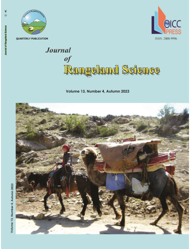

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Multihazard rangelands susceptibility mapping (drought, flood, and fire) in Siah Bisheh watershed in north of Iran

Soodeh Miarrostami[1], Seyed Akbar Javadi[1]*, Hossein Arzani[2], Mohammad Hasan Jouri[3]

[1]Department of Rangeland Management, Faculty of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran.
[2]College of Natural Resources, University of Tehran, Iran.
[3]Department of Rangeland, Faculty of Natural Resources, Islamic Azad University Nour branch, Nour, Iran.

*__Corresponding author__: a.javadi@srbiau.ac.ir

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Abstract:
This study was conducted to prepare a map of multi-hazard (drought, fire, and flood) to manage the rangelands of the Siah Bisheh watershed located in the west of Mazandaran province, Iran, Iran from 2017 to 2018. For drought assessment, the Standardized Precipitation Index (SPI) was used using the rainfall data of 21 meteorological stations for a period of 30 years. The multi-criteria decision-making method was used to weigh the existing layers and prepare the fire risk map. The results of the drought investigation showed that the study area was in a severe to moderate drought range with an SPI of -2.14 to -0.76, and most of the adjacent areas were also in the normal and near normal drought class. The vegetation types Bromus tomentolus-Festuca ovina and Festuca ovina-Bromus tomentolus were observed in the areas with higher drought susceptibility. The fire investigation showed that distance from the village (0.249), litter (0.166), and rainfall (0.151) were the most effective factors than others, respectively. The fire risk map showed that the northern part of the study area was highly susceptible to fire. Moreover, the rangeland of the study area was not affected by flood risk, and only the areas around the river were affected by floods. The results of the drought, fire, and flood risk maps of the study area showed that the central and northern parts of the watershed were of high and very high susceptibility in terms of multi-hazards. Based on the results obtained from flood modelling using the frequency ratio method, it was determined that this method had an efficiency of 0.98 based on receiver operating characteristic criteria. To determine the final risk map of the Siah Bisheh sub-basin, the drought, fire, and flood risk maps were consolidated. According to the final risk map, generally, the central and northern parts of the basin showed high and very high susceptibility in terms of multi-hazards. This research is useful in areas such as Iran and saves time and cost on studies.

Keywords: Risk management; Natural hazards; Multi-criteria decision making; Frequency ratio; Multi-hazards; Chalous Rud

1. Introduction

Natural disasters can reduce the services of rangelands to people. Drought is one of these disasters. This phenomenon occurs every few years as a result of reduced rainfall in different parts of the world, and if there is no coherent plan in production and sustainable development, it will cause famine [1]. The knowledge of drought, by predicting and zoning the drought severity, can significantly reduce the risk of its damage [2].
Drought prepared conditions for fire in rangeland areas [3]. Fire, as one of the ecological processes (along with climate and livestock grazing) and a natural and reproducible force [4], plays an important role in the resistance, shape and ecosystems survival [5, 6], and is one of the primary mechanisms for maintaining structure, diversity, production and yield [7] and affects the evolution of many plant species [8]. Lack of proper management before and after the fire has caused this factor to become a threat and reduce the vegetation cover area, plant biomass, and consequently endanger livestock and rangeland beneficiaries in rangeland

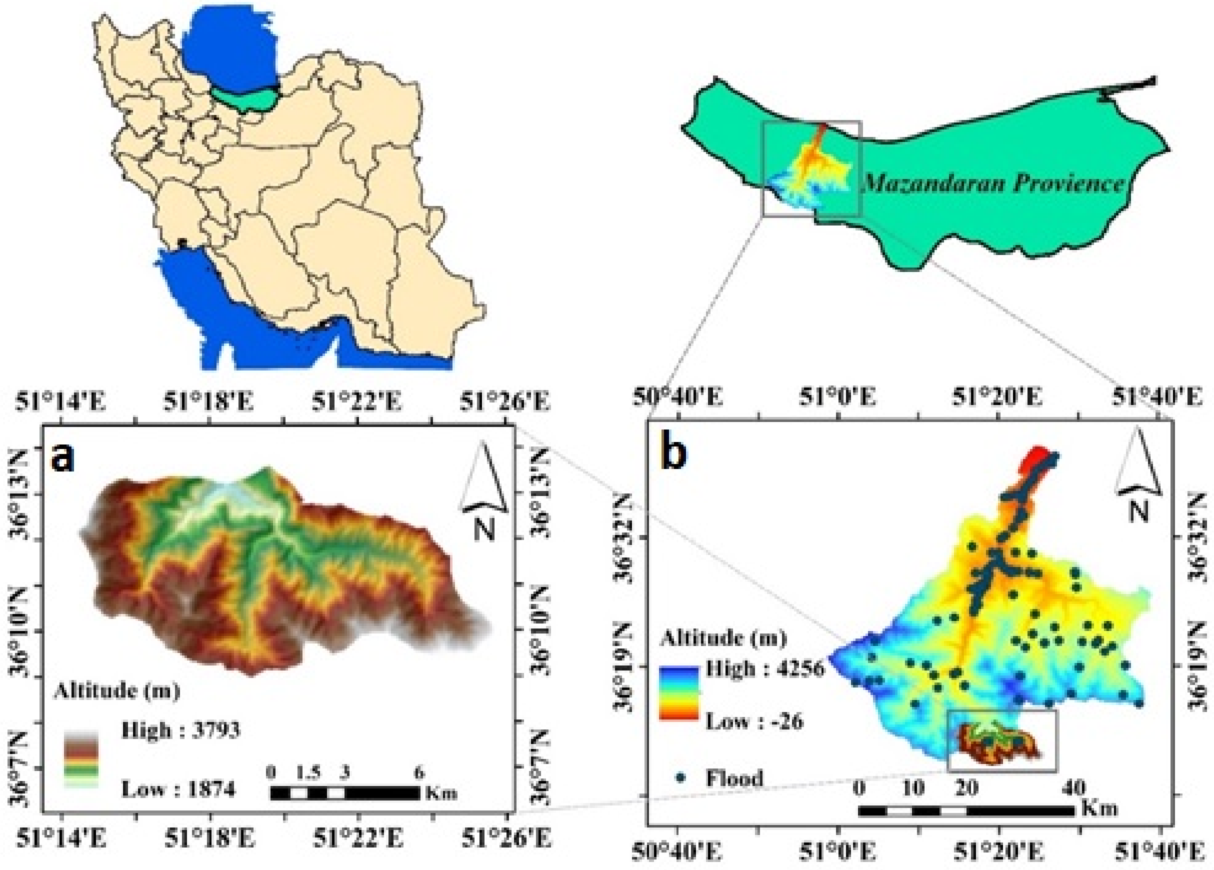

Figure 1. Location of the study area: (a) Siah Bisheh sub-basin (b) Chalous Rud basin, Mazandaran province and Iran.

ecosystems. Preparing fire risk management plans plays an important role in controlling this phenomenon.

Floods are a natural hazard that is generally caused due to loss of vegetation. Since the flood event itself is caused by various natural and unnatural factors, it is possible to reduce the possibility of flooding, especially its damages and adverse effects, by applying management and technical measures [9]. The flood phenomenon, despite all its complexities, can be studied and identified, and appropriate solutions can be sought to control and reduce its damage, and even for economic exploitation of floods.

Flood is the biggest and most important climate crisis that kills thousands of people every year and causes great damage to human society and the environment [10, 11]. Excessive use of natural resources and its degradation, in addition to the arid and semi-arid climate of the country, has caused floods to increase significantly year by year, both in terms of the number of times and the severity of the damage [12]. Also, due to human intervention in the natural water cycle through the degradation of vegetation in watersheds, the possibility of flooding in various areas has increased. The flood occurrence indicates that the flood cannot be prevented, but with useful management actions, it is possible to prevent the loss and damage caused by it. Flood susceptibility zoning is one of the ways to reduce damage in management areas [13].

Until recently, and given that natural hazards are complex phenomena, the vast majority of published studies have paid close attention to a single risk phenomenon. However, a particular area is usually not just affected by a natural hazard and is affected by two or more hazards simultaneously or sequentially. In this regard, the use of a risk map for any type of natural disaster would be uncontrollable when several types of hazards had to be considered [14]. The multi-hazards analysis is the solution to this problem, which can be used with confidence in the preparation of natural and basic risk models using GIS-based methods.

There have been several studies on natural hazards studied by various researchers, including floods [9, 15], fires [16–19], and drought [20]. Also, in recent years, multi-hazards have been studied using multi-criteria decision-making (MADM) methods, and data mining models, including investigation of multiple floods, landslide and fire hazards [21], landslides, floods, earthquakes [22, 23], multiple earth hazards [24], floods and landslides [25]. The reports showed that multi-hazards assessment could be effective in the proper and efficient management of the study area.

Dangerous natural disasters can significantly affect the natural and artificial environment, changing the landscape of the earth, and in some cases, even limiting human interaction with the ecosystem. Proper planning is important to minimize losses and reduce the economic impact associated with their occurrence. Accordingly, reliable information on

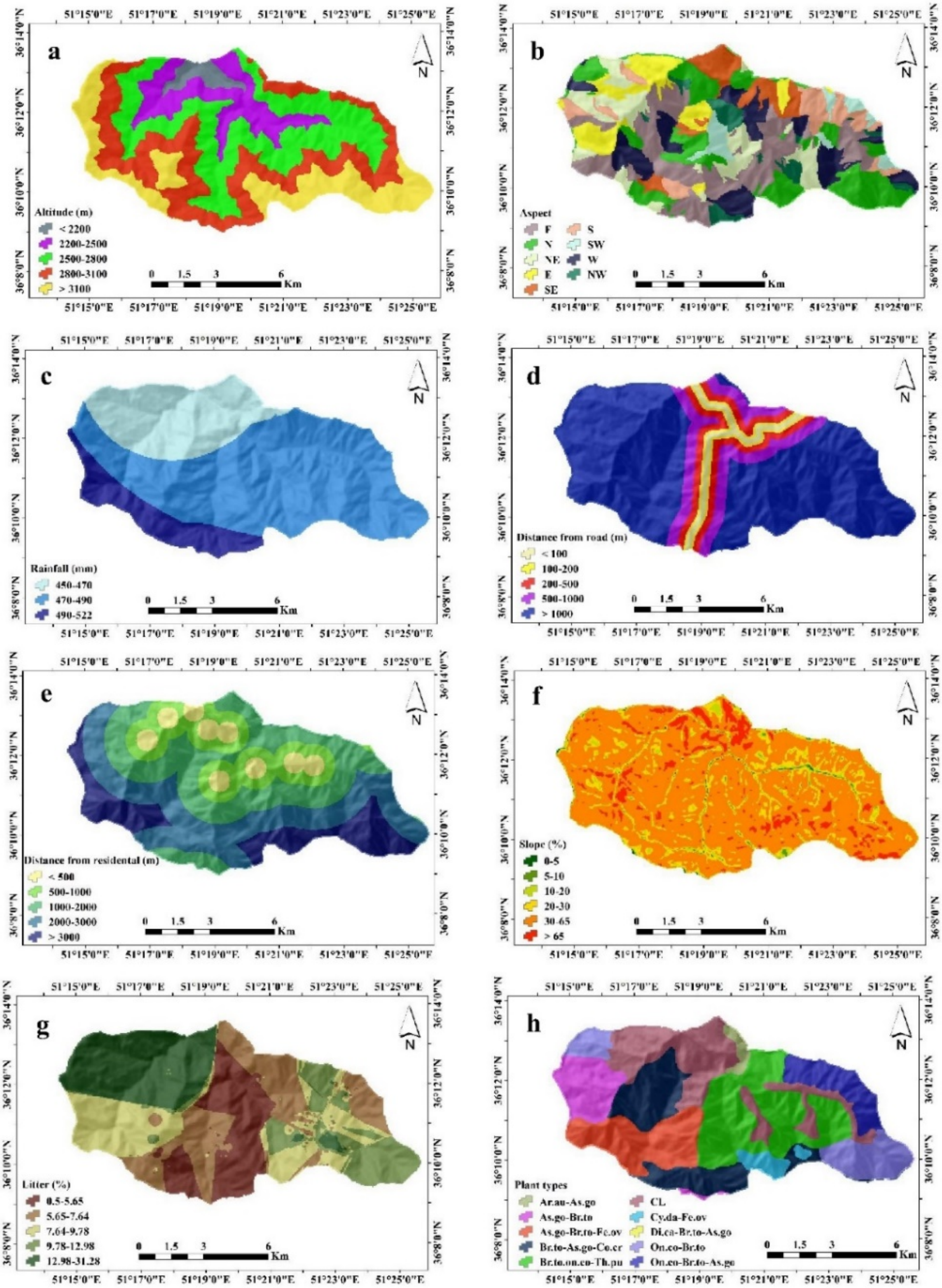

Figure 2. Influential variables used in the rangeland fire (a) Altitude (b) Aspect (c) Rainfall (d) Distance from road (e) Distance from residential (f) Slope (g) Litter (h) Plant type.

the spatial distribution of natural disasters is an important tool that environmental planners and engineers are trying to identify the affected areas to reduce potential risk. Given the above phenomena, the multiple assessment of natural hazards is essential as a tool to combat or control natural hazards. Risk management is a precautionary approach that

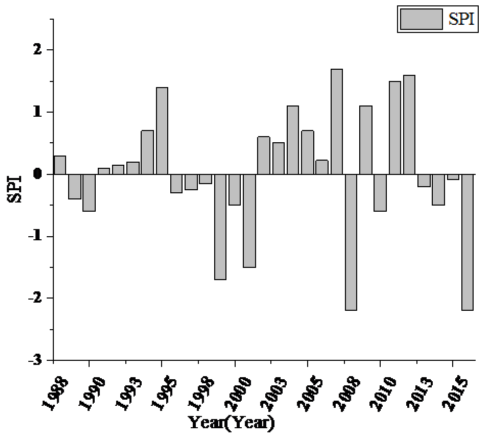

Figure 3. Drought zoning based on SPI in areas adjacent to the basin.

minimizes vulnerabilities [22].
The rangelands of Siah Bisheh sub-basin are no exception to natural and sometimes unnatural hazards such as drought, fire and flood, and the above phenomena have occurred annually in this area. The literature review shows that researchers have studied the effects of different hazards in watersheds [17, 18, 22, 25] while the effects of multi-hazards of flood, drought, and fire have not been considered on rangelands. Considering the importance of rangelands in the water supply of Tehran, tourism area, environmental values, etc., the purpose of this study was to investigate the risks of drought, floods and fires as the main risks of the study area and to prepare a risk management map of the rangelands studied based on these risks.

2. Materials and methods

2.1 Description of the study area

Siah Bisheh sub-basin is located in Chalous Rud watershed in the central Alborz highlands on the Chalous-Karaj road in Mazandaran province. The basin is located at longitudes 15° 51″ to 25° 51″ E and latitudes 09° 36″ to 14° 36″ N. The study area is about 9312 ha. This area has a semi-humid and very-cold climate based on the Demarton method and a cold climate based on the Emberger method. The average slope of the basin is 45%. The average annual rainfall is 500 mm. The minimum altitude of this region is 1874 m and the maximum altitude is 3793 m above sea level (asl) (Fig. 1). The rangelands of Siah Bisheh watershed are good to moderate range condition, and the dominant vegetation types include Festuca ovina-Bromus tomentellus, Bromus tomentellus-Festuca ovina, and Bromus tomentellus-Astragalus-Hordeum (Rangeland management plans in the General Department of Nowshahr Natural Resources Office, 2008). The most important rangelands in the case area include Duna, Sarkhas, Khakak, Gookol, Gazanak, Pole zanguleh, Estakhr sar. To study the vegetation in the study area, sampling was done from these rangelands.

2.2 Drought assessment map

To study the drought, the statistics of Meteorological stations in the study area were prepared monthly and 21 stations in the Chalous Rud sub-basin were identified by considering various criteria such as having long-term statistics, having little missing statistics, and proper distribution in the region. The 30-year statistical period (1977 to 2016) was determined as the base period for the study of drought in the study area. Missing data were reconstructed using regression method based on base stations. Data accuracy and homogeneity of data were investigated by the run test method using SPSS19 software.
In this study, drought events were determined using standard precipitation index (SPI), normal percentage index (PNI), and decile index (DI) based on the suggestions of various researchers [26, 27]. For this purpose, the time scales of 1, 3, 6, 9, 12, 18, 24, 48 months and one year were used for the SPI, and monthly, seasonal and annual scales were used for the DI. The above indicators were calculated in the Drought Indices Package (DIP) software version 2. By comparing the three drought indices EDI, PNI, and SPI, it was found that the SPI had a high efficiency in drought analysis of the study area. Therefore, annual drought zoning was performed using the SPI index and Kiriging interpolation method in the GIS software environment.

2.3 Flood inventory map

To prepare flood probability and susceptibility maps, the frequency ratio method was used using parameters including altitude, slope, land curvature, TWI, SPI, average rainfall, distance from river, lithology, soil type, and land use in the rangelands of the study area. Flood locations are an important level of the relationship between flood occurrence and its causes. Floods inventory is used as a basis for predicting future floods so that areas close to past events are highly susceptible to flooding. Thus, 70 flood locations in the study area were prepared based on the statistics of previous floods reported by the Regional Water Department of Mazandaran Province and the General Department of Natural Resources of Nowshahr, 70% of which were for modelling and 30% was for validation.

2.4 Influential variables on fire risk

The occurrence of a fire in a rangeland depends on several factors, each of which varies depending on the natural and socio-economic conditions of the region. Since these factors have a high multiplicity and variety, these parameters were identified by reviewing the relevant literature and also using the results of the analysis of the questionnaire distributed among 30 experts in this field. Finally, nine factors affecting the fire, including vegetation, human factors (distance from road and land use), slope, distance from river, rainfall, slope aspect, altitude, vegetation density, litter content, and rangeland condition were considered (Fig. 2).
The baseline map for preparing the effective factors was a digital elevation model (DEM) map with a spatial resolution of 30 m. In this study, slope, aspect and altitude factors were prepared using DEM map and classified in ArcGIS software. In this regard, tourists also play an undeniable role in cre-

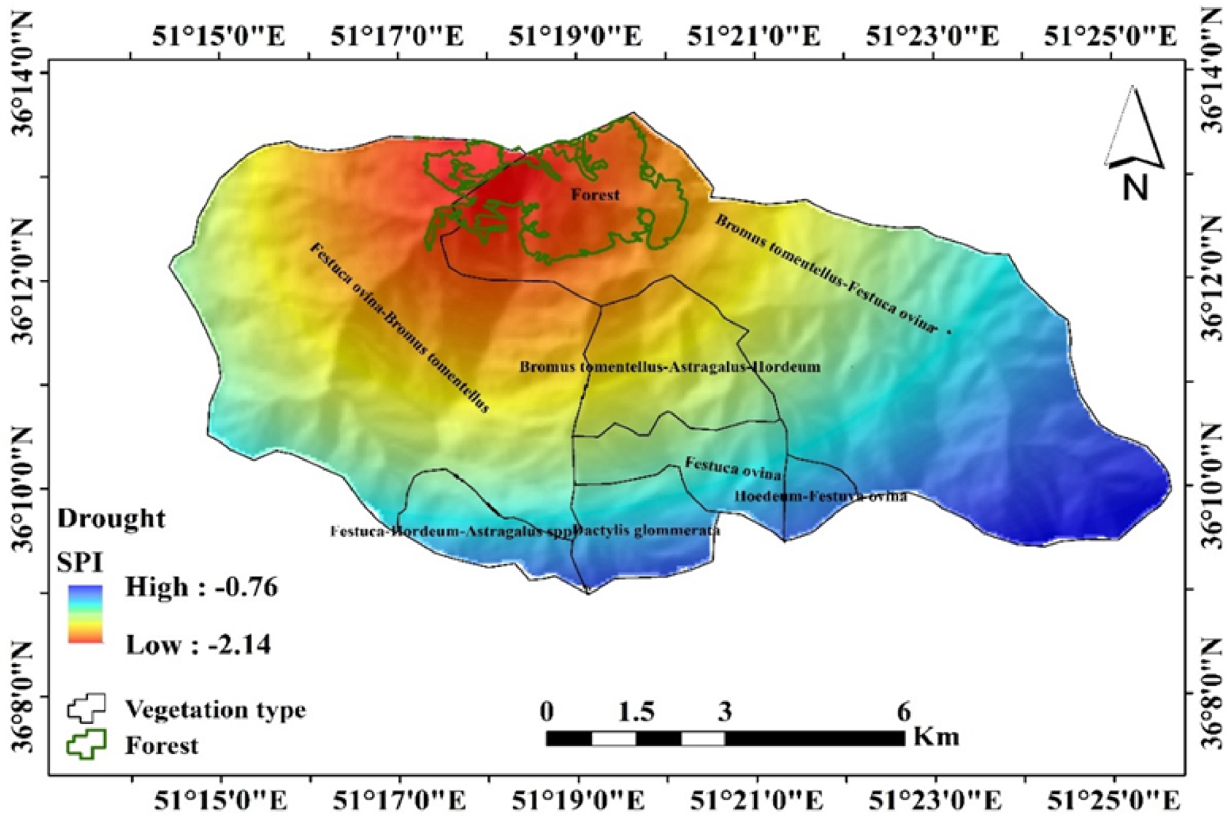

Figure 4. Results of drought zoning based on vegetation type in the rangelands of Siah Bishe sub-basin in the Chalous Rud watershed, Iran.

ating fires. For this purpose, two factors related to human factors, including distance from the road and distance from residential areas, were considered. To prepare the distance from the road factor, first the existing roads in the study area were separated from the road map of Iran, then the distance from the road was prepared using the DISTANCE tool in ArcGIS software. The closer the area is on the road, the more likely it is that there will be a fire. The distance from residential area factor was also prepared using the buffer tool in ArcGIS software. Proximity to residential areas increases the fire capability of these areas.
To prepare the annual rainfall map of the study area, seven rain gauge (synoptic) stations with a statistical period of 30 years were used. Also, in order to prepare the rainfall zoning map of the study area, kriging interpolation method was used and classified using ArcGIS software (Fig. 2). The vegetation type and the obtained litter reflect the amount and availability of combustible materials in each fire [28]. So, after identifying the vegetation types in the study area, four 100-m transects were established to study vegetation factors

Table 1. Vegetation types, characteristics in the rangelands of Siah Bishe sub basin.

Ordinary Rangeland	Plant Types	Perennial Coverage (%)	Litter (%)	Average Elevation (m)	Range Condition	Rangeland Trend	Total Production (Kg.h)
Duna	Festuca-Hordeum-Astragalus spp	62	9.5	2825	Good	Decreasing	1740.6
Duna	Festuca ovina-Bromus tomentellus	56.6	8.6	2975	Good	Stable	1345.1
Sarkhas	Bromus tomentellus-Festuca ovina	46.3	5.5	2918	Moderate	Stable	1157.2
Khakak	Bromus tomentellus-Festuca ovina	50.1	5.7	2849	Moderate	Stable	1295
Gookol	Hoedeum-Festuva ovina	63.5	9.4	3329	Good	Decreasing	1764.7
Gazanak	Bromus tomentellus-As-Hordeum	36.9	5.7	3124	Moderate	Decreasing	1018.2
Polezanguleh	Festuca ovina	64.6	5.2	2480	Good	Stable	1452.7
Estakhr sar	Dactylis glommerata	81	10	2474	Good	Stable	1969.1

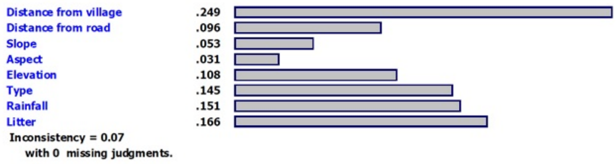

Figure 5. Results of AHP method for fire susceptibility using Expert Choice software.

(canopy cover percent, litter percent, stone and gravel percent, production rate, and density of plants). The location of the first transect was determined randomly, and the rest was systematically determined. The distance between transects was 50 m and the distance of the plots in each transect was 10 m. The required number of plots in each plant type was determined based on statistical methods, and the size of plots was determined based on the vegetative form of plants in the region (40 plots of 1 m^2). To determine the rangeland condition, the four-factor method was used and the trend of each type was determined based on the trend balance method (Fig. 2) [29, 30].

3. Description of the model used

3.1 Analytic hierarchy process (AHP)

The mechanism of using AHP method is that after designing the hierarchy for the criteria and options, the indices are evaluated with a pairwise matrix. Then, to calculate the degree of importance of each of the indices and options, first the geometric mean was calculated for each cell of pairwise matrices. After calculating the geometric mean of all pairwise comparison matrices, the results were normalized and the weights of the criteria were obtained by combining the weights of the lower level criteria with the corresponding upper level in the hierarchy.
The consistency ratio of all pairwise comparison matrices should be less than or equal to 0.1, indicating the stability of the comparisons. Otherwise, it is necessary for the relevant expert to repeat the judgment in order for the matrices to be consistent [31]. In this research, the opinions of 15 experts were used. After calculating the weight of the classes of each criterion and considering the weight of the pairwise comparison obtained by experts and literature review, the pairwise comparison matrix of criteria and sub-criteria was applied by AHP method, and the final weight of each criterion and sub-criteria was determined using WLC method. To make pairwise comparisons, Expert Choice Ver.11 software was used to calculate the inconsistency rate, prioritize options, and analyze the susceptibility.

3.2 Frequency ratio (FR)

The frequency ratio model as a bivariate statistical model was used as a simple spatial tool to calculate the probabilistic relationship between independent and dependent variables, which includes several classified maps. The frequency ratio of each class of each criterion was calculated based on Equation 1:

$$\mathrm{FR} = \frac{\mathrm{A/B}}{\mathrm{C/D}} \tag{1}$$

Where:
A = the number of pixels with phenomenon for each factor,
B = total number of location phenomenon in the study area,
C = the number of pixels in each class of the factor,
D = the total number of pixels in the study area, and
FR = the frequency ratio of one class for each factor [31].

3.3 Receiver operating characteristic (ROC)

The ROC curve, known as the performance characteristic curve, is a graphical diagram that demonstrates the ability to detect a binary classification measurement system. This curve is one of the performance measurement tools of a test method, which can be used to examine concepts such as cutoff, sensitivity and specificity of a test [32]. The ROC curve was used to determine the accuracy of the flood susceptibility map in this study as it was used by [21]. The area under the ROC curve (AUC) indicates the predictive accuracy of the model used in modelling the occurrence and non-occurrence of predetermined events [32]. In this study, to evaluate the model results, 30% of the data that were not used in modelling were used to draw the ROC curve. Therefore, to draw this data curve, they entered the SPSS software and the ROC curve was drawn.

3.4 Multi-hazards map

After preparing drought, fire and flood risk maps, they were integrated in GIS software to determine the overall risk of the area. Given that different methods were used to determine the risk of drought, fire, and flood, initially, the risk maps were standardized so that the lowest risk layer was scored 0 and the highest risk was scored 1. Then, three standardized maps were integrated and the overall risk map of the study area was obtained.

4. Results

It was determined that seven vegetation types including forbs, grasses, and shrubs were present in the study area. Characteristics of vegetation types including the names of vegetation types, perennial cover percent, production rate, litter, rangeland trend and condition were measured (Table 1).

4.1 Results of drought assessment

Based on SPI index, the wettest periods occurred in 2011 and 2012 in January. The most severe drought was related to the year 2008-2009 in September (Fig. 3). The result of zoning the average annual drought for the areas adjacent to the basin and the study area (Chalous Rud Basin) was shown in Fig. 3.
The results of drought zoning of Siah Bisheh sub-basin showed that the minimum SPI in this region was -2.14, as severe drought, and the maximum SPI was -0.76 as moderate drought (Fig. 4). Accordingly, a small part of the north of the study area has a severe drought condition and most of the adjacent basin is in the normal and near normal drought class. Also, the study of different vegetation types in the Siah Bisheh rangeland shows that the vegeta-

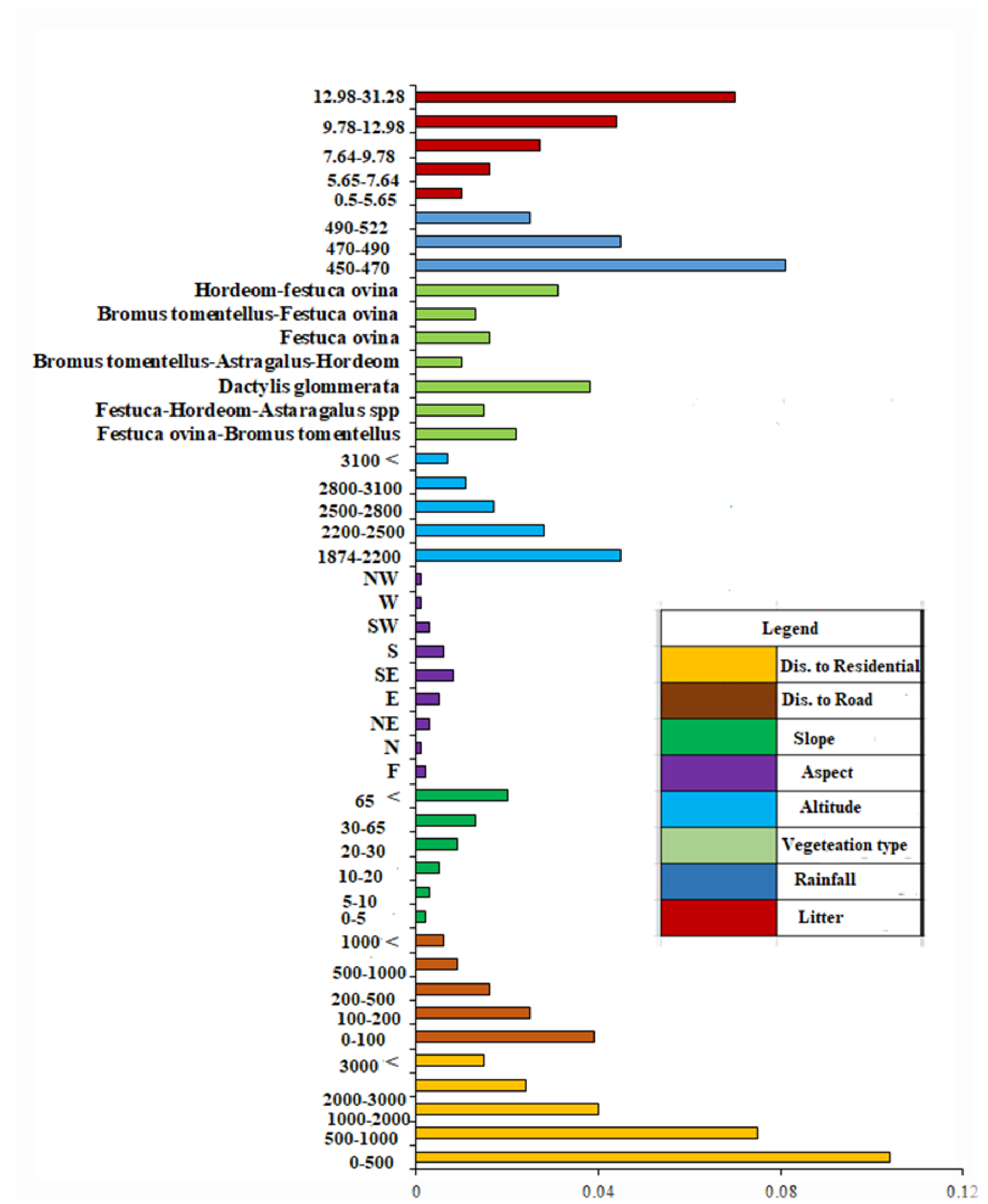

Figure 6. Weighting of criteria and sub-criteria using WLC method.

tion types of Bromus tomentolus-Festuca ovina and Festuca ovina-Bromus tomentolus are more located in drought regions (Fig. 4).

4.2 AHP results for the studied criteria

The results of the AHP process are presented in Fig. 5. The IR (inconsistency rate) was also calculated for pairwise comparison matrices, which indicates the consistency of the results. Since the IR value is 0.07, the consistency has been observed in the judgments.

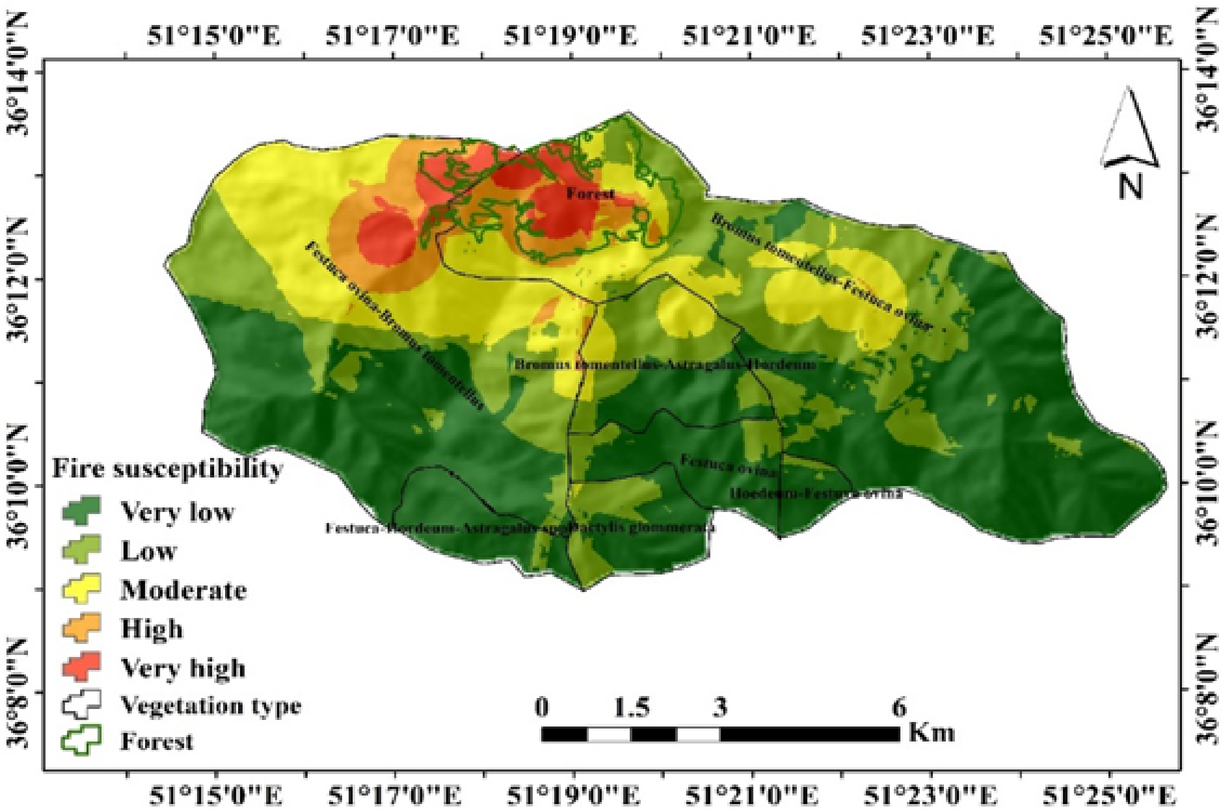

Figure 7. Fire susceptibility map in the rangeland vegetation types of the Siah Bisheh sub-basin in the Chalous Rud watershed.

According to the Fig. 5, the highest weight among the studied criteria is related to the distance from the village (0.249), litter (0.166), rainfall (0.151), vegetation type (0.145), altitude (0.108), distance from road (0.096), slope (0.053), and aspect (0.031).

4.3 Combining the final weight of the criteria

After obtaining the weight of the classes of each criterion and considering the weight of the pairwise comparison obtained by the experts as well as reviewing the scientific sources, the pairwise comparison matrix of the criteria and sub-criteria was applied by AHP method and using the WLC method, the final weights of each Criteria and sub-criteria were determined.

4.4 Zoning of rangeland fire susceptibility using AHP method

After transferring the obtained weights to the sub-criteria field in each information layer, using ArcGIS software, all eight integration criteria and the fire susceptibility raster map were prepared with a resolution of 30×30 m. The final fire susceptibility map was divided into five different classes, including (I, II, III, IV, V, represent very low, low, moderate, high, and very high hazard, respectively).

the fire susceptibility classes are presented in Fig. 7. According to the fire susceptibility map, the northern part of the study area has high and extreme fire susceptibility. Moreover, the results of the sensitivity of different vegetation types to fire are shown in Fig. 7. Based on the results, it was determined that Bromus tomentolus-Festuca ovina and Festuca ovina-Bromus tomentolus vegetation types were the most susceptible to fire.

4.5 Results of flood assessment

A comparative analysis was performed between the location floods and environmental parameters affecting the occurrence of floods, and based on that, the impact weight of each class of variables was determined. The impact weight of each of the studied variables using the frequency ratio method is presented in Table 2. As it can be seen from the results in Table 2, for the altitude, the maximum weight is related to the altitude class less than 500 m. For the slope percent factor, the $0-5\%$ class had the highest weight. For the land curvature, the maximum weight was related to the concave class. In the study of the distance from the river, the highest weight was related to the class of $0-500$ m from the river. For the rainfall, the $650-750$ mm rainfall class had a higher weight than the other classes. The weight of flooding increased with increasing the value of TWI, and the highest weight was recorded for the $12.34-20.07$ class. For the land use changes, the residential use had the highest weight compared to other uses. Soil study shows that the sandy soil has the highest weight compared to other classes. The lithology of the study area indicated that the Pel lithology had a higher weight than other classes.

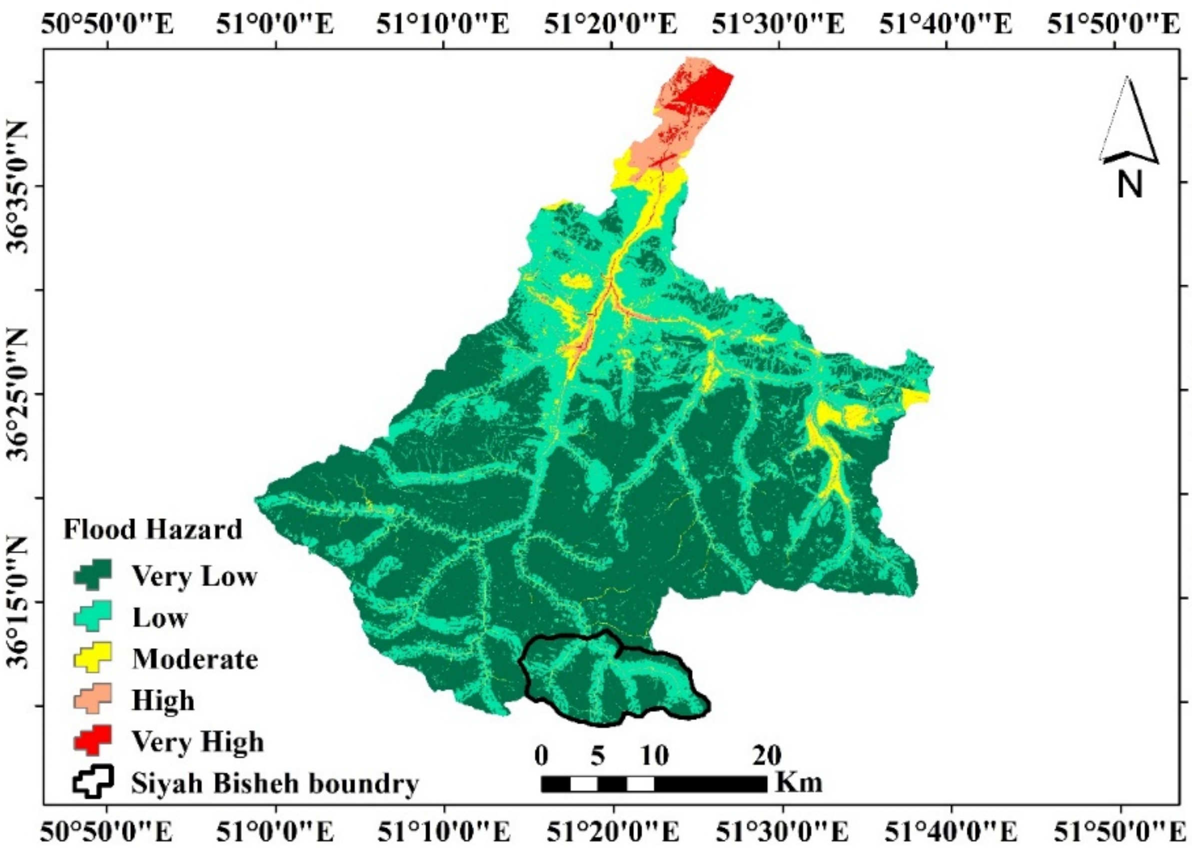

Figure 8. Determining the flood susceptibility in Chalous Rud Basin using frequency ratio method.

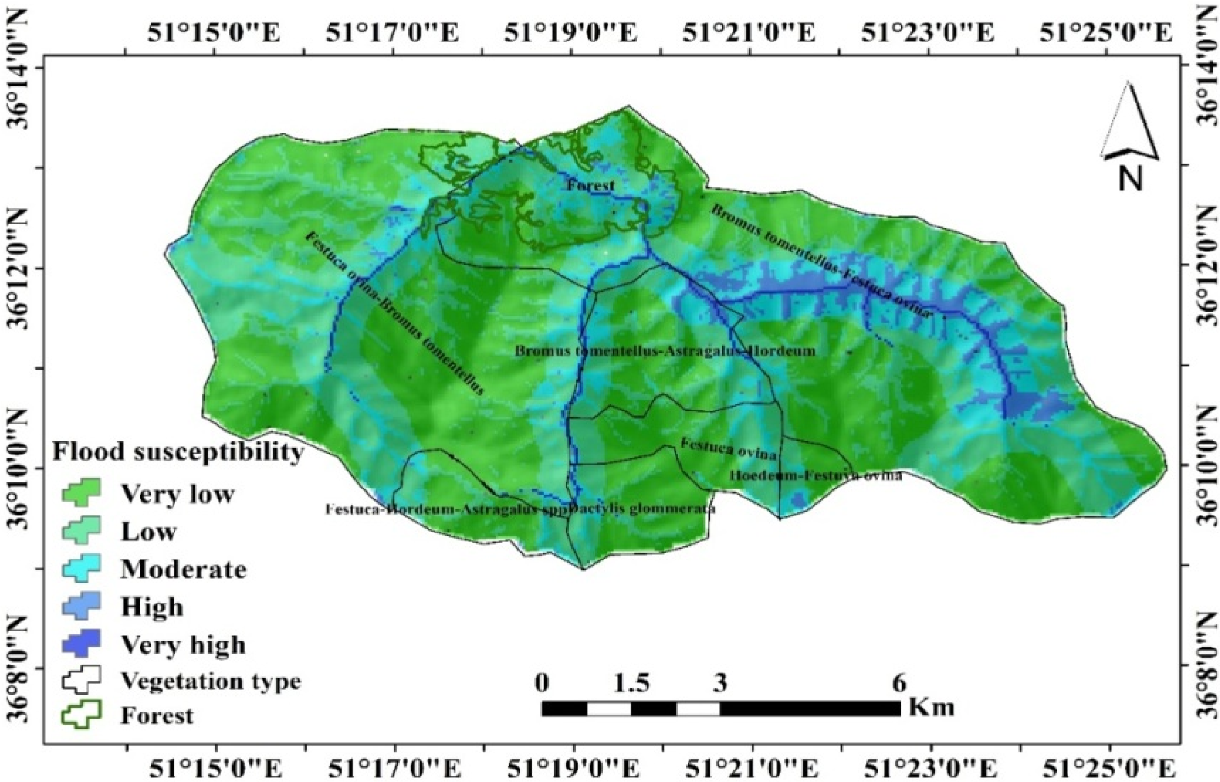

Figure 9. Flood susceptibility zoning based on frequency ratio method in Siah Bishe sub-Basin.

Table 2. Determining the weight of classes using the frequency ratio method.

Factor	Class	Pixel percent	No. flood event	Percent flood event	FR
Altitude (m)	< 500	4.77	38	71.7	15.04
	500 – 1000	9.85	15	28.3	2.87
	0 – 5	2.32	15	28.3	12.21
	5 – 10	2.27	7	13.21	5.82
Slope (%)	10 – 20	8.02	11	20.75	2.58
	20 – 30	13.40	11	20.75	1.54
	30 – 65	56.55	9	16.98	0.3
Curvature	Concave	16.95	17	32.07	1.89
	Flat	63.09	36	67.93	1.07
Dis. To river (m)	0 – 500	28.17	53	100	3.55
Rainfall (mm)	350 – 450	15.2	5	9.43	0.62
	450 – 550	64.07	23	43.4	0.67
	550 – 650	17.51	8	15.09	0.86
	650 – 750	2.59	17	32.08	12.37
TWI[1]	2.14 – 5.22	32.68	4	7.55	0.23
	5.22 – 6.62	42.66	14	26.42	0.62
	6.62 – 8.67	17.91	16	30.19	1.68
	8.67 – 12.34	5.36	5	9.43	1.75
	12.34 – 20.07	1.39	14	26.42	19.06
LU/LC[2]	Agriculture	14.26	25	47.17	3.31
	Residential	0.76	7	13.21	17.49
	Forest	32.76	7	13.21	0.4
	Range	49.85	12	22.64	0.45
	River	0.63	1	1.89	2.98
	Road	1.28	1	1.89	1.47
	Sand	0.15	1	1.89	12.68
Soil	Melisols	86.17	52	98.11	1.13
Lithology	K2l2	14.59	22	41.51	2.84
	Kbvt	6.82	5	9.43	1.38
	Ktzl	0.95	2	3.77	3.96
	Pel	0.19	2	3.77	20.38
	Qft1	0.29	1	1.89	6.46
	Qft2	2.63	15	28.30	4.26
	TRJs	10.53	5	11.32	1.07

4.6 Flood susceptibility map

The weights obtained for each class were applied in the relevant layers in the GIS and the flood susceptibility map was prepared for the Chalous River Basin using overlaying functions. Using the Natural Break method in ArcGIS 10.5, the flood susceptibility map was divided into five classes: very low, low, moderate, high, and very high (Fig. 8). After preparing the flood susceptibility map of Chalous Rud, the flood susceptibility map of the Siah Bisheh sub-basin, which is located in the southern part of the Chalous Rud Basin, was extracted from this map using the frequency ratio method (Fig. 9). According to the flood susceptibility map of Siah Bisheh, most of the basin has low and very low flood susceptibility, and the areas around waterways have high and very high flood susceptibility.

4.7 Models evaluation

The AUC shows the system prediction quality to model the occurrence and non-occurrence of predetermined events [33]. According to the obtained results, the frequency ratio method has an efficiency coefficient of 0.98 based on the ROC criterion.

4.8 The integrated map of risk management

To prepare the final risk map of Siah Bisheh sub-basin, the maps were standardized, and then, the final risk map was obtained from the integration of drought, fire, and flood risk maps and ategorized into five classes in terms of risk (Fig. 10). According to the final risk map, the central and northern parts of the basin showed a high and very high susceptibility in terms of multi-hazards (Fig. 10).
Multi-hazards maps for the Siah Bisheh rangelands are also shown in Fig. 11. It shows that multi-hazards areas often include the Bromus tomentolus-Festuca ovina and

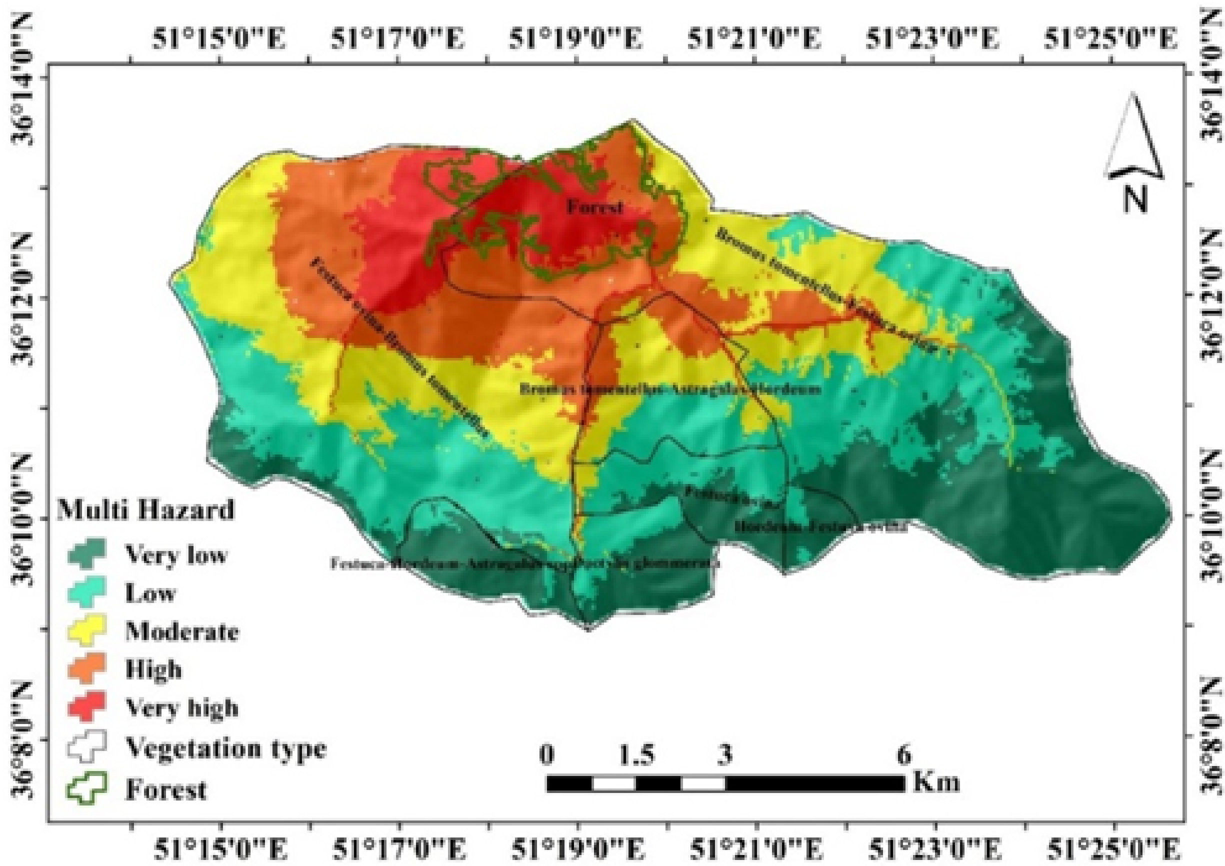

Figure 10. Hazard zonation map of vegetation types in rangelands of the Siah Bishe sub-basin of the Chalous Rud watershed.

Festuca ovina-Bromus tomentolus vegetation types, so in case of hazard, a lot of damage will be done to these species. Also, the results showed that the vegetation types Bromus tomentolus-Festuca ovina and Festuca ovina-Bromus tomentolus have multi-hazards of drought, fire, and flood in combination and separately; moreover, these vegetation types compared to other types in the region have the greatest impact on the risks of fire, flood, and drought.

5. Discussion

Drought has many economic, social, and environmental costs, and most of its effects are exacerbated by human activities [10]. The zoning of drought with the SPI index in the Siah Bisheh region showed that the SPI ranged from –2.14 to -0.76, indicating a severe to relatively severe drought. In the absence of risk reduction systems, environmental hazards such as drought have the potential to become a devastating disaster for human communities, causing significant damage to agriculture, natural resources, and water resources. Therefore, the risk of losses caused by drought can be significantly reduced by knowing and predicting the drought condition and the extent of its severity. Therefore, by knowing the dry months of the year (June, July and August), it is possible to apply management programs such as reducing the number of livestock in these seasons or complementary programs such as supplying hand feed forage or long-term grazing capacity policy.

In general, the rangelands of the study area in terms of vegetation types include two general types of grassland and grassland-shrubland. As a rule, grasslands are more sensitive to drought than grassland-shrubland and react sooner. Among grassland species, some species such as Dactylis glommerata and Festuca ovina are more sensitive and react sooner than species such as Hoedeum bulbosum. Therefore, rangeland management should be planned based on vegetation types and their degree of susceptibility to drought. Rangelands close to residential areas in this area are more prone to fire because the activity of the human factor is higher, which is consistent with the findings of [34]. Litter is another factor influencing fire sensitivity. The risk of fire is higher where vegetation causes a large number of leaves to accumulate since plant litter is very susceptibility to fire [35]. Rainfall indirectly affects the fire by affecting the amount and type of vegetation.

The risk of fire in the species belonged to Gramineae family is higher than other families, so the vegetation community consisting of this family had a higher score than forbs and shrubs plants. Therefore, in the vegetation composition, the higher the number of species from the Gramineae family (especially tall grasses) with higher canopy cover percentage, the higher risk of fire will be expected [36]. About altitude, the probability of spreading fire is higher at lower altitudes since residential areas and human access are higher in these areas. In relation to the

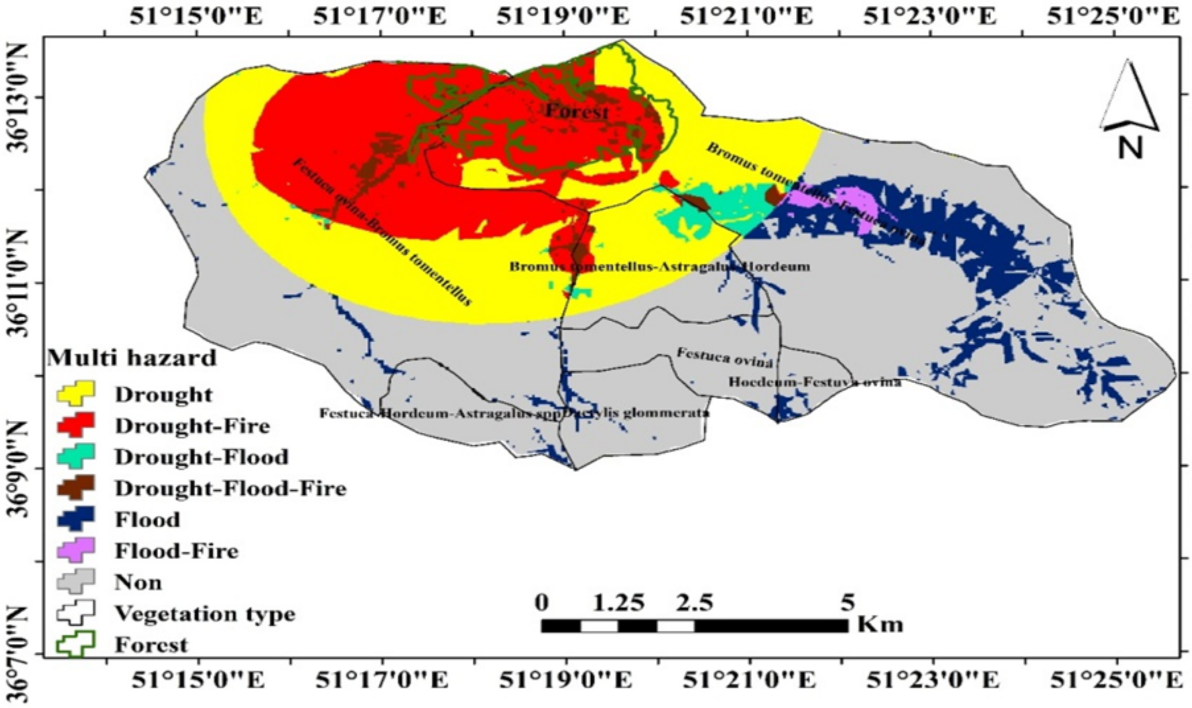

Figure 11. The multi-hazards map of Siah Bishe sub-basin.

distance from road, the maximum fire rate is at a distance of less than 100 m, and the probability of fire is lower at longer distances; this is due to the presence of tourists and accidental or deliberate fires [37].

In the case of slope aspects, considering that the sunlight is maximum in the southern and western aspects, the weight of the classes in these aspects increases compared to the eastern and northern aspects receiving less light [19]. However, less biomass on these slopes can also reduce the risk of fire, so it must be acknowledged that a single factor can never clearly reveal the risk, and therefore, a set of factors is considered. Therefore, the final weight of the criteria is applied in this field, and combining all the weighted maps can be closer to reality in producing the final fire risk management map of the region. So, an area that has a high risk in terms of slope or litter may have a low to medium risk in the final map.

The amount of vegetation and litter is the most important factor in the occurrence of fires in the rangelands. Also the amount of vegetation has a significant effect on the occurrence of flood (positive effect) and fire (negative effect). The vegetation factor has the highest impact on the fire risk followed by human layers (road, residential, landuse) and so on. Management must be dynamic and intelligent. This means that the increase in grazing pressure should be considered in part of the rangeland management, where there is a possibility of fire, even in droughts. Conversely, the decrease in grazing pressure should be considered by the rangeland manager in part of the rangeland where there is a possibility of flooding, even in wetlands [38]. The results of this study showed that multi-criteria decision making methods are a suitable tool to determine and identify areas at risk of fire risk; that these findings are consistent with the results of [39–41].

The altitude class < 500 m had a higher weight in floods compared to other classes, which is consistent with the results of [42] because in areas with high altitude and slope, water accumulation is less and water is drained quickly. Therefore, due to the lower altitude and slope $(0-5\%)$ in the downstream areas, the runoff height increases and increases the probability of flood damage. According to the results of the distance from the river, the highest flooding was recorded for the $0-500$ m class. This can be attributed to the distance from the river, and the smaller the distance from the river, the greater the possibility of flooding, which is consistent with the results of [43]. There is a direct relationship between rainfall and the occurrence of flooding in the study area. Only the $88-750$ mm class does not follow this rule, in which the interference of other parameters has probably been effective and reduced its score. According to the results of the TWI, the rate of flooding increases with the increase of this index because the highest TWI is near the river, which causes an increase in flooding and high weight of this index. The results of the land-use factor showed that residential land use had a higher weight than other land uses. In areas where humans have caused the land-use change and impenetrable lands by building residential and road areas, the susceptibility of the area to flooding has been increased, which is in agreement with the results of [44].

The results of the frequency ratio method showed that this method has a good efficiency in determining flood risk areas, which is consistent with the findings of [20,43,45]. The results of the final risk map showed that the northern parts and center of the basin were very susceptible to the fire and drought all risks. The outlet water-ways are also located in the northern part of the basin, around which the susceptibility to floods is high. Bromus tomentolus-Festuca ovina and Festuca ovina-Bromus tomentolus vegetation types are most susceptible to multi-hazards. The results also showed that in Bromus tomentolus-Festuca ovina and Festuca ovina-Bromus tomentolus community, multi-hazards of drought, fire and flood are active separately. These plant types have the greatest impact against fire, flood and drought hazards compared to other types in the region; one of the most important reasons for this is the proximity of these areas to the outlet of the watershed and residential areas.

6. Conclusion

Multi-hazard analysis, due to the use of a wide range of data provides a more realistic model of the natural environment and allows the selection of the best management strategies. In this regard, various studies focusing on spatial approaches by analyzing different data examined how a combination of environmental hazards extention and determined their level of risk and vulnerability. This study was conducted to determine the multi-hazard map of floods, droughts, and fires in the Siah Bisheh of Mazandaran province. The study of drought phenomenon from the standardized precipitation index (SPI) showed that the study area has severe to moderate drought, but only a small part of the north of the study area has a severe drought situation. Vegetation types Bromus tomentolus-Festuca ovina and Festuca ovina-Bromus tomentolus are located in areas with severe drought susceptibility. The results of the fire susceptibility map showed that the distance from the road, rainfall, and litter factors have the greatest impact on fire in the study area and the northern part is sensitive to fire. The results of the flood probability map also showed that only the areas along the Chalous rud river have the probability of floods and the probability of floods in other areas is low. The final multi-hazard map prepared using the FR method showed that the central and northern parts of the Siah Bisheh sub-basian are highly susceptible to all three hazards. The presence of natural hazards in the central and northern parts of the study area increases the probability of extensive human and financial damage in these areas. Therefore, it is suggested that the process of prioritization, resilience, and creation of solutions and scenarios to deal with crises should be considered by the executive departments.

Conflict of interest statement:
The authors declare that they have no conflict of interest.

References

[1] IPCC. *Managing the Risks of Extreme vents and Disasters to Advance Climate Change Adaptation, Special Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press; UK, 2012.

[2] G. T. Miller and S. Spoolman. *Environmental Sciences*. Cengage Learning, 14th edition, 1997.

[3] M. C. Stambaugh, R. P. Guyette, R. Godfrey, E. R. Mcmurry, and J. M. Marschall. "Fire, drought, and human history near the western terminus of the Cross Timbers, Wichita Mountains, Oklahoma, USA ". *Fire Ecology*, **5**:51–65, 2009.

[4] J. F. Vallentine. *Grazing management in rangeland*. Academic Press, 2th edition, 2001.

[5] S. W. Carleton and S. R. Loftin. "A response of 2 semiarid grasslands to cool-season prescribed fire". *Journal of Range Management*, **53**:52–61, 2000.

[6] L. H. Cassie, J. E. Smith, and K. Cromack. "Invasive plant species and soil microbial response to wildfire burn severity in the cascade range of oregon". *Applied Soil Ecology*, **42**:150–159, 2009.

[7] R. B. Kristofor. "Soil physiochemical changes following 12 years of annual burning in humid-subtropical tall grass prairie: a hypothesis". *Acta Ecologica*, **30**:407–413, 2006.

[8] G. Dale, R. Brockway, G. Gatewood, and R. B. Paris. "Restoring fire as an ecological process in short grass prairie ecosystem: initial effects of prescribed burning during the dormant and growing seasons". *Journal Environmental Management*, **65**:135–152, 2002.

[9] R. Costache, Q. B. Pham, A. Arabameri, D. C. Diaconu, I. Costache, A. Crăciun, N. Ciobotaru, M. Pandey, A. Arora, S. Ajim Ali, B. T. Pham, H. Nguyen, H. A. Tuan, and M. Avand. "Flash-flood propagation susceptibility estimation using weights of evidence and their novel ensembles with multicriteria decision making and machine learning". *Geocarto International*, **37**:276–282, 2021.

[10] G. Zhao, B. Pang, Z. Xu, D. Peng, and L. Xu. "Assessment of urban flood susceptibility using semi-supervised machine learning model". *Science of the Total Environment*, **659**:940–949, 2019.

[11] M. Avand, A. Kuriqi, M. Khazaei, and O. Ghorbanzadeh. "DEM resolution effects on machine learning performance for flood probability mapping". *Journal of Hydro-environment Research*, **40**:1–16, 2021.

[12] W. Jonkhoff. "Flood risk assessment and policy in the Netherlands. Green Cities; new approaches to confronting climate change". *OECD workshop proceeding, LAS Palmas de Gran Canaria, Spain*, :23, 2009.

[13] C. Cao, P. Xu, Y. Wang, J. Chen, L. Zheng, and C. Niu. "Flash flood hazard susceptibility mapping using frequency ratio and statistical index methods in coalmine subsidence areas". *Sustainability*, **8**:948, 2016.

[14] C. J. Van Westen and S. Greiving. *Environmental Hazards Methodologies for Risk Assessment and Management*. Iwa Pub, 1th edition, 2017.

[15] H. Moradi, M. T. Avand, and S. Janizadeh. "Landslide susceptibility survey using modelling methods". *Spatial Modeling in GIS and R for Earth and Environmental Sciences*, **2019**:259–275, 2019.

[16] S. Shahrokhi Sarduo, R. Bagheri, H. Ahmadi, and F. Mahdavi. "Investigation of fire effects on physical and chemical characteristics of soil in Golandaz Dehbekri rangeland". *Journal of Rangeland Science*, **2**:465–471, 2012.

[17] B. T. Pham, A. Jaafari, M. Avand, N. Al-Ansari, T. Dinh Du, H. P. H. Yen, and I. Prakash. "Performance evaluation of machine learning methods for forest fire modeling and prediction". *Symmetry*, **12**:1022, 2020.

[18] B. T. Pham, T. V. Phong, M. Avand, N. Al-Ansari, S. K. Singh, H. V. Le, and I. Prakash. "Improving voting feature intervals for spatial prediction of landslides". *Mathematical Problems in Engineering*, **2020**:4310791, 2020.

[19] M. Leuenberger, J. Parente, M. Tonini, M. G. Pereira, and M. Kanevski. "Wildfire susceptibility mapping: Deterministic vs. stochastic approaches". *Environmental modelling and software*, **101**:194–203, 2018.

[20] M. J. Lee, J. E. Kang, and S. Jeon. "Application of frequency ratio model and validation for predictive flooded area susceptibility mapping using GIS". *IEEE International geoscience and remote sensing symposium, IGARSS, Munich, Germany*, :895–898, 2012.

[21] H. R. Pourghasemi, A. Gayen, M. Panahi, F. Rezaie, and T. Blaschke. "Multi-hazard probability assessment and mapping in Iran". *Science of the Total Environment*, **692**:556–571, 2019.

[22] H. D. Skilodimou, G. D. Bathrellos, K. Chousianitis, A. M. Youssef, and B. Pradhan. "Multi-hazard assessment modeling via multi-criteria analysis and GIS: a case study". *Environmental Earth Sciences*, **78**:47, 2019.

[23] S. K. Aksha, L. M. Resler, L. Juran, and L. W. Jr Carstensen. "A geospatial analysis of multi-hazard risk in Dharan, Nepal". *Geomatics, Natural Hazards and Risk*, **11**:88–111, 2020.

[24] H. R. Pourghasemi, N. Kariminejad, M. Amiri, M. Edalat, M. Zarafshar, T. Blaschke, and A. Cerda. "Assessing and mapping multi-hazard risk susceptibility using a machine learning technique". *Scientific Reports*, **10**:1–11, 2020.

[25] V. H. Nhu, A. Shirzadi, H. Shahabi, W. Chen, J. J. Clague, M. Geertsema, and B. T. Pham. "Shallow landslide susceptibility mapping by random forest base classifier and its ensembles in a Semi-Arid region of Iran". *Forests*, **11**:421, 2020.

[26] S. Ghasemi Nejad, S. Soltani, and A. Sofyanian. "Drought risk assessment of Isfahan province". *Journal of Agricultural Science and Technology and Natural Resources, Soil and Water Sciences*, **68**:213–225, 2014.

[27] P. Mahmoudi, A. Rigi, and M. M. Kamak. "Evaluating the sensitivity of precipitation-based drought indices to different lengths of record". *Journal of Hydrology*, **579**:124181, 2019.

[28] K. P. Vadrevu, A. Eaturu, and K. Badarinath. "Fire risk evaluation using multicriteria analysis-a case study". *Environmental Monitoring and Assessment*, **166**:223–239, 2010.

[29] M. Mesdaghi. *Management of Iran's rangelands*. Imam Reza University, 1995.

[30] J. Imani, H. Arzani, and M. A. Zare Chahouki. "Comparison of the efficiency of methods for estimating the density of three rangeland species Bromus tomentellus, Festuca ovina, and Prangos ferulacea (Case study: Saral rangelands of Kurdistan)". *Rangeland and Watershed Management*, **66**:179–190, 2013.

[31] H. Hong, A. Jaafari, and E. K. Zenner. "Predicting spatial patterns of wildfire susceptibility in the Huichang County, China: An integrated model to analysis of landscape indicators". *Ecological Indicators*, **101**:878–891, 2019.

[32] S. Yousefi, M. Avand, P. Yariyan, H. J. Goujani, R. Costache, S. Tavangar, and J. P. Tiefenbacher. "Identification of the most suitable afforestation sites by Juniperus excels specie using machine learning models: Firuzkuh semi-arid region, Iran)". *Ecological Informatics*, **65**:101427, 2021.

[33] M. Avand, H. R. Moradi, and M. Ramazanzadeh Lasboyee. "Spatial prediction of future flood risk: an approach to the effects of climate change". *Geosciences*, **11**:25, 2021.

[34] J. Ahmadi, M. Farzam, and A. Lagzian. "Investigating effects of a prescribed spring fire on symbiosis between Mycorrhiza fungi and range plant species". *Journal of Rangeland Science*, **7**:138–147, 2017.

[35] J. R. De Long, E. Dorrepaal, P. Kardol, M. C. Nilsson, L. M. Teuber, and D. A. Wardle. "Understory plant functional groups and litter species identity are stronger drivers of litter decomposition than warming along a boreal forest post-fire successional gradient". *Soil Biology and Biochemistry*, **98**:159–170, 2016.

[36] R. S. Ajin, A. M. Loghin, P. G. Vinod, and M. K. Jacob. "Forest fire risk zone mapping using RS/GIS techniques: A study in Achankovil forest division, Kerala". *India Journal of Earth Environment and Health Sciences*, **2**:109–115, 2016.

[37] N. J. Gralewicz, T. A. Nelson, and M. A. Wulder. "Factors influencing national scale wildfire susceptibility in Canada". *Forest Ecology and Management*, **265**:20–29, 2012.

[38] D. M. Anderson. "Seasonal stocking of Tobosa managed under continuous and rotation grazing". *Journal Range Management*, **41**:78–83, 1998.

[39] D. A. Driscoll, M. Bode, R. A. Bradstock, D. A. Keith, T. D. Penman, and O. F. Price. "Resolving future fire management conflicts using multicriteria decision making". *Conservation Biology*, **30**:196–205, 2016.

[40] L. M. Andersen and M. M. Sugg. "Geographic multi-criteria evaluation and validation: A case study of wildfire vulnerability in Western North Carolina, USA following the 2016 wildfires". *International Journal Disaster Risk Reduction*, **39**:101–123, 2019.

[41] M. A. Ardakani, M. Rajabi, and A. S. Ardakani. "Forest wildfire potential zoning using multi-criteria decision-making methods ". *Geography and Environmental Planning*, **26**:171–198, 2016.

[42] D. S. Fernandez and M. A. Lutz. "Urban flood hazard zoning in Tucuman Province, Argentina, using GIS and multicriteria decision analysis". *Engineering Geology*, **111**:90–98, 2010.

[43] M. Avand, H. R. Moradi, and M. Ramazanzadeh lasboyee. "Spatial modelling of flood probability using Geo-environmental variables and machine learning models, case study: Tajan watershed, Iran". *Advances in Space Research*, **67**:3169–3186, 2021.

[44] Q. T. Bui, Q. H. Nguyen, X. L. Nguyen, V. D. Pham, H. D. Nguyen, and V. M. Pham. "Verification of novel integrations of swarm intelligence algorithms into deep learning neural network for flood susceptibility mapping". *Journal of Hydrology*, **581**:124379, 2020.

[45] P. Yariyan, M. Avand, R. A. Abbaspour, A. Torabi Haghighi, R. Costache, O. Ghorbanzadeh, S. Janizadeh, and T. Blaschke. "Flood susceptibility mapping using an improved analytic network process with statistical models". *Geomatics, Natural Hazards and Risk*, **11**:2282–2314, 2020.