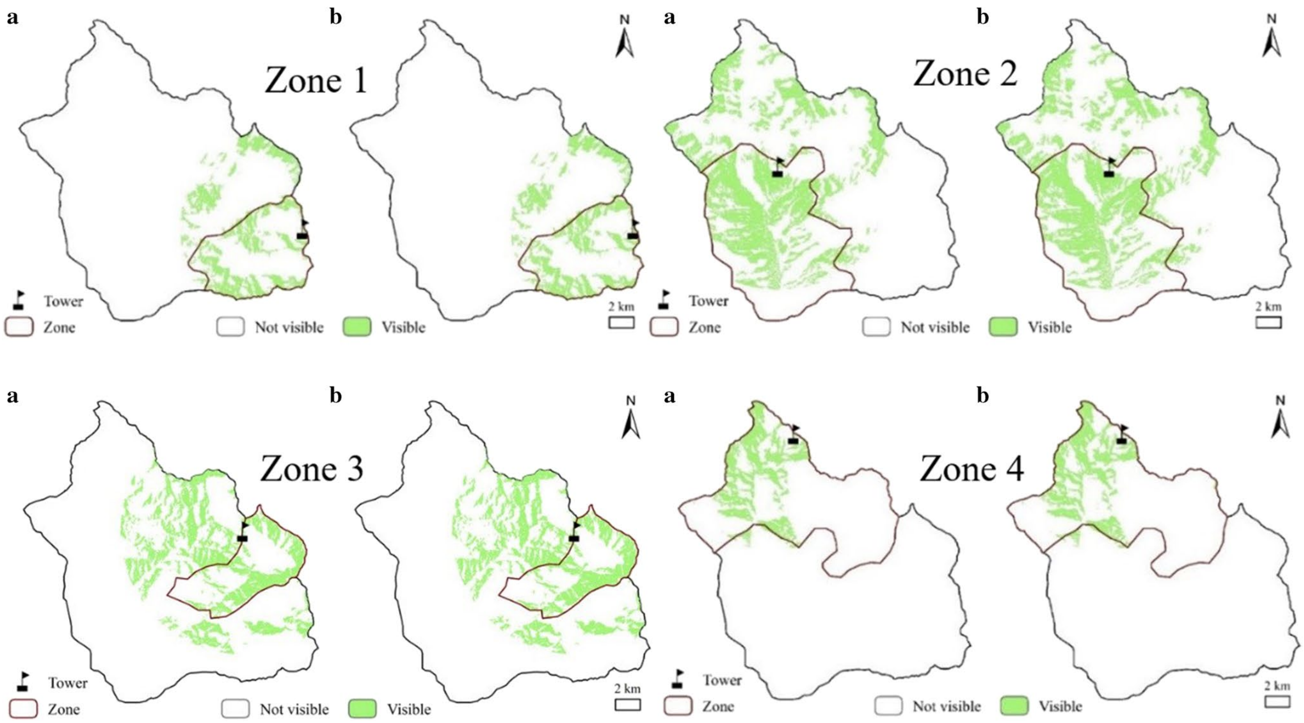


Fig. 7 Spatial distribution of visible and not visible areas observed by selected towers with a 10 (**a**) and 15 (**b**) m heights at each sub-catchment

locations for lookout towers with 10 and 15 m heights, respectively (Table 6).

Finally, the results of overlapping of all four selected points on previous burned areas showed that 46.5% and 46.7% of these areas are visible using 10 and 15 m height towers respectively (Table 7).

Discussion

Forest fire monitoring towers play a very important role in finding fires as quickly as possible. It is also very important to choose the best points for installing these towers. Different factors and criteria affect the selection of these points, and different methods have been developed to determine as well as suggest the most important criteria so far. In this study, first the most important criteria and sub-criteria were selected based on the opinion of experts related to forest fires, which were then weighed and prioritized using AHP technique. Finally, suitable points for tower installation were extracted by considering the weights of criteria and sub-criteria and using GIS. Regarding the weight and importance of the identified criteria, the elevation, as expected, was found as the most important criterion. Those points located on the highest ridges should be considered for constructing forest fire lookout towers, since high-altitude zones cover more extensive areas with fire risk (Akbulak and Özdemir 2008). The criterion of distance from road was selected as the second most effective criterion, whereas proximity of forest fire lookout towers to road would provide far easier and faster access for the lookout operator to put in forest fire lookout towers on a daily basis. Eugenio et al. (2016) considered the

Table 4 Visible area from each tower through sub-catchments and total visible area in each sub-catchment by all selected towers with 10 and 15 m heights

Sub-catchment	Area	Tower in the 1st sub-catchment		Tower in the 2nd sub-catchment		Tower in the 3rd sub-catchment		Tower in the 4th sub-catchment		Total visible area			
										10		15	
		10	15	10	15	10	15	10	15	ha	%	ha	%
1	5459.63	1745.01	1913.58	165.87	168.93	717.66	726.66	0.00	0.00	2628.54	48.15	2809.17	51.45
2	11,820.00	87.75	89.91	4528.47	4608.34	841.41	852.75	38.79	39.06	5496.42	46.50	5590.06	47.29
3	4586.70	989.10	1009.26	60.48	184.05	1753.74	1882.89	0.00	0.00	2803.32	61.12	3076.20	67.07
4	10,580.50	70.38	74.79	3035.47	3199.10	2247.75	2339.01	2293.65	2423.61	7647.25	72.28	8036.51	75.96
Total	32,446.83	2892.24	3087.54	7790.29	8160.43	5560.56	5801.31	2332.44	2462.67	18,575.53	57.25	19,511.95	60.13

shortest distance from the road for the watchmen walking as a significant criterion. Based on the results, the criterion of distance from the previous fires was the third most effective criterion in allocating land to the lookout tower. Fire-prone areas are considered as one of the most effective criteria in locating forest fire lookout towers. The number and frequency of fire occurrences specify vulnerable points, and potentially hazardous locations the towers should cover. Our results indicated that the locations with lower slope category increase their importance in allocating to the lookout tower. Also, the low slope areas allow the watchman to spend less energy to reach the lookout tower.

In previous studies (Nogueira et al. (2002), Akbulak and Özdemir (2008), Singh et al. (2014), Eugenio et al, (2016), Küçük et al. (2017), Heyns et al. (2019), and Akay et al. (2020)), the criteria were considered separately and with the same weight, but in our study, a combination of criteria and sub-criteria with different weights have been included in the model. Another important issue is that the ranking of criteria and sub-criteria was done by experts with experience in fire and familiar with the physiography of the study area. Thus, if the same criteria are ranked in an area with different vegetation and physiography, the weight and importance of the criteria may differ from the results of our research. In other words, the importance of altitude and slope in a flat area may be negligible, while in a rugged, high-altitude area, it may be the most important. Another difference between this research and previous studies is the division of each criterion into sub-criteria and ranking them. Accordingly, the sub-criteria of 1900–2371 m elevation, 0–100 m distance from the road, 0–2000 m distance from past fires, 0–5% slope, and 0–1000 m distance from residential areas were recognized as the most important sub-criteria (Table 2). Thus, it was expected that the 4 points proposed for the construction of the towers would have these sub-criteria, but the results of Table 2 show that this is not the case. For example, all 4 proposed points are not in the best sub-criteria in terms of slope and distance from past fires. This is because a flat spot that is very close to the past burned area may not be located at high points and may not have wide visibility. Indeed, the areas proposed to build a lookout tower were selected by assigning weights to different features (effective factors) based on the criteria given by the experts, and the WLC allowed us to use the full potential of our factors as continuous surfaces of suitability (Drobne & Lisec 2009). Thus, the advantage of the method used in this research is that by considering the relative weight of criteria and sub-criteria in the model, it proposes the optimal points for the construction of the towers. Use of the AHP technique could help prioritize the criteria and sub-criteria correctly in our study. In this case, the choice of weights and weighting techniques played a crucial role. This may lead to different results for suitability maps and can affect the final decision with regard

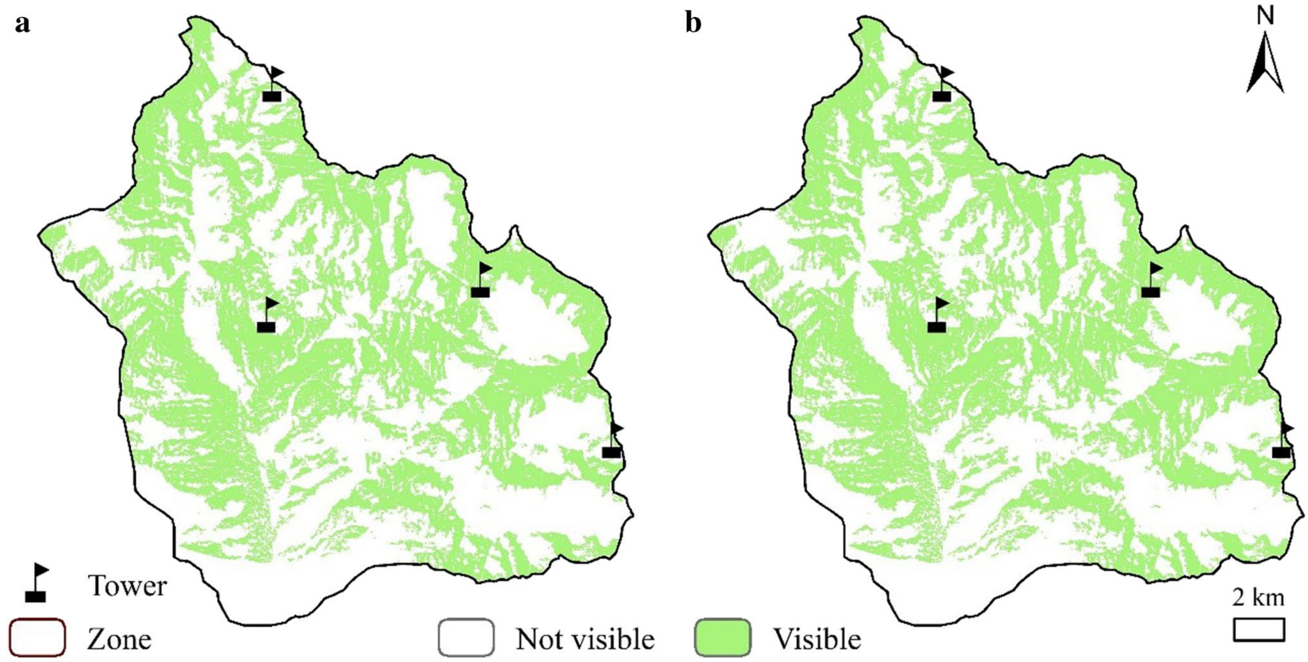


Fig. 8 Spatial distribution of visible and not visible areas observed by all towers with a 10 (**a**) and 15 (**b**) m heights in the entire region

Table 5 The common areas (ha) of visible and not visible areas by selected towers with 10 and 15 m heights in sub-catchments

No. of sub-catchments	10 m tower height	15 m tower height
1 and 2	24.75	776.25
1 and 4	738.9	25.92
2 and 3	858.42	941.94
2 and 4	507.42	547.38
3 and 4	64.89	66.69
1, 2, and 3	108.36	112.32
2, 3, and 4	28.89	35.82
Total	2331.63	2506.32

to the overall objective. Nevertheless, it must be noted that the method presented in this study is merely a tool to aid decision-makers and refers to the decision itself.

Due to a 10-km effective fire visibility range in this study, results of overlapping visibility maps of all the four selected points showed that 57.25% and 60.13% of the study area (32,446 ha) were directly visible from 10 and 15 m height towers, respectively. Singh et al. (2014) proposed two points for construction of towers, which covered a total of 14% of the study area (13,500 ha) in the Indian Himalayas. In Brazil, using GIS, 140 points were proposed for tower construction, which covered 67% of the study area with an area of 4,600,000 ha in the southeast (Eugenio, et al. 2016). In another study conducted in Turkey's

Table 6 Combination results of visible and not visible layer with fire risk map

Fire risk class	Tower height (m)									
	Area		10				15			
			Visible		Not visible		Visible		Not visible	
	ha	(%)	ha	(%)	ha	(%)	ha	(%)	ha	(%)
Very low	4530.8	16.6	2457.0	54.2	2073.0	45.8	2626.9	58.0	1902.1	42.0
Low	7575.7	27.7	3666.5	48.4	3904.2	51.5	3839	50.7	3730.8	49.3
Moderate	4595.4	16.8	2429.3	52.9	2161.6	47.0	2487.4	54.1	2103.5	45.8
High	5851.8	21.4	2115.4	36.6	3735.1	63.9	2176.8	37.2	3673.7	62.8
Very high	4757.1	17.4	2009.5	42.2	2746.7	57.7	2052.8	43.2	2703.4	56.8

Table 7 Combination results of visible and not visible layers with actual fire zones (150.7 ha area)

Ridge location	Tower height (m)							
	10				15			
	Visible		Not visible		Visible		Not visible	
	ha	(%)	ha	(%)	ha	(%)	ha	(%)
Sub-catchment 1	45.81	30.39	80.37	53.31	46.44	30.81	80.64	53.49
Sub-catchment 2	6.03	4			6.12	4.06		
Sub-catchment 3	11.97	7.94			10.98	7.28		
Sub-catchment 4	6.57	4.36			6.57	4.36		
Total	70.38	46.69	80.37	53.31	70.11	46.51	80.64	53.49

Western Black Sea region with an area of 166,354 hectares, Küçük et al. (2017) managed to expand the coverage of the region from 73 to 81% by proposing two new towers along with 6 existing ones. Heyns et al. (2019) could increase coverage of visible areas by 20 towers from 54–56% to 60.5–69.5% in an area of 150,500 hectares in NE South Africa by optimizing the method of selecting points for constructing of towers. Akay et al. (2020) proposed building towers in 5 new points which in addition to 5 other towers that had already been built in the region could enhance coverage of the study area (118,484 ha) from 77.12 to 81.47% in southern Turkey. Thus, according to the results mentioned in the above research, it can be concluded that covering more than 60% of our study area using 4 towers can be a good result. As such, GIS can play a crucial role in determining the location of lookout towers for forest fires (Catry et al. 2007; Nogueira et al. 2002). Akbulak and Özdemir (2008) indicated that GIS provided a practical and useful tool for determining the observation conditions from lookout towers to select the best location for erecting lookout towers in the Gallipoli peninsula located in the east of Turkey.

Among the 4 proposed points, the point in sub-catchment 2 had the highest visibility, followed by the point in sub-catchment 3, the point in sub-catchment 1, and the point in sub-catchment 4. Thus, if the construction of towers should be prioritized due to lack of budget, it is suggested to build the tower first in sub-catchment 2 and then proceed to build the remaining three towers in the order mentioned.

The proposed towers with heights of 10 m and 15 m covered 57.25% and 60.13% of the study area, respectively. Thus, due to the approximately 3% difference in visibility, it is better to consider the height of 10 m for building the towers to save costs. Singh et al. (2014) also indicated that there is only 1% difference between areas directly viewed by 16 and 30 m height towers. On the other hand, Akay et al. (2020) were only able to add about 4% to the visible area by adding 5 new towers to the existing 5 ones but emphasized that even adding this small amount coverage can be very important as it is a critical area in terms of fire.

To ensure the suitability of the four proposed points for constructing towers, the visibility map of these towers was compared with the forest fire risk map previously prepared by Beygi Heidarlou et al. (2014) for the study area. It was found that approximately 50% of the areas with medium risk and 40% of the areas with high and very high fire risk can be seen by the towers. Perhaps the reason for the medium percentage of coverage of these areas by the proposed towers is that this forest fire risk map is based on the 10-year period of recorded forest fires (2014–2005) delivered by administration of Natural Resources of West Azerbaijan Province; it was later determined that, for some reason, the number of fires was lower than the actual value reported. Thus, if this map was prepared based on real statistics, perhaps the coverage of high-risk areas in terms of forest fires would be far higher than the mentioned value.

Conclusions

This study investigated a method that aimed to determine the most suitable points for constructing forest fire monitoring towers in Sardasht, NW Iran, in which no towers have been constructed so far. In this method, first the most appropriate criteria and sub-criteria in determining the appropriate points for tower construction were determined based on the opinion of experts related to forest fires and then were weighed using AHP. These criteria were in order of priority: elevation, distance from road, distance from previous burned area, slope, and distance from residential areas. Moreover, sensitivity analysis showed that sensitivity of the priorities to the elevation was higher than other criteria. Finally, 4 points were suggested as the most suitable points for constructing the forest fire lookout towers using GIS as well as based on the weight of criteria and sub-criteria. The results revealed that the visible areas from the 4 proposed towers constituted more than 60% of the study area, which can be suitable. Meanwhile, note that the percentage of coverage in the area could be enhanced by increasing the number of proposed towers; however, considering that no tower has been built in the study area so far, it was decided to accept this extent of coverage by 4 towers as a basis and then after the construction and review of the results obtained from them in future, the number of towers will be increased if necessary. Finally, all presented results showed that the GIS and AHP combination method developed in this research could adequately suggest the optimal points for the construction of forest fire lookout towers. These proposed towers could cover properly the study area. Since the selection and ranking of criteria is based on the opinion of experts in each region, it can be used in all forest types with different physiographic characteristics. Definitely, to confirm its suitability for widespread use, it is necessary to conduct further studies using the proposed method in different parts of the world.

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Author contribution Conceived and designed the experiments: ABSh and HBH. Performed the experiments: TA and HBH. Analyzed the data: ABSh, TA, ME, and OH. Contributed reagents/materials/analysis tools: ME, HBH, and OH. Wrote the paper: ABSh, TA, and HBH.

Data availability Data used in this study are available to submit upon reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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