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[Research]

Design and evaluation of helicopter landing variants for firefighting in Golestan National Park, Northeast of Iran

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ABSTRACT

Helicopter landing sites in proximity to the forest fire-risk zones are necessary for the delivery of supplies and fire emergency response teams. In this paper, we initially prepared forest fire risk map using Random Forest algorithm by overlaying the effective factors on fire occurring including vegetation types, physiographic, climatic and human factors. Then, three variants of natural candidate sites for helicopter landing were designed by analysis of terrain slope, site areas, canopy gap, and fire risk zone. The value of each variant was evaluated using proximity analysis. In this analysis, proximity to river, area covered by landing and time cost of response teams from landing to fire zone was estimated. The optimum variant was selected by Analytical Hierarchy Process. Based on results, it strongly recommends the use of the variant one whenever possible, since the time cost and proximity to the river were lower and the area covered was higher than other variants.

Key words: Risk map; Firefighting; Helicopter landing; Time cost; Golestan National Park.

INTRODUCTION

Forest fires are frequency occurred in Golestan Province, especially in Golestan National Park Located in Alborz Mountains, the northeast of Iran. More than 52 cases of forest fire were recorded in this park in 2001 (Shataee *et al.* 2012). Forest fires caused air pollution and loss of ecological and socio-economic patterns (Kim *et al.* 2005). Therefore, it is important to prevent fires damages through the evaluation of the fire risk and prediction of fire behavior. Fire risk map refers the zones where the risk of the fire occurring and its spread is very high.

Thus, preparing this map can be useful in identifying high-risk zones and implementing firefighting plans to minimize the damages caused by fires (Kandya *et al.* 1998). Aerial firefighting by helicopter against forest fires is common practice throughout the world (Konishi *et al.* 2008).

Helicopters compete on economic and environmental terms particularly in stands with the absence of adequate road networks (Larry Mason 2005).

In a recent study Bordado & Gomes (2007) showed that firefighting polymers can be applied via helicopters. The landing site for helicopters is a level piece of ground free of trees, scrub, logs and boulders (Yu *et al.* 2007). Landing sites in proximity to the high-risk zones are necessary for the delivery of supplies, fire emergency response teams and construction of water pool. The proximity of helicopter landings to the river is extremely important to collect water from pools for firefighting in the forest (Stefanović *et al.* 2015).

For firefighting operations in unknown forest terrain, it is necessary to assess the safety and efficiency of landing sites. Landing site should be free from obstacles and vegetation with 50-75 m diameter. Besides, the slope gradient of landing should be less than 5% (Scherer *et al.* 2012). Ground trails are defined as extended linear features that are used for access to the fire emergency response teams from landing to fire zone (Chiou *et al.* 2010). The maximum walking speed of a fire emergency response team is evaluated on the base of physiological properties of terrain and it is used to find the best trail to target after landing (Knoblauch *et al.* 1996; Sanders & Mitchell 2000). Besides, time cost of walking on the trail is an important indicator to find the optimum route between points (Chiou *et al.* 2010). Dijkstra's algorithm is often applied to find the least-cost trails (Rees 2004). In current study multi-criteria, decision-making process is used to determine the best landing variant. In this system, different alternatives of helicopter landing are identified and then the best one is selected based on the values and preferences of the decision maker. The purposes of this study were to prepare forest fire risk map and then evaluate the forest terrain conditions to find natural candidate sites for helicopter landing. Moreover, the optimum variant of landing sites was determined using GIS-based proximity analysis by estimating distances to the river, forest areas covered by helicopter flight as well as time cost of fire emergency response teams on trails from landing to the fire zone.

MATERIALS AND METHODS

Study site

Golestan National Park with an area of 91890 ha is located in Golestan Province. It ranges from 37° 16' 43"N to 37° 31' 35"N and 55° 43' 25"E to 56° 17' 48"E. There are 1350 plant species and 302 animal species with variety of habitats like temperate broadleaf forests, grasslands, shrubs and rocky areas in this forest. Altitude was 1000 to 1400 m above sea level (Fig. 1).

The annual rainfalls are ranging from 150 mm to 750 mm and decrease from west to east. Annual temperature is from 11.5 to 17. 5°C.Wildfire has been a constant event in Golestan National Park for a long time (Safaian *et al.* 2005).

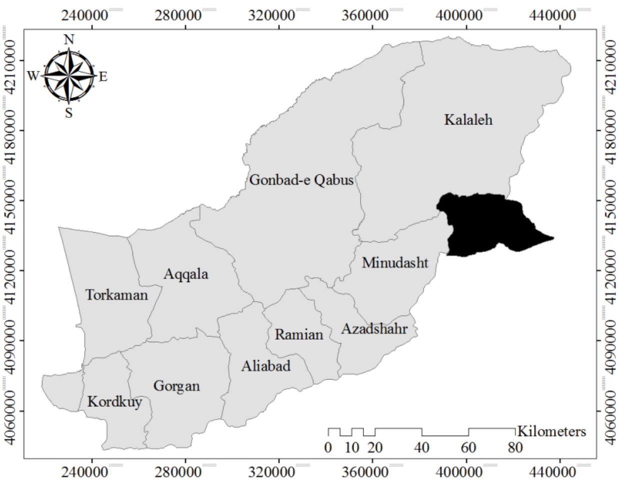

Fig. 1. The geographical position of the study area.

Data collection and analysis

The maps of effective factors on fire occurring including vegetation types, physiographic, climatic and human factors were prepared from different sources. The fire risk modeling and zoning were done in Random Forest (RF) using 70% of the fire points as training samples. The obtained fire risk map was zoned into five categories as very low-risk, low risk,

Moderate, high and very high-risk zone (Eshaghi & Shataee 2014).

Three variants of natural candidate sites for helicopter landing were designed by consideration of terrain slope, site areas, canopy gap, and fire risk zone. Digital elevation model (DEM) and triangulated irregular network (TIN) was used to extract slope data less than 5% and area with at least 50 meters in diameter (more than 2000 m^2). Canopy gap was analyzed using high-resolution imagery on Google Earth.

Suitable natural sites for landing selection were the sites without canopy cover, slope less than 5%, an area more than 2000 m^2 and close to fire risk zone. Buffers with a width of 0-1000, 1000-2000, 2000-3000, 3000-4000, 4000-5000 meter as helicopter landing coverage were designed in the study area. Moreover, buffers with widths of 0-600, 600-1200, 1200-1800 & >1800 were designed at both sides of rivers.

Each landing position can be accessed from parameters such as walking distance, time required to walk the trail to fire zone and walking speed, especially in mountainous forests with uphill and downhill slopes. Time cost of walking on each trail in the study was built on the evaluation of the maximum walking speed a walker weighting 60 kg can reach in an area (Chiou *et al*. 2010).

Walking speed (V) is calculated using Equation 1.

Time cost (K) can be modelled as Equation 2 (Rees 2004):

$$\frac{1}{V} = 0.75 + 14.6m^2 \quad (1)$$

$$K = \frac{d}{V} \quad (2)$$

Where V is walking speed in $km.h^{-1}$, m is mean of slope in % (m is defined as $dh.dx^{-1}$ where h was height and x was the horizontal distance), K is time cost in a minute, d is mean of walking distance in the kilometer.

The optimal helicopter landing variant based on the proximity to river, area covered by landing and time cost of response teams were identified using AHP in Expert Choice software.

RESULTS

Locating candidate sites for helicopter landing

In the current research, the relative frequency percent of risk classes in fire risk maps prepared in very low-risk, low risk, moderate-risk, high-risk and very high with RF algorithm were 28%, 16%, 23%, 14% & 19% (Fig. 2). In this study slope, less than 5% of area more than 2000 m^2 and without canopy cover were selected as candidate sites for helicopter landing preparation (Fig. 3).

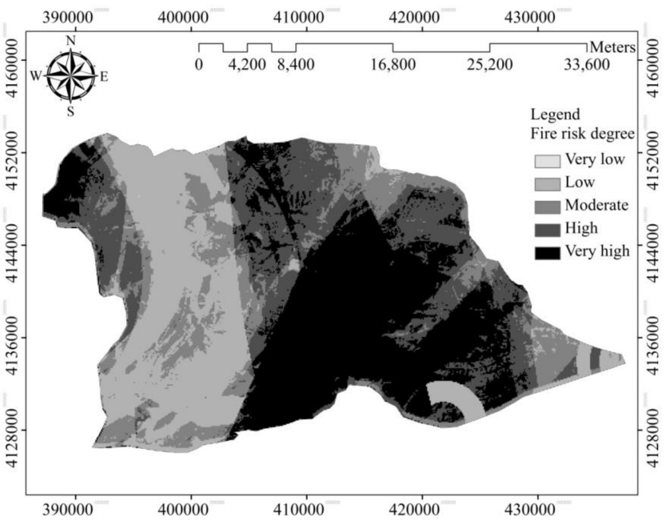

Fig. 2. Fire risk map.

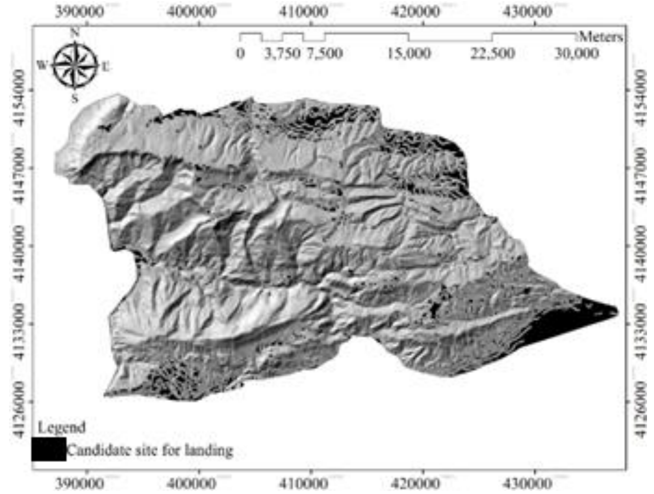

Fig. 3. The position of candidate sites for landing preparation.

Analysis of the time cost, areas covered by landing and proximity to river

We focused on trial determination in the case of forest fire. Our goal here is to provide natural, safe, cost effective, fast and consequently optimal helicopter landing variants for managing forest fire. If the speed of the helicopter is 200 km.h^{-1}, then the time traveled every buffer of 1000, 2000, 3000, 4000, 5000 are the 0.3, 0.6, 0.9, 1.2 & 1.5 minutes (Figs. 4 - 6). In this study, landings are the start node, while the risk grid is the end node. The trails based on the nearest distances to seven nodes were identified in GIS. Mean slope and distances of trails for each landing are shown in Tables 1 - 2, respectively.

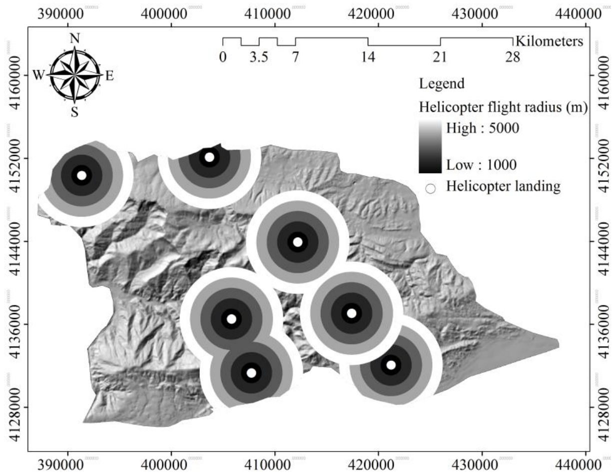

Fig. 4. Forest area covered by helicopter landing variant 1.

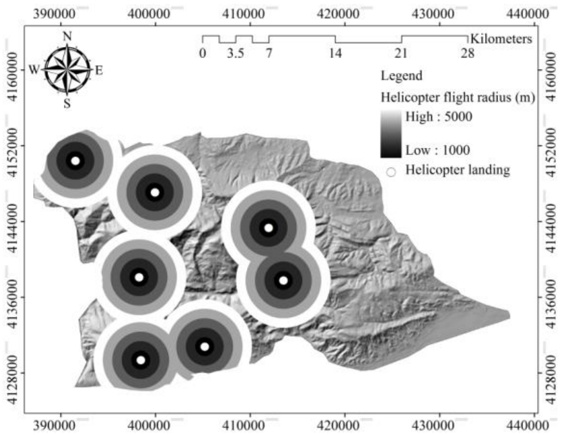

Fig. 5. Forest area covered by helicopter landing variant 2.

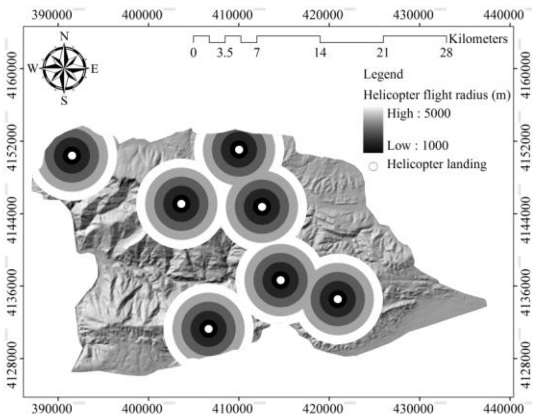

Fig. 6. Forest area covered by helicopter landing variant 3.

Table 1. Mean slope of trails for each landing to center of risk grid (%).

Variant	1	2	3	4	5	6	7
Variant 1	27	29	23	24	36.5	37	15.5
Variant 2	24.5	11.8	12	25.1	26.3	41	20.5
Variant 3	24.1	15	15	25.7	37.7	24.7	20

A comparison between these three variants reveals that the area covered by landing variant 1 (69.92%) was much greater than that of the other variants. The difference between the landing variants is that the time cost on trails chosen for the variant 1 was much lower than the trails chosen for the other landing variants (Table 3). The distance of landing variants 2 from the river was shorter than the other landing variants (Fig. 7).

Table 2. Mean theoretical distance of each landing to center of risk grid.

Variant	1	2	3	4	5	6	7
Variant 1	3480	4850	4752	4942	4961	4915	4410
Variant 2	5111	4580	3328	4571	4820	6543	4564
Variant 3	5079	4337	4600	4589	4814	4898	5301

Table 3. Basic information for optimal landing variant.

Variant	Area covered by landing (%)	Proximity to river (m)	Walking speed ($km.h^{-1}$)	Time cost (minute)
Variant 1	69.92	366.7	1.77	157.7
Variant 2	66.98	228.9	1.51	190.1
Variant 3	67.20	348.9	1.50	194.8

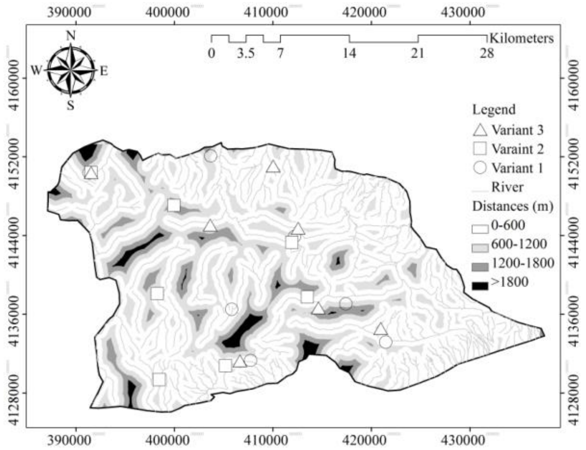

Fig. 7. The distances of different helicopter landing variants from rivers.

Selection of the Best variant

Based on AHP, the greatest importance (0.42) (Rees 2004) was given to a time - cost criterion relating to spent time for fire emergency response teams to access to fire zone (Table 4).

In AHP process it was selected variant 1 as the most suitable option (Fig. 8). The overhead image of the optimum variant is shown in Fig. 9.

Table 4. Weights and ratings assigned to landing variants optimization criteria (Scherer *et al.* 2012).

Variant Rating	Proximity to river (0.37)	Area covered by landing (0.21)	Time cost (0.42)
Variant 1	1	3	3
Variant 2	3	1	2
Variant 3	2	2	1

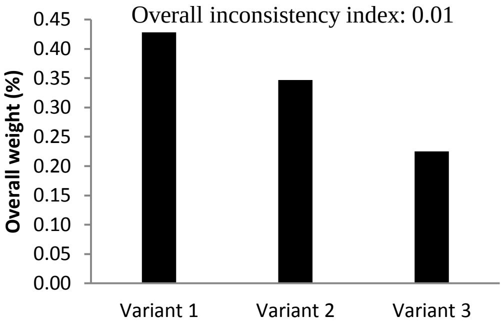

Fig. 8. Overall weights of different variants.

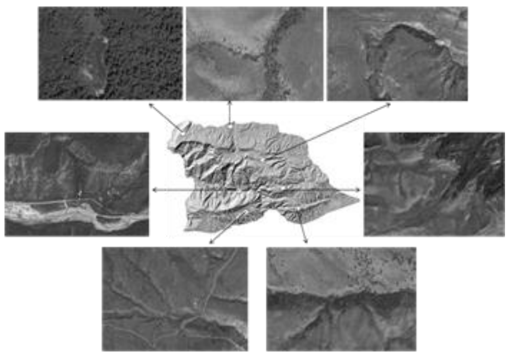

Fig. 9. The overhead image of selected variant.

ISCUSSION

Over the years, fire occurrence and severity in Iranian forests have been increasing and therefore more efforts are needed to detect and control forest fire. In the present study, GIS plays a vital role on mapping and predicting fire as well as analyzing alternative fire-fighting strategies, and directing those in the field (Borisov & Tsipenko 2012; Furdu *et al.* 2013). Five factors including physiographic, vegetation, ecological and human factors, as well as distance from the river were used as the independent input variable of RF data-mining model, which were used for predicting fire risk in Golestan National Park.

In this study, slope, less than 5 % of the area more than 2000 m^2 and without canopy cover were selected as candidate sites for helicopter landing preparation.

Westcott & Cleary (1950) selected a natural clearing measuring 55 by 28 meters as a landing site for the helicopter. Scherer *et al.* (2012) used Light Detection and Ranging-based perception system to select landing sites and approach paths by considering factors such as plane fitting, terrain condition, load bearing capability of the contact surface, rotor clearance, ground paths and wind direction. In this study, landings are the start node, while the risk grid is the end node. The trails based on the nearest distances to seven nodes were identified in GIS. Wang *et al.* (2014) proposed a model and algorithm which were effective in planning routes to avoid one or more fire-affected areas. Helicopter landing sites may be adjacent to a river or a lake, a railroad, a freeway, or a highway, all of which offer the potential for multi-functional land usage (Singh *et al.* 2014). The method of AHP is one of the many methods of Multiple Attribute Decision Making (MADM) that can be applied when selecting the best variant of helicopter landing site. The greatest importance (0.42) was given to a time - cost criterion relating to spent time for fire emergency response teams to access to the fire zone. In AHP process variant 1 was selected as the most suitable option. The selected variant proves that the investment is economically justified.

CONCLUSIONS

Our approach has extended the state of the process in finding natural helicopter landing by incorporating not only forest fire risk zone but also by considering factors such as terrain slope, site area, canopy gap and ground trails. We also present results from three successful landing variants with varying pattern in proximity to the fire zone. The selection of the best landing variant was made on the basis of four criteria of proximity to river, area covered by landing, the walking speed, and time cost. Based on our findings, we strongly recommend the use of the variant 1whenever possible, since the time cost and proximity to the river were lower and the area covered was higher than other variants. Fire-fighting in Golestan National Forest Park requires creation and improvement of fire-fighting helicopters.

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طراحی و ارزیابی محل‌های مختلف فرود بالگرد جهت اطفاء حریق در پارک ملی گلستان

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چکیده

نزدیک بودن محل‌های فرود بالگرد به مناطق مستعد حریق در جنگل به‌منظور توزیع امکانات و ارسال گروه‌های واکنش سریع امری لازم و ضروری است. در این تحقیق، نخست نقشه خطر آتش‌سوزی جنگل با بهره‌گیری از الگوریتم جنگل تصادفی و از طریق روی‌هم‌گذاری لایه‌های اطلاعاتی مؤثر در وقوع حریق مانند نوع پوشش گیاهی، مشخصات فیزیوگرافی زمین، فاکتورهای انسانی و اقلیمی تهیه شد. سپس سه گزینه برای فرود بالگرد از میان محل‌های طبیعی مناسب به‌کمک آنالیز شیب عوارض، مساحت مناطق، فضای خالی تاج پوشش و مناطق خطر آتش‌سوزی طراحی گردید. ارزش هر گزینه با بهره‌گیری از تحلیل میزان نزدیکی به رودخانه، وسعت مناطق تحت پوشش بالگرد و هزینه زمان صرف شده برای اعزام گروه‌های واکنش سریع از محل فرود بالگرد به منطقه آتش‌سوزی تعیین شد. گزینه بهینه از طریق فرآیند تحلیل سلسله مراتبی مشخص شد. بر اساس نتایج به دست آمده، می‌توان استفاده از گزینه اول را در هر زمان ممکن پیشنهاد داد، زیرا هزینه زمان و نزدیکی به رودخانه در گزینه اول کمتر از دیگر گزینه‌ها و مناطق تحت پوشش بالگرد در آن بیشتر از آن گزینه‌ها بود.

* مولف مسئول