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Zoning of Forest Fire Risk Based on Environment, Human and Land Factors (Case Study: Golestan Province, Iran)

Kami Kaboosi* and Osman Majidi[1]

Department of Agricultural Science and Natural Resources, Gorgan Branch
Islamic Azad University, Gorgan, Iran
[1]Golestan Meteorological Administration, Gorgan, Iran
✉ kkaboosi@yahoo.com

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Abstract: Several factors are involved in forest fire occurrence and these parameters are divided into environment, human and land. Research showed that forest fires had significant correlation with meteorological and topographical variables. So, one way to prevent and control forest fire is its prediction based on effective factors including climatic ones (precipitation, air temperature and wind speed and direction), land use, elevation, slope and its direction and human activities (distance from roads and residential and agricultural land). In this study, risk zoning map of forest fires in Golestan province, Iran, was prepared considering all above factors. Zoning maps of these parameters were overlaid by classification weighted method. In order to risk zoning map verification, this map was matched with the fire events map in recent years in province.

Results showed that safe, low, moderate, high and very high fire risk zones covered 66, 14.5, 15.3, 4.1 and 0.1 percent of province land, respectively. Also, Bandar Torkeman, Gomishan and Agh-ghalla counties had no risky zone while other counties have risky zone with various degrees of fire. In aspect of county distribution, most percent of very risk zone belonged to Kalaleh (550 ha) and Maraveh Tappeh (360 ha) and risk zone to Kalaleh (36,110 ha), Galikesh (15,269 ha), Maraveh Tappeh (14,398 ha), Minoodasht (13,293 ha) and Azadshahr (2839 ha). Acceptable accuracy of the fire risk zoning map was found because a relative good compliance between the fire risk zoning map and fire distribution map in recent years.

Key words: Distance, elevation, precipitation, slope, temperature.

Introduction

Forest ecosystems, including tropical deciduous forests and savannas, occupy about 14 percent of Earth's terrestrial area (18.6×10^6 km^2) and constitute 15% of global vegetation carbon stocks (Suleiman et al., 2017). Iran has 0.3 percent of world forest and placed in the rank 49 among 227 countries having the forests in the world. The world's forest capita is 0.55 hectares per person while figure for Iran is only 0.13 hectares per person (FAO, 2017). In the past three decades, the Iran forests have been reduced from about 18 million hectares to about 10.7 million hectares and the area of north forests has been reduced from about 3.4 to 1.9 million hectares (FAO, 2017; Soleimani and Memarian, 2011). Iran is among the countries with the highest rate of forest loss. While world annual average rate of forest loss is 3.3 percent (Suleiman et al., 2017), one is 5.6 percent in Iran.

*Corresponding Author

Forest fires are responsible for 14-20 percent of the annual global burned area (Wang et al., 2017). The estimates showed that annually 6-14 (Eskandari et al., 2014; Encinas et al., 2007) to 50-90 million hectares of the forests have got fired in the world (Wang et al., 2017). Based on available data from 118 countries representing 65 percent of the global forest area, an average of 19.8 million ha (1 percent) of all forests significantly is affecting each year by forest fires (Suleiman et al., 2017). While annual average fire in the world's forests is reducing, the number of fires in Iran has an ascending trend so that Iran among Middle East and North Africa countries, in terms of forest destruction by fire, has the fourth rank (Garavand et al., 2013; Soleimani and Memarian, 2011). The increase rate of number and area of Iran forest fires between years 2000 and 2010 has been 6.23 and 5.56 percent, respectively. Provinces of Golestan, Mazandaran, Gilan, Kordestan, Lorestan and Chahar Mahal Bakhtiari were among the provinces with many fires (Soleimani and Memarian, 2011). The review of Golestan Province forest and pasture fires over a period of 20 years between the years 1990 and 2010 showed that there 1677 fire cases have occurred with an area of more than 141 km^2. Also, April, May, June, October, the second half of February and March had no significant fire and these six months can be considered as the forest peace time of the fire crisis (GDGNRW, 2013).

One of the important plans to control and reduce fire is to prepare fire risk zoning maps. Fire risk zoning is to classify the region to parts with similar potential fire area based on the features affecting it. In other words, given the factors involved in occurring fire, the region can be divided into parts with different risk possibilities that despite this, it is possible for better and scientific decision to deploy firefighting tools and equipment (Mirdeylami et al., 2014). Several factors are involved in occurring forest fire that these parameters are divided into two categories involving environment and human (Suleiman et al., 2017). It is reported that human induced forest fire was the major cause of forest degradation in some countries (Suleiman et al., 2017; Kessy et al., 2016). Human factors include proximity to roads and residential areas, population and travel density etc. Environmental factors include the type and density of land cover (vegetation), fuel quality (quality of vegetation), topography, altitude, slope and its direction, air temperature, rainfall, wind speed and direction etc. (Wang et al., 2017). The research has shown that a significant correlation was found between the probability of the forest fire and meteorological variables (Aleemahmoodi Sarab et al., 2013; Dimitrakopoulos et al., 2011).

The fire risk map using GIS and AHP for a part of Paveh forests showed that 90% of burned areas are in zones with high risk (Mohammadi et al., 2010). The results of examining the fire risk zoning map of Gilan three forest areas using fuzzy hierarchical and GIS showed that 66 percent of last burned region was in high and very high risk areas (Zarekar et al., 2013).

So far, many studies have been carried out to predict the risk of fire and prepare a map of fire risk zoning in the world and Iran by different methods including weighted linear combination (Mirdeylami et al., 2014; Dong et al., 2005), logistic regression (Zhang et al., 2009; Martinez et al., 2009; Hernandez-Leal et al., 2006; Preisler et al., 2004), logistic fuzzy and analytical hierarchy process (AHP) to determine the weight of each factor affecting occurrence of forest fire (Mohammadi et al., 2010; Vadrevu et al., 2010), neural network (Vasilakos et al., 2007), genetic algorithm (Iliadis, 2005) etc. Each of these methods, due to the complexity of the fire process in different areas and different factors' influence, have the advantages and disadvantages that in many cases may not have required efficiency for accurate prediction and fire risk zoning in different regions (Mirdeylami et al., 2014). Respect to this, present study was conducted to zoning of forests fire risk based on environment, human and land factors in Golestan province, Iran by considering all effective factors.

Methods

Golestan Province is located between the provinces of Mazandaran, Semnan and Northern Khorasan. The forest of the province from the Galooghah in the West to Golidagh in the East with approximately 260 kilometres length and an area equal to 4517 km^2 covers more than 22 of the province and has contributed to per capita share of 0.28 hectares per person (GDGNRW, 2013).

According to examining 20-year forest and pasture fire statistics in the province, the months July, August and September due to the occurrence of fire in high areas with bush forests sometimes with wide levels and grassland fuel can be half-critical time. Since the second half of November to the end of the first half of February more fires have occurred. So, in analyses of rainfall and temperature, this period is considered. In this regard, some researchers to predict the risk of the forest fire used six-month average rainfall and temperature in summer and autumn during which the most fires had happened (GDGNRW, 2013).

In the present study, nine meteorology and land resources variables were examined and used to predict the fire risk in Golestan province forest as following:

1. *Elevation:* At higher altitude, moisture is higher and temperature is lower. So, the likelihood of occurring fire is reversely correlated with increased elevation (Zarekar et al., 2013; Chuvieco and Congalton, 1989). The parameter has been considered as an important factor in occurring fire by researchers (Eskandari et al., 2014; Mirdeylami et al., 2014; Garavand et al., 2013; Mohammadi et al., 2010). So, the digital elevation model (DEM) of the province was prepared based on maps of 1: 25,000 with pixel size of 10 × 10 m.
2. *Slope percent:* The slope affects the amount and direction of fire spread (Vadrevu et al., 2010). According to investigations, the amount of destruction and damage is also more in steeper slope (Chuvieco and Congalton, 1989): where the slope is more than 20% the rate of fire spread is twice more than where the slope is less (Zarekar et al., 2013; Chandra, 2005). Fire in low slope spreads slowly and in high slope spreads very rapidly.
3. *Slope direction:* Fire distribution is different according to directions of the earth because different directions vary in terms of receiving light, solar radiation and heat, the amount and type of vegetation and moisture content (Garavand et al., 2013; Chuvieco and Congalton, 1989). In general, the southern and eastern directions receive the highest amount of solar radiation, and as a result in more favourable conditions for the fire occurrence. Then, the western, north and flat areas respectively receive less radiation (Zarekar et al., 2013; Chandra, 2005).
4. *Rainfall:* This parameter is an important factor in preventing fire occurrence (Mirdeylami et al., 2014; Zarekar et al., 2013; Mohammadi et al., 2010).
5. *Air temperature:* A significant positive correlation is found between the parameters of maximum and average temperature and the number and extent of fire so that by increasing these variables, the forest fire is increased (Aleemahmoodi Sarab et al., 2013).
6. *Land cover:* The vegetation as the main fuel material is a factor affecting each fire. The density of vegetation also represents the amount and availability of fuel material in the fire. This parameter has been considered as an important factor in predicting the occurrence of fire by many researchers (Eskandari et al., 2014; Mirdeylami et al., 2014; Zarekar et al., 2013; Sowmya and Somashekar, 2010; Mohammadi et al., 2010; Stolle et al., 2003; Jaiswal et al., 2002; Almedia, 1994).
7. *Distance from the road:* In general, if the forest area is closer to the road, the risk of fire will be greater (Zarekar et al., 2013). Then, the map of roads of the province was prepared and buffers were defined at specified intervals from the road. The closer distance has the greatest fire potential while being away from the road reduces the fire risk.
8. *Distance from residential areas:* The role of the human in intentional and inadvertent forest fire has been reported (Zarekar et al., 2013). This parameter has been considered as an important factor in predicting the occurrence of fire by researchers (Eskandari et al., 2014; Jaiswal et al., 2002; Dong et al., 2005).
9. *Distance from agricultural land:* Forest area adjacent to agricultural land is also one of the major factors of the forest fire. Farmers after harvesting the product, burn the residual of the product in order to prepare the land soon for the next planting; this and the inability of farmers to control the fire cause the fire spread to the forest areas (Mirdeylami et al., 2014).

According to the above, after the classification of meteorological and land variables and human activities in Golestan province in relation to the forest fire risk prediction as shown in Table 1 and providing relevant zoning maps, weighting method was used for the information layers' overlay and the fire risk zoning map of the province was prepared in five classes. In order to verification, obtained fire risk zoning map was prepared by statistical data of important fire occurred during the years 2006-2013.

Results and Discussions

The map of the factors affecting the forest fire has been provided according to the presented classifications in Figure 1. The final zoning map of forests and pastures fire risk (Figure 2) was produced by overlaying the basic maps. Accordingly, the zoned areas can be described and analyzed as follows:

1. *Safe zone:* This area consists about 66 percent of the province extent and mainly covers the northern regions and the plains of the province because in the area almost there is none of the fire risk factors.
2. *Low risk zone:* This area approximately consists about 14.5 percent of the province extent. The area mostly cover the high and south regions that despite

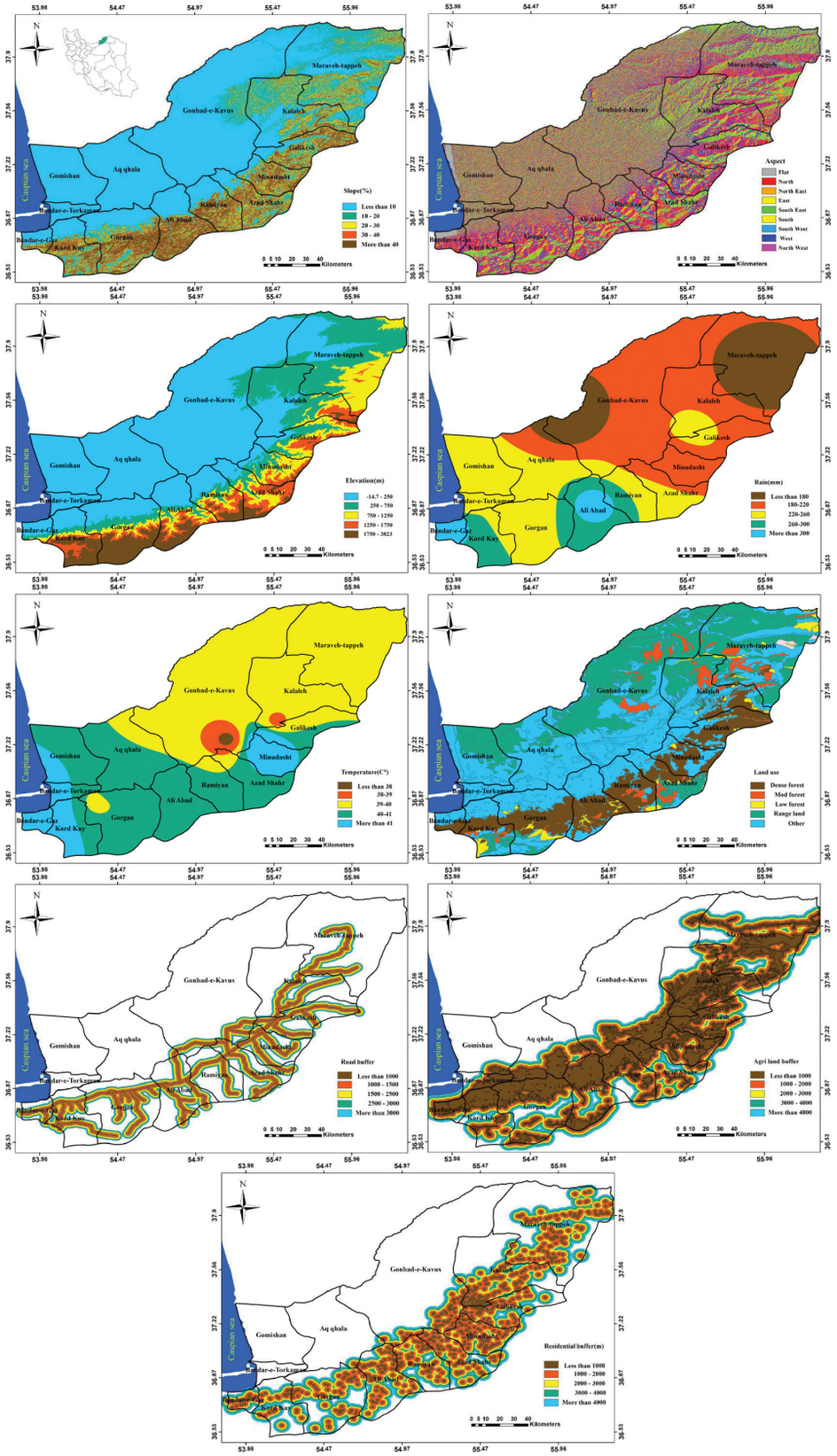

Figure 1: The maps of the factors affecting the forest fire.

Table 1: Classification of meteorological and land variables and human activities in relation to the forest fire risk prediction

Risk class	*Elevation (m)*	*Slope (%)*	*Direction*	*Precipitation (mm)*	*Air T. (°C)*	*Land use*	*Road D. (m)*	*Residential D. (m)*	*Agriland D. (m)*
Safe	1750-3823	0-10	North	<180	<38	Other	>3000	>4000	>4000
Low	1250-1750	10-20	East and Northeast	180-220	38-39	Range	2500-3000	300-4000	300-4000
Moderate	750-1250	20-30	Flat	220-260	39-40	Low forest	1500-2500	2000-300	2000-300
High	250-750	30-40	West and Northwest	260-300	40-41	Mod. forest	1000-1500	1000-2000	1000-2000
Very High	-14.7-250	>40	South and Southwest	>300	>41	Dense forest	<1000	<1000	<1000

T. and D. mean temperature and distance.

the vegetation due to high elevation, rainfall and air moisture, low temperature and lack of access to the zone by the human it is considered as low risk zone.

3. *Moderate risk zone:* This zone covers about 15.3 percent of the province extent where farming is done. Human factors can be responsible for the fire occurrence in this zone.
4. *High-risk zone:* This zone approximately covers 4.1 percent of the total area of the province that generally forest areas with low and middle coverage; mount regions of Ramian, Azadshahr, Minoodasht, Galikesh, Kalaleh and Maravehtapeh are located in this area.
5. *Very high-risk zone:* This zone covers an area of about 0.1 percent including Azadshahr, Minoodasht, Gonbad, Galikesh, Kalaleh and Maravehtapeh. These areas are generally located in mount regions with a high temperature and many roads and agricultural lands.

The results showed that the widest extent of very high-risk zone is located in Kalaleh (550 hectares) and Maravehtapeh (360 hectares) and high-risk zone is

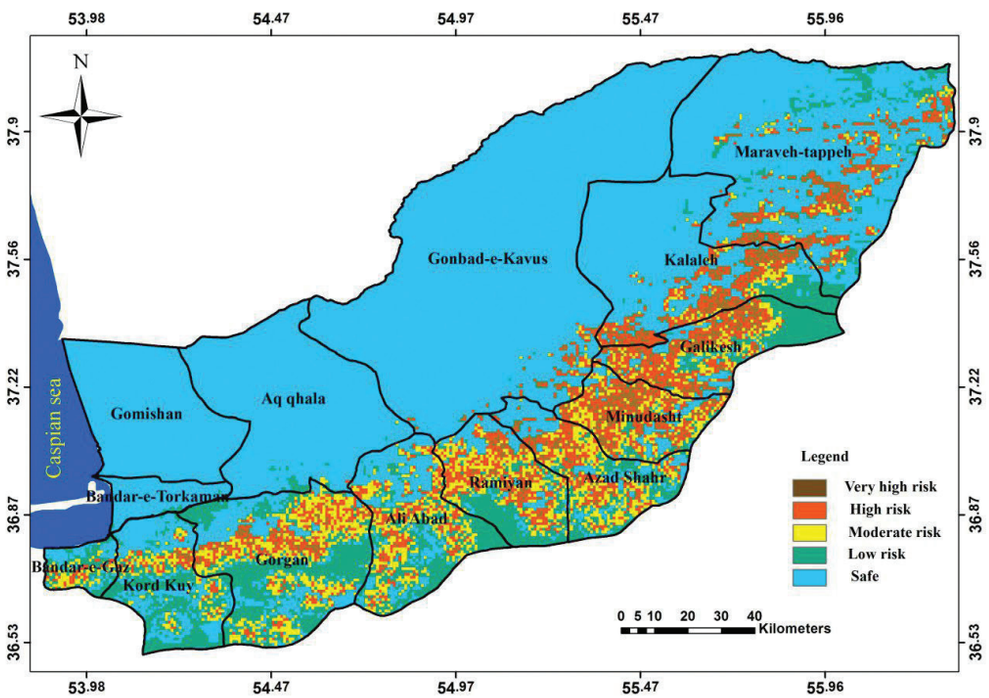

Figure 2: Fire risk zoning map of forests in Golestan province.

Table 2: Extents (ha) of forest and pasture fire risk zones

County	*Safe*	*Low*	*Moderate*	*High*	*Very high*	*Total*
Bandar-Gaz	4154	8944	10502	0	0	23600
Kord-Kuy	32440	44129	8047	85	0	84700
Bandar-Torkaman	27418	83	0	0	0	27500
Gomishan	125000	0	0	0	0	125000
Gorgan	29276	89246	38720	157	0	157400
Agh-Ghala	182726	1474	0	0	0	184200
Aliabad	29100	36540	43651	109	0	109400
Ramian	7939	18608	55326	827	0	82700
Azadshahr	22629	21961	35989	2839	84	83500
Gonbad	492179	1139	495	545	644	495000
Minoodasht	4208	1804	47428	13293	67	66800
Galikesh	7421	24140	38385	15269	85	85300
Kalaleh	116579	15397	14664	36110	550	183300
Maraveh-tapeh	252231	29422	16589	14398	360	313000
Golestan province	1333300	292884	309795	83632	1789	2021400
Percent	65.96	14.49	15.33	4.14	0.09	100

located in Kalaleh (36,110 hectares), Galikesh (15,269 hectares), Maravehtapeh (14,398 ha), Minoodasht (13,293 hectares) and Azadshahr (2839 hectares).

According to statistics, over a period of 20 years between the years 1980 and 2010 a total of 1677 fire cases with an extent more than 141 km^2 had occurred in forests and pastures of Golestan province (GDGNRW, 2013). Unfortunately information of these fires has not been registered, but the information registration is being done in the recent years. The 92 fire cases' specifications were obtained with a total area of 1644 hectares of the General Directorate of Natural Resource and Watershed of Golestan province. In order to verify the forest fire zoning map, it was matched with the map of these fires. Result has been shown in Figure 3. According to Figure 3 the fires have happened especially in the eastern part of the province mainly located in high and very high-risk zones that indicates the acceptable verification of the risk zoning map. The results of this study are consistent with the results of the previous studies that showed the fire risk prediction map can be prepared based on basic land and weather properties (Zarekar et al., 2013; Paz et al., 2011; Maeda et al., 2011; Sowmya and Somashekar, 2010).

Conclusion

The results indicate acceptable accuracy of the fire risk zoning map because a relative good compliance was observed between the fire risk zoning map and fire distribution map in recent years. According to the results, safe, low, moderate, high and very high risk zones respectively cover 66.0, 14.5, 15.3, 4.1 and 0.1 percent of the total area of Golestan province. Bandar Torkaman, Gomishan and Agh-galla have no risky fire zones. At the same time, the most area of very high-risk zone is located in Kalaleh (550 hectares) and Maravehtapeh (360 hectares) and high-risk zone is located in Kalaleh (36,110 hectares), Galikesh (15,269 hectares), Maravehtapeh (14,398 ha), Minoodasht (13,293 hectares) and Azadshahr (2839 hectares). High risk and very high-risk areas generally cover Ramian, Azadshahr, Minoodasht, Galikesh, Kalaleh and Maravehtapeh that in addition to the high temperature at a critical time, because of roads and agricultural lands close to the forest, the fire risk is high there. Climate change can impose significant effect on wildfire (Campbell and Shinneman, 2017; Wang et al., 2017). According to reduction of rainfall due to drought and global warming, it is suggested that the effect of

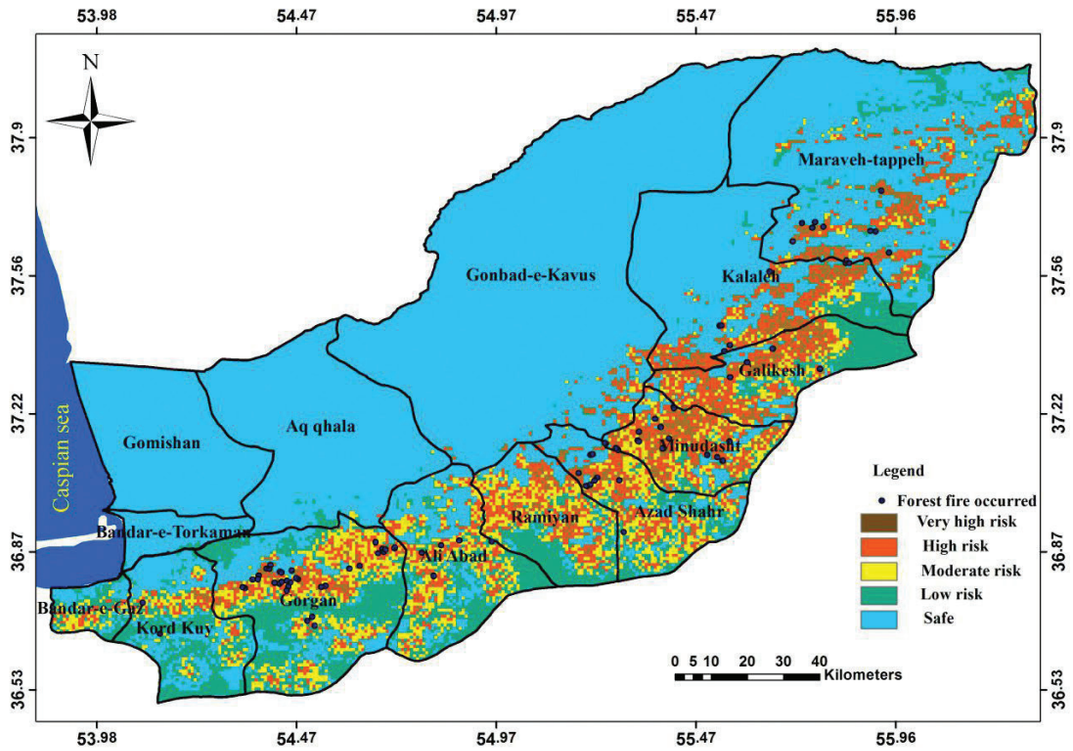

Figure 3: Verification of forest fire risk zoning with happened fires.

different scenarios of climate changes on the fire risk zoning in Golestan province forests be examined.

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