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Detection of fire-prone areas using the PROMETHEE decision-making method (case study: watershed basin of Shourdareh, Golestan Province, Iran)

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Abstract:

Decision makers in fire management are faced with many alternatives and criteria. In decision making about the event of fire, various criteria including technical, economic, social and environmental criteria have to be considered simultaneously. Management to prevent and control fires in forests and rangelands will be effective if fire-prone areas and management identify and focus on these critical areas. Therefore, the present study was conducted in 2022 to identify fire-prone areas using PROMETHEE decision-making method in the watershed basin of Shourdareh, Golestan province, Iran. In the present study, according to fire expert's opinion, 29 different environmental and social criteria were used to detect of fire-prone areas. In this regard, The Shannon entropy method was used to weigh the criteria. Then, according to the weight and value of each criterion for each sub-basin, the data were analyzed using the PROMETHEE II technique. Based on the results of PROMETHEE II technique, sub-basins of Gh3, Gh8 and Gh1 with Phi values of 0.335, 0.148 and 0.239, respectively, were in high susceptibility to fire class. While rangelands of sub-basins Gh2, Gh5, Gh6 and Gh7 with Phi values of -0.220, -0.117, -0.136 and -0.241 were in the low susceptibility to fire class. Sub-basins of Gh9, Gh10 and Gh11 with Phi values of 0.114, -0.078 and 0.025 were in the moderate susceptibility to fire class. To evaluate the method, the results of this study were compared with results of actual fire areas that prepared by the department of natural resources of Golestan province, Iran. According to the obtained kappa coefficient with the value of 0.82, the method had good and acceptable accuracy. Therefore, since the proposed method was a reliable screening method to identify areas at risk of fire, it can help the authorities in carrying out preventive activities.

Keywords: Fire; Prioritization; Shannon weighting; Shourdareh; Golestan Province; Iran

1. Introduction

Fire causes extensive damage to rangelands' ecosystems in arid and semi-arid regions (Asadian et al., 2022). Fire in forests and rangelands is an important criterion in the destruction of natural resources and has devastating impact on the economic, social and environmental aspects of development (Zhang et al., 2016; Akinola and Adegoke, 2019). Fires may destroy soil structure to reduce nutrient and water availability for plants (Ahmadi et al., 2017). Fires reduce the forage production for livestock (Pournemati et al., 2021). In addition to human causes, these fires include lightning, global warming and climate change, improper management, insufficient precipitation, hot winds, bed buildup and friction between dry beds are some of the factors that can cause fires in rangelands and forests (Chuvieco et al., 2012; Ganteaume et al., 2013; Rahimi et al., 2020).

Fire hazard is an important concept that is significantly formed in fire management planning (Gai et al., 2011). Therefore, having an effective prevention strategy to deal with recurrent and destructive fires is essential (Sakellariou et al., 2019). Since Iran is located in the dry belt of the Earth as the high-pressure subtropical zone, atmospheric conditions are provided for fires in forests and rangelands. On the other hand, human causes fire or deliberate fires to convert forest and rangeland lands into agriculture leading to fires in forest and rangeland areas and causes irreparable damage to ecosystems and ecological areas every year.

Decision makers face many options and criteria in rangeland management and planning. One of their most important challenges is choosing the best and most appropriate option and prioritizing the options according to the defined criteria. In this regard, multi-criteria decision-making techniques could be a good solution to solve such problems. In an efficient management and decision on natural resource projects, various indicators including technical, economic, social and environmental indicators must be considered simultaneously. One of the strongest and most effective multi-criteria decision-making methods is the PROMETHEE[1] II method. The PROMETHEE method is easily able to apply criteria with different measurement scales and define six separate functions in proportion to the information and standard scale; so, in multi-criteria decisions where the criteria usually have different scales, it is a suitable method for decision making (Chou et al., 2004). PROMETHEE is compatible and efficient in situations where many options have to be evaluated based on several quantitative, qualitative and often contradictory criteria (Albadvi et al., 2007). The PROMETHEE method is able to use criteria with different measurement scales without need to scale the criteria. The PROMETHEE method has been used successfully in a wide range of real-world applications such as water resources management, health center prioritization, wastewater facility location, and watershed vulnerability (Banias, 2010; Huang and Tsai, 2010; Asghryzadeh and Nasrallahy, 2007). In Ghana, Darkwah et al. (2012) used the PROMETHEE method to rank the performance of their corporate operators. In their study, five criteria were ranked in the form of four options using the PROMETHEE method. The results showed that the PROMETHEE decision-making method was an efficient method in solving classification problems (Darkwah et al., 2012). The PROMETHEE method has also been described as one of the most efficient MCDM[2] supersonic techniques for selecting the optimal flood reduction design in Athens (Maragoudaki and Tsakiris, 2005). In a study to plan and manage water resources in Romania, Anagnostopoulos et al. (2005) using PROMETHEE method showed that it was an efficient method in water resources management (Anagnostopoulos et al., 2005). Eskandari et al. (2013) used two methods of fuzzy hierarchical analysis and correlation in order to develop a model for the risk of fire and prepare a potential fire hazard map in the part of the forests of northern Iran. The parameters included four main criteria (topography, biological, climatic and human) and 12 sub-criteria. After preparing the maps of all criteria and determining the weight of them by both methods, fire risk models were obtained. Then, the maps of all effective criteria overlapped by considering their weight according to the fuzzy hierarchical analysis method. Enoh et al. (2021) in Niger prepared the final forest fire risk zone map using some criteria as land cover, aspect, elevation, slope and proximities to roads and settlements in the ArcGIS environment. Dehghan (2017) compared the different multi-criteria decision making methods to determine suitable areas for implementing some water and soil protection activities in Gonabad watershed, Khorasan Razavi province, Iran. He stated that the results of hierarchical analysis, network analysis and PROMETHEE II were close to each other.

Decision makers in fire management and planning are faced with many options and criteria. One of their most important challenges is to identify the most vulnerable areas and prioritize areas according to defined criteria. In this regard, multi-criteria decision-making techniques can be a good solution to solve such problems. In order to effectively manage and make the right decision in the event of a fire, various criteria including technical, economic, social and environmental criteria must be considered simultaneously. Management operations to prevent and control fires in forests and rangelands are effective when fire-prone areas are identified and remedial and management measures are focused on these areas. Therefore, the present study was conducted with the aim of identifying fire-prone rangelands in order to properly manage these areas using PROMETHEE decision making method in Shourdareh basin of Golestan province, Iran.

2. Materials and methods

2.1 Study area

The study area is known as Shourdareh and is located in Golestan province, Iran. The study area lies between 55°27′ to 55°40′ E and 36°56′ to 37°5′ N (Akhzari et al., 2013). The eastern part of the basin is located in Maraveh Tappeh County and the rest is located in Kalaleh County. The villages of Qarnaq and Aq Chatal are located in the Shourdareh basin. It has 11 sub-basins including Gh1 to Gh11. The area of the basin is 120.74 km^2 (Figure 1).

2.2 Research method

The current research was carried out as following steps. The schematic diagram of research method is presented in Figure 2.

2.2.1 Step 1: Determining the effective criteria for rangeland fire

At first, based on the review of scientific sources and available information and data that can be collected, a list of criteria was prepared and given to fire experts. Based on the research method, 10 experts from the department of natural resources with more than 10 years of work experience and 15 university professors in the fields of rangeland and forestry were selected to choose the efficient criteria. Finally, 29 criteria were selected for this research. The

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[1] Preference Ranking Organization Method For Enrichment Evaluation.

[2] Multi-Criteria Decision-Making.

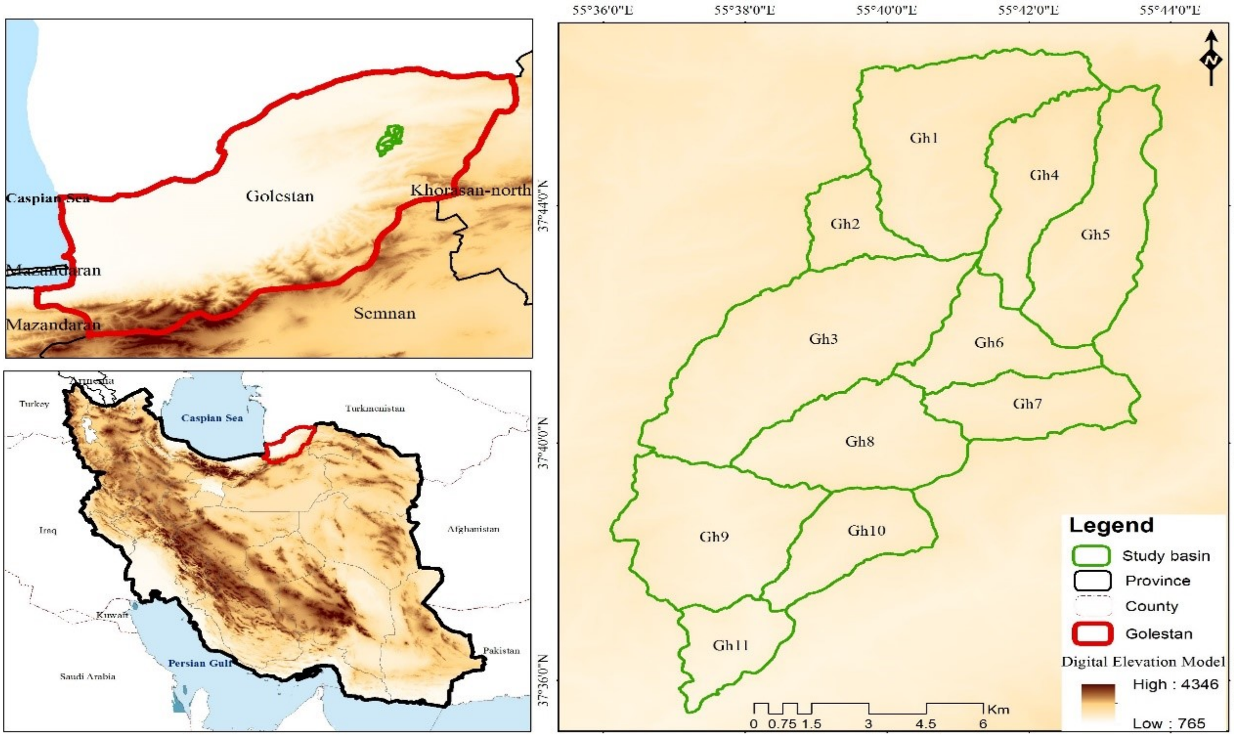

Figure 1. Geographical location of Shourdareh watershed in Iran and Golestan province, Iran.

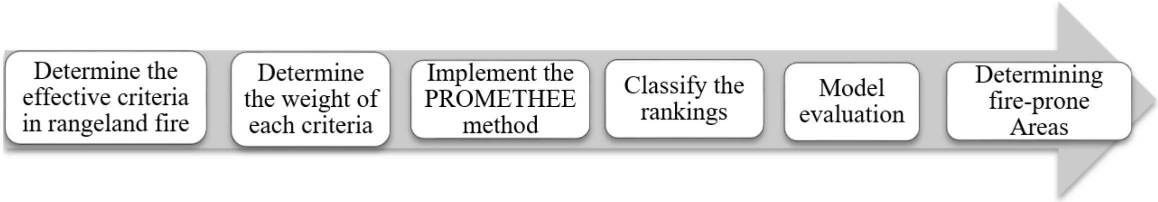

Figure 2. The schematic diagram of PROMETHEE decision-making method.

following criteria were examined as effective criteria in rangeland fires due to the high coefficient of variation in the basin:

Average annual and seasonal precipitation:

In order to estimate the amount of precipitation in Shourdareh basin, 24-hour precipitation information of Kachik climatology station was provided.

Slope and altitude:

The slope and elevation information layer of the region was recorded and used in a GIS software environment and the slope and elevation classes of the area were determined.

Annual and seasonal temperature:

In order to determine the annual and seasonal temperature of the studied area, the data of synoptic stations of Shourdareh basin were collected and used.

Relative humidity:

To obtain the relative humidity parameter in the study area, the relationship between the relative humidity parameters and temperature in the Kachik climatology station was used.

Evaporation:

Evaporation was determined using the evaporation pan using the Equation 1. The amount of evaporation from the free surface of water was estimated (Doorenbos and Pruitt, 1977):

$$ET_0 = K \times E_{\text{pan}} \tag{1}$$

Where:
ET_0 = reference evapotranspiration (mm/day),
E_{pan} = pan evaporation (mm/day),
K = coefficient of evaporation pan.

Type of climate:

The type of climate was determined by the Emberger method (Emberger, 1943):

$$Q_2 = \frac{2000P}{M^2 - m^2} \tag{2}$$

Where:
Q_2 = Climate coefficient of Emberger,
M = Average maximum temperatures in the hottest month

of the year (kelvin),
m = Average minimum temperatures in the coldest month of the year (kelvin),
P = Annual precipitation (mm).

Plant types:

Based on field operations in 11 sub-basins, the vegetation type of Shourdareh watershed was classified by physiognomy-floristic method based on two or three dominant (permanent) species (Mesdagi, 2003).

Rangeland production:

In this study, according to field operations in 11 sub-basins, field sampling was performed based on random-systematic method. The sampling units were plots located along linear transects. For this purpose, according to the conditions of the region, in each plant type, four 100 m transects in the slope direction and two 100 m transects perpendicular to the slope direction were established in the representative area of each type. Then, 10 plots of 2 m^2 were installed on each transect (Arzani, 1997). Then, the amount of production in each plot was measured by cutting and weighing method (Mesdagi, 2003).

Rangeland condition:

Based on field operations in 11 sub-basins, a 4-factor method was used to determine the rangeland condition. To determine the rangeland trend, the scales method was used (Mesdagi, 2003).

Topographic Wetness Index (TWI):

Topographic Moisture Index (TWI) is another topographic factor that was prepared and used based on the following equation (Sorensen et al., 2006):

$$TWI = \ln\frac{\alpha}{\tan\beta} \tag{3}$$

Where:
α is the area of the drained area and
β is the slope (tan) angle in degrees.
TWI plays an important role in soil moisture and slope stability. Then, the TWI map was prepared using a digital elevation model map in SAGA GIS software with 3 classes.

Land use map:

In order to prepare the land use map of the basin and identify and separate the boundaries of arable lands from rangelands, reference images of satellite images from Google Earth software were used along with Landsat images. Then, this map was modified based on the geomorphological map and field visit and the final map was prepared.

Village and population density:

In the study of the number of population and households in the villages of the basin determined, the results of the Golestan health network and the statistics of health houses in the villages in the basin in 2017 were used.
It is worth mentioning that for other criteria, the scientific reports of Golestan Province Natural Resources Department were used.

2.2.2 Step 2: Determining the weight of each of the criteria

In the second step of the research, the weight of each criterion was calculated based on the Shannon entropy method as follows:

Decision super matrix:

First, the decision super matrix was formed with degree m×n. This super matrix includes m rows (11 sub-basins of Shourdareh watershed) and n columns (slope, evaporation, vegetation, etc.). Then, the weight of the indices was calculated using the Shannon entropy method (Zhi-hong et al., 2006).

2.2.3 Step 3: Implement the PROMETHEE method

In the third step of the research, based on the weights obtained from Shannon entropy method, PROMETHEE method was implemented using Visual PROMETHEE software (Kuncova and Seknickova, 2022).

2.2.4 Step 4: Classify the rankings

In the fourth step of the research, the classification of rankings was performed using the K-means clustering method (Chahoki Zare, 2012). The obtained rankings according to PROMETHEE technique for each sub-basin were classified using SPSS18 software package.

2.2.5 Step 5: Model evaluation

In order to compare real fires with fire-prone areas resulting from this study, the result of burned areas prepared by the General Department of Natural Resources of Golestan Province was used. The Kappa statistical coefficient was used to evaluate and validate the result of fire-prone areas of the Shourdareh watershed in Golestan province, Iran using the PROMETHEE II technique (Cohen, 1960) with the result of burned areas prepared by the General Department of Natural Resources of Golestan Province, Iran.

3. Result

3.1 Weighting criteria

The results of weighting of each criterion based on the Shannon entropy method are presented (Table 1). Based on the results, the variables of annual temperature and annual precipitation with the weight of 0.1488 and 0.1019, respectively, had the highest weight and the criteria of rangeland condition with the weight of 0.00001 had the lowest weight.

3.2 Weighting matrix

The data in Table 1 are without scale, the weighted matrix was formed for 11 sub-basins of the Shourdareh region of Golestan province, Iran presented in Table 2.

3.3 Fit functions

The proportional function of most criteria is the V-shape function because the V-shape functions are the best choice for most quantitative criteria, and it is a special case of the

Table 1. Criteria weighting matrix based on the Shannon entropy method.

Variables	The entropy of each criteria	Degree of deviation	Normalized weight	Rank
	E_j	d_j	W_j	
Elevation (m)	0.9916	0.00838	0.00125	19
T mean (summer) (°C)	0.9999	0.00009	0.00001	28
T mean (year) (°C)	0.0038	0.99616	0.14886	2
Precipitation (summer) (mm)	0.9998	0.00022	0.00003	21
Precipitation (spring) (mm)	0.9998	0.00022	0.00003	23
Precipitation (year) (mm)	0.3177	0.68231	0.10196	3
Evaporation (mm)	0.9998	0.00005	0.00001	29
T max (summer) (°C)	0.9998	0.00022	0.00003	22
T max (year) (°C)	0.9999	0.00012	0.00002	27
Relative humidity	0.9998	0.00018	0.00003	25
Climate	0.9171	0.08292	0.01239	15
Dry farming (ha)	0.9629	0.03706	0.00554	16
Residential (ha)	0.4266	0.57344	0.08569	7
Length of road (km)	0.7381	0.26185	0.03913	9
Dam (ha)	0.9998	0.0002	0.00003	24
Vegetation type (I) %	0.9139	0.0861	0.01287	14
Vegetation type (II) %	0.4724	0.52761	0.07884	8
Vegetation type (III) %	0.3282	0.67179	0.10039	4
Grasses %	0.9112	0.08882	0.01327	13
Forbs %	0.8733	0.12668	0.01893	11
Shrubs %	0.9049	0.09515	0.01422	12
Bushy tree %	0.7899	0.21013	0.0314	10
Poor range condition (ha)	0.9999	0.00004	0.00001	30
Population density (n)	0.4002	0.59979	0.08963	5
Educated people (n)	0.4003	0.5997	0.08962	6
Slope %	0.9951	0.00493	0.00074	20
Stream length (km)	0.9816	0.01837	0.00274	18
South aspect %	0.9999	0.00013	0.00002	26
TWI	0.9808	0.01924	0.00287	17

Table 2. Scale weighted super matrix of Shourdareh watershed sub-basins.

	Gh1	Gh2	Gh3	Gh4	Gh5	Gh6	Gh7	Gh8	Gh9	Gh10	Gh11
Elevation	0.108	0.109	0.086	0.111	0.109	0.091	0.099	0.081	0.073	0.081	0.053
T mean (summer)	0.089	0.089	0.091	0.089	0.089	0.091	0.090	0.092	0.093	0.092	0.095
T mean (year)	0.088	0.088	0.092	0.088	0.088	0.091	0.090	0.093	0.094	0.093	0.097
Precipitation (summer)	0.088	0.091	0.087	0.092	0.094	0.091	0.097	0.090	0.089	0.094	0.087
Precipitation (spring)	0.088	0.091	0.087	0.092	0.094	0.091	0.097	0.090	0.089	0.094	0.087
Precipitation (year)	0.088	0.091	0.087	0.092	0.094	0.091	0.097	0.090	0.089	0.094	0.087
Evaporation	0.090	0.090	0.091	0.089	0.090	0.091	0.090	0.092	0.092	0.092	0.094
T max (summer)	0.090	0.090	0.091	0.089	0.090	0.091	0.090	0.092	0.092	0.092	0.094
T max (year)	0.089	0.089	0.092	0.088	0.089	0.091	0.090	0.092	0.093	0.092	0.096
Relative humidity	0.093	0.093	0.090	0.091	0.093	0.092	0.093	0.086	0.091	0.092	0.086
Climate	0.111	0.111	0.000	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.000
Dry farming	0.067	0.036	0.151	0.062	0.113	0.060	0.108	0.090	0.163	0.096	0.053
Residential	0.364	0.002	0.152	0.000	0.000	0.000	0.000	0.482	0.000	0.000	0.000
Length of road (km)	0.139	0.045	0.187	0.000	0.000	0.052	0.000	0.109	0.135	0.082	0.060
Dam	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
Vegetation type (I)	0.167	0.044	0.241	0.097	0.119	0.075	0.029	0.059	0.093	0.036	0.040
Vegetation type (II)	0.005	0.000	0.288	0.464	0.005	0.000	0.000	0.000	0.235	0.004	0.000
Vegetation type (III)	0.585	0.000	0.027	0.000	0.000	0.000	0.000	0.388	0.000	0.000	0.000
Grasses	0.191	0.042	0.229	0.093	0.112	0.070	0.027	0.078	0.088	0.034	0.037
Forbs	0.270	0.032	0.188	0.081	0.086	0.054	0.021	0.141	0.073	0.026	0.029
Shrubs	0.206	0.038	0.220	0.100	0.102	0.064	0.025	0.092	0.088	0.031	0.034
Bushy tree	0.310	0.014	0.160	0.144	0.040	0.024	0.009	0.188	0.087	0.013	0.013
Poor range condition	0.399	0.000	0.018	0.000	0.000	0.000	0.000	0.583	0.000	0.000	0.000
Population density	0.490	0.000	0.105	0.000	0.000	0.000	0.000	0.405	0.000	0.000	0.000
Educated people	0.519	0.000	0.111	0.000	0.000	0.000	0.000	0.370	0.000	0.000	0.000
Slope	0.112	0.098	0.106	0.109	0.093	0.089	0.065	0.086	0.084	0.074	0.085
Stream l length	0.128	0.053	0.138	0.111	0.111	0.072	0.063	0.083	0.101	0.067	0.072
South slope	0.089	0.056	0.117	0.085	0.066	0.061	0.099	0.080	0.146	0.131	0.070
TWI	0.088	0.088	0.090	0.088	0.091	0.091	0.092	0.093	0.093	0.090	0.096

linear preference function, which covers even small differences. The proportional function for qualitative criteria is also the usual function (Nasiri et al., 2013). The status of each criterion and the corresponding functions were presented in Table 3. At this stage, the Max and Min functions were determined for each criterion. Thus, according to the purpose of the research, among the selected criteria, the criteria that prevent fire risk were selected as the Min function and the criteria that increases the fire risk were selected as the Max function.

3.4 The amount of Phi

The Phi rate for each of the eleven sub-basins of the study area based on the criteria of that sub-basin is presented in Table 4.

Negative Phi indicates the weakness of one sub-basin compared to other sub-basins. The higher Phi value determines that sub-basin is high in terms of the criteria under consideration. If a sub-basin has higher amount of Phi and positive sign, it will have higher risk to fire while the lower amount of Phi and negative sign indicates the lower risk of sub-basin in relation to fire. For example, regarding the elevation criterion, the sub-basin (Gh6) has the lowest amount of Phi (-0.55); therefore, it has the lowest fire risk in terms of the elevation criterion compared to other sub-basins if the sub-basin (Gh5) with the highest amount of Phi ($+0.90$) has the highest fire risk compared to other sub-basins.

3.5 Ranking of Shourdareh watershed sub-basins of Golestan province

Results show the ranking of sub-basins based on the Phi value for each sub-basin. According the results, sub-basin (Gh3) has the highest Phi value with a score of 100, so Gh3 has the highest fire potential compared to other sub-basins. While the sub-basin (Gh7) has the low fire susceptibility in terms of fire compared to other sub-basins Because of the lowest Phi and with a score of 30 (Figure 3). The low and negative value of Phi indicates the weakness of one sub-basin compared to other sub-basins in terms of fire susceptibility. While the high and positive amount of Phi shows that sub-basin is more susceptible than the other sub-basins. Also, the vectors show the superiority of sub-basins to each other. The ranking results of Shourdareh watershed sub-basins are presented in Table 5.

Based on the results of K-means clustering presented in (Table 5), the rangelands of sub-basins Gh3, Gh8 and Gh1 with Phi rates of 0.335 (has the highest fire potential compared to other sub-basins), 0.148 and 0.239, respectively, were in the high susceptibility to fire class, Sub-basins Gh2, Gh5, Gh6 and Gh7 with Phi rate of -0.20, -0.117, -0.136 and -0.241(has the low fire susceptibility in terms of fire compared to other sub-basins) were in the medium susceptibility to fire class and rangelands of sub-basins Gh9, Gh10 and Gh11 with Phi 0.114, -0.078 and 0.025, respectively, were in the low susceptibility to fire class.

Results of the fire susceptibility map of Golestan province

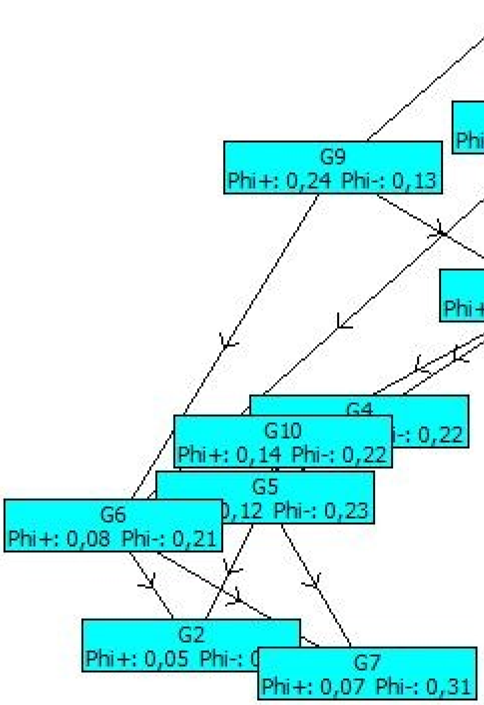

Figure 3. Ranking network by PROMETHEE II.

Table 3. Status and functions of the criteria used for the PROMETHEE II method.

	Min (low risk to fire)/Max (high risk to fire)	Preference fn.	Preference
T mean (year)	Max	V-shape	1.34
T mean (summer)	Max	V-shape	1.21
Precipitation (year)	Min	V-shape	27.51
Precipitation (summer)	Min	V-shape	5.57
Precipitation (spring)	Max	V-shape	9.18
Evaporation	Max	V-shape	46.76
T max (year)	Max	V-shape	1.61
T max (summer)	Max	V-shape	1.37
Relative humidity	Min	V-shape	3.26
Climate	Max	Usual	1.12
Dry farming	Max	V-shape	402.93
Residential	Max	V-shape	21.46
Length of road	Max	V-shape	24.22
Dam	Max	V-shape	1.14
Vegetation type (I)	Max	V-shape	747.54
Vegetation type (II)	Max	V-shape	70.54
Vegetation type (III)	Max	V-shape	324.85
Grasses	Max	V-shape	401.57
Forbs	Max	V-shape	100.98
Shrubs	Max	V-shape	378.2
Bushy tree	Max	V-shape	68.26
Poor range condition	Max	V-shape	33.33
Population density	Max	V-shape	408.85
Educated people	Min	V-shape	282.95
Slope	Max	V-shape	11.25
Stream length	Max	V-shape	13366.5
South slope	Max	V-shape	15.43
TWI	Min	V-shape	1.21

Table 4. Amount of Phi sub-basins of Shourdareh watershed by PROMETHEE II method.

Variables	Sub-basins Phi										
	Gh1	Gh2	Gh3	Gh4	Gh5	Gh6	Gh7	Gh8	Gh9	Gh10	Gh11
Elevation	0.14	−0.46	0.31	0.53	0.90	−0.55	0.30	−0.48	0.00	−0.49	−0.21
T mean (year)	0.00	−0.10	0.00	0.00	0.50	−0.10	0.00	−0.10	0.00	−0.10	−0.10
T mean (summer)	0.17	0.17	0.17	0.17	0.88	−0.68	0.17	−0.68	0.17	0.17	−0.68
Precipitation (year)	0.54	0.45	0.20	0.30	0.65	−0.22	−0.51	−0.51	−0.02	−0.02	−0.85
Precipitation (summer)	0.54	0.41	0.25	0.25	0.54	−0.28	−0.44	−0.44	0.10	−0.09	−0.84
Precipitation (spring)	−0.52	−0.42	−0.20	−0.31	−0.70	0.26	0.48	0.48	0.02	0.02	0.88
Evaporation	0.14	−0.46	0.31	0.51	0.90	−0.55	0.31	−0.48	0.01	−0.48	−0.20
T max (year)	−0.10	−0.10	0.10	0.10	0.70	−0.40	0.10	−0.10	−0.10	−0.10	−0.10
T max (summer)	0.00	−0.10	0.00	0.00	0.60	−0.10	0.00	−0.10	−0.10	−0.10	−0.10
Relative humidity	0.18	−0.24	0.81	−0.13	0.81	−0.13	−0.13	−0.42	−0.24	−0.24	−0.24
Climate	0.90	−0.20	−0.20	−0.20	−0.20	−0.20	0.90	−0.20	−0.20	−0.20	−0.20
Dry farming	0.73	−0.30	−0.01	0.82	−0.47	−0.36	0.07	0.30	−0.38	−0.65	0.24
Residential	0.20	0.83	0.92	−0.24	−0.24	−0.24	−0.24	−0.24	−0.24	−0.24	−0.24
Length of road	0.89	0.57	0.21	0.53	−0.33	−0.26	−0.10	−0.18	−0.41	−0.48	−0.44
Dam	−0.10	−0.10	1.00	−0.10	−0.10	−0.10	−0.10	−0.10	−0.10	−0.10	−0.10
Vegetation type (I)	0.95	0.64	−0.23	0.03	−0.38	0.06	−0.41	0.24	−0.11	−0.34	−0.46
Vegetation type (II)	0.78	−0.18	−0.19	−0.19	−0.19	0.96	−0.19	−0.19	−0.19	−0.19	−0.19
Vegetation type (III)	−0.14	0.95	−0.21	0.82	−0.21	−0.21	−0.21	−0.21	−0.21	−0.21	−0.21
Grasses	0.92	0.76	−0.09	−0.02	−0.39	0.02	−0.41	0.18	−0.15	−0.36	−0.46
Forbs	0.67	0.93	0.35	−0.10	−0.38	−0.05	−0.39	−0.02	−0.22	−0.37	−0.42
Shrubs	0.89	0.82	0.00	−0.02	−0.40	0.08	−0.42	0.09	−0.20	−0.37	−0.46
Bushy tree	0.40	0.95	0.40	0.00	−0.37	0.31	−0.37	−0.25	−0.32	−0.37	−0.39
Poor range condition	−0.17	0.84	0.95	−0.20	−0.20	−0.20	−0.20	−0.20	−0.20	−0.20	−0.20
Population density	0.05	0.92	0.86	−0.23	−0.23	−0.23	−0.23	−0.23	−0.23	−0.23	−0.23
Educated people	−0.07	−0.94	−0.83	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Slope	0.55	0.69	−0.25	−0.25	−0.25	0.62	−0.56	0.12	−0.08	0.20	−0.77
Stream length	0.78	0.67	−0.16	0.21	−0.36	0.39	−0.44	0.40	−0.35	−0.65	−0.49
South slope	0.40	−0.02	−0.20	0.91	−0.48	−0.20	0.54	−0.32	−0.44	−0.44	0.26
TWI	0.00	0.00	−0.10	−0.10	−0.10	0.30	0.00	0.00	0.00	0.00	0.00

Table 5. Ranking of Shourdareh watershed sub-basins by PROMETHEE II method.

Row	Sub-basins	Cluster	φ^+	φ^-	φ	Score	Ranking
1	Gh9	1	0.244	0.130	0.114	62	4
2	Gh8	2	0.301	0.157	0.143	66	3
3	Gh7	3	0.073	0.314	−0.241	30	11
4	Gh6	3	0.077	0.214	−0.137	37	9
5	Gh5	3	0.115	0.233	−0.118	39	8
6	Gh4	1	0.160	0.223	−0.063	43	6
7	Gh3	2	0.421	0.086	0.336	100	1
8	Gh2	3	0.050	0.270	−0.221	31	10
9	Gh11	1	0.239	0.215	0.025	52	5
10	Gh10	1	0.138	0.217	−0.078	42	7
11	Gh1	2	0.389	0.149	0.240	81	2

show in three classes including:

- Low susceptibility to fire which is marked in green on the map (Figure 4), in these sub-basins, the amount of participation, topographic wetness index and relative humidity, which are the factors influencing the fire, are higher than other sub-basins.
- High susceptibility to fire which is marked in red on the map (Figure 4), It is noteworthy that in these sub-basins, criteria such as population density and the number of villages were higher than other sub-basins, which has increased the fire potential. Also,
- Moderate susceptibility to fire which is marked in yellow on the map (Figure 4), in this class, the values of criteria are intermediate between the two classes of high susceptibility to fire and low susceptibility to fire.

4. Discussion

In the present study, various environmental and social criteria were used to determine the areas prone to rangeland fires in the Shourdareh region of Golestan. The main criteria which were used in this research included topographic, biological and climatic criteria that are consistent with the research of Eskandari et al. (2013). Topographic criteria had three important sub-criteria of elevation, slope and aspect; the climate had four sub-criteria of temperature, evaporation, humidity and precipitation, which was consistent with Johar Jafar (2016). Also, some criteria such as land use, distance from the road, distance from residential areas and distance from the river criteria which is consistent with criteria used by Sitanggang et al. (2013) and Parajuli et al. (2020). The results by weighting criteria of present research based on

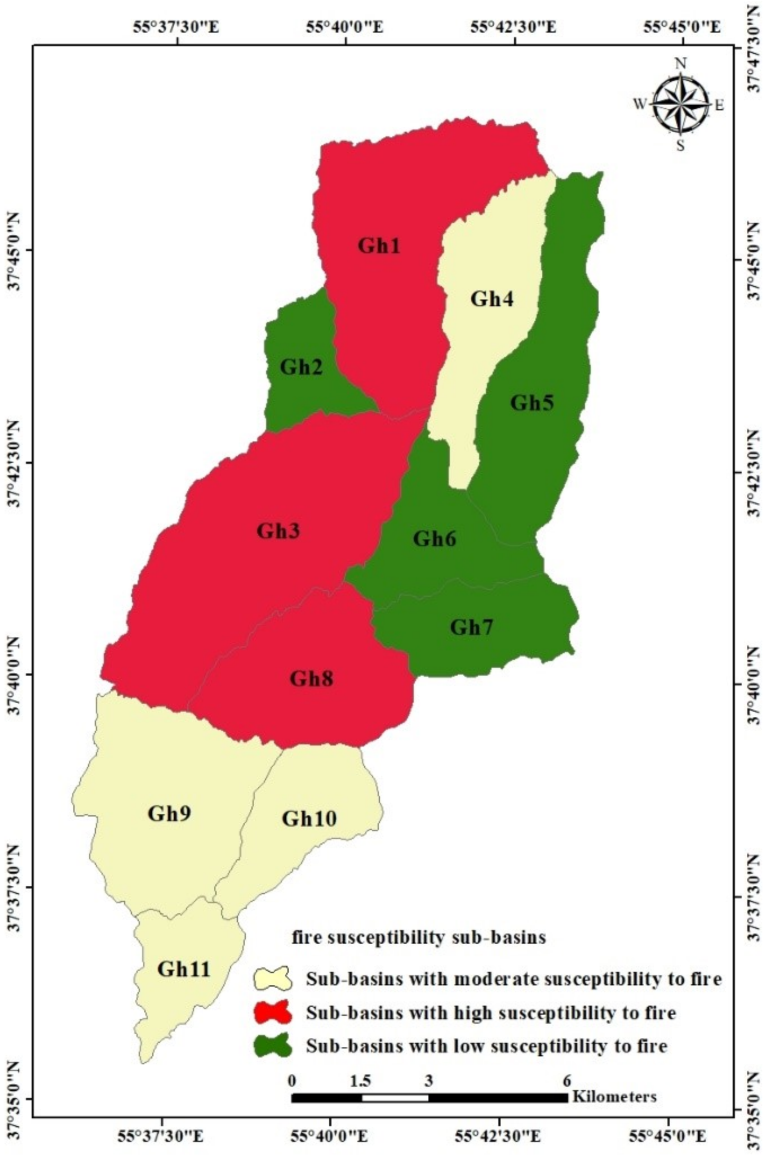

Figure 4. Fire susceptibility map of Golestan province, Iran.

the Shannon entropy method showed that the criteria of annual temperature and annual precipitation with the weights of 0.14 and 0.10, respectively, had the highest weight to determine the areas prone to rangeland fires in the Shourdareh region of Golestan. Other researchers emphasized the importance of precipitation and temperature criteria in the field of fire occurrence (Ariapour and Mohammad Shariff, 2014; Abedi Gheshlaghi and Valizadeh Kamran, 2018).

Based on the results of the present research, it was determined that the ranking of sub-basins based on the Phi value for each sub-basin, sub-basin Gh3 with Phi rates of 0.335 has the highest Phi value and a score of 100 and has the highest fire potential compared to other sub-basins. The Gh7 sub-basin with Phi rates of -0.241 has the lowest fire susceptibility in terms of fire with the lowest Phi compared to other sub-basins. Based on the results of this research, the sub-basins that had higher ratings such as Gh3 being more susceptible to fire than other sub-basins had less amount of participation, relative humidity and topographic humidity which causes the creation of suitable environmental conditions and therefore, the fuel is to be prepared for fires. In this regard, Janbazghobadi (2018) also confirmed the current research and stated that temperature is one of the most important criteria in the occurrence of fire as high temperature increases evapotranspiration and decreases humidity and therefore increases the fire. Precipitation also reduces the risk of fire by regulating soil uptake and moisture. These results are consistent with (Ariapour and Mohammad Shariff, 2014) who stated that high spring precipitating causes biomass growth (fuel factor) and high evaporation causes fuel drying and capability of flammability of most materials. It was also consistent with the results of the research of Dashti et al. (2021) that showed the highest probability of fires occurring in the period between June and September when the temperature, evaporation, fuel content are high and humidity is low.

The highest slope percent of the Gh3 sub-basin was located in the southern aspect. Aspect plays a key role in fire behavior because in the northern hemisphere, the southern slopes are in a better position than the northern slopes in the event of a fire. The results of Musaybeigi and Mirzabeigi (2016) showed that the highest incidence of fires occurred in areas with southern aspects due to receiving the most amount of sunlight. Vice versa, the sub-basins that have less potential such as Gh7 have more participation, relative humidity, topographic humidity and less evaporation that is consistent with (Eslami et al., 2019; Polat et al., 2019).

The results of the present study showed that the population density is high in the fire-prone sub-basins, the access way to these sub-basins, proximity to roads and settlements is more, which s consistent with Johar Jafar (2016) and Ajin et al. (2017). The results of Dalir et al. (2021) research also showed that human criteria play a decisive role in the occurrence of forest and rangeland fires. Research reported by Yang et al. (2007) showed that more than 90% of fires are caused by humans. In this regard, based on research findings by Arndt et al. (2013), forest roads and population density have a significant role in the occurrence of fires. In other words, increasing access by road puts more pressure on forest and rangeland ecosystems, and this effect is exacerbated by population growth.

The results of present research based on the Shannon entropy method illustrated that the criteria of annual temperature and annual precipitation with weight of 0.1488 and 0.1019, respectively had the highest weight to determine the areas prone to rangeland fires in the Shourdareh region of Golestan that is consistent with Azizi and Yosefi (2009). In order to investigate the compatibility of real fires with the fire prone areas resulting from this study, the results of burned areas prepared by the General Department of Natural Resources of Golestan Province were used. Based on the kappa coefficient, which is 0.82, according to the classification of kappa Coefficient, the model has a good and acceptable accuracy. This result is consistent with the research result of Al-Fugara et al. (2021) stating that the areas where fires have occurred in the past need to be recorded and then, compared with the fire potential areas resulting from the methods used to determine the relationship between them. Foody (2020) also used kappa coefficient to evaluate their model and stated that kappa coefficient greater than 0.80 indicates the high accuracy of the model. In general, the proposed method is a reliable screening tool to identify fire prone areas that it can help the authorities to take preventive measures. In order to increase the accuracy and precision in future research, efforts should be made to use as much as possible all the criteria affecting the fire phenomenon in determining critical and fire-prone areas.

5. Conclusion

In general, based on the kappa coefficient which is 0.82, the proposed method is a reliable screening tool to identify fire prone basins that can help the authorities to take preventive measures. Low susceptibility sub-basins to fire such as Gh7 which were marked in green on the map (Figure 4) in these sub-basins, the amount of participation, topographic wetness index and relative humidity, which were the factors influencing the fire, were higher than other sub-basins. While high susceptibility sub-basins to fire such as Gh3 were marked in red on the map (Figure 4), they were noteworthy that in these sub-basins, criteria such as population density and the number of villages were higher than other sub-basins, which have increased the fire potential. In order to increase the accuracy and precision in future research, efforts should be made to use as much as possible all the criteria affecting the fire phenomenon in determining critical and fire-prone areas. It is recommended that more research should be done on the use of other techniques such as data mining, neural networks and other decision-making techniques to identify more powerful techniques for sub-ranking to identify fire prone basins. Finally, it is suggested that suitable management measures should be used for sub-basin with high potential for fire such as Gh3 as well as appropriate management measures to prevent the spread of fire to other sub-basins. Using methods such as fuel break through mechanical and manual methods, burning vegetation using unskilled workers has been introduced as the cheapest and best way to deal with fire in high susceptibility sub-basins to fire.

Authors Contributions

All authors have contributed equally to prepare the paper.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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