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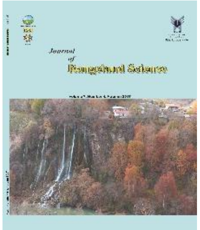

Research and Full Length Article:

Mapping Natural Resources Vulnerability to Droughts Using Multi-Criteria Decision Making and GIS (Case Study: Kashkan Basin Lorestan Province, Iran)

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Abstract. Zagros Mountains in west of Iran are covered by unique forests and rangelands. Increasing population, low level of development and high dependence of local people on natural resources for primary livelihood needs resulted in degradation of Zagros forests and rangelands. Along with these factors, since the last decade, climate change including severe drought is an important issue in the world, particularly in semi-arid natural areas of Iran including Zagros. This research was conducted to develop an integrated method for mapping vulnerability of natural resources to droughts in Kashkan basin Lorestan province, Iran in 2015. Hence, a combined method including AHP as a Multi-Criteria Decision Making method and GIS was used. Based on literature review, study area conditions and experts' opinions, six criteria and nineteen sub criteria were determined. The weights of this initial set of criteria and sub criteria were determined by experts using pairwise comparisons and weights of them were calculated. Then, maps of different sub criteria were analyzed in the GIS environment using calculated weights. Results showed that the most important criteria in drought sensitivity were hydro climate, physiography, and vegetation cover. Annual mean precipitation and temperature, vegetation cover were the most important sub criteria. Findings of research also indicated that 17.11%, 26.28% and 7.67%, of the studied area were classified as low, moderate and high vulnerable areas, respectively. In addition, 8.50% of the studied area is classified as extremely high vulnerable to droughts. This study introduces a combined method to mapping vulnerability of natural resource to droughts. Findings of this study could be considered by managers to develop proper plans for vulnerable areas.

Key words: Zagros, Drought, Analytical hierarchy process, Rangeland, Forest

Introduction

Zagros Mountains in west region of Iran are covered by unique forests and rangelands. Zagros forests with area of around 5 million ha consist almost 40% of Iran's forests (Marvi Mohajer, 2013). These forests and rangelands provide a home and livelihood for approximately 10% of Iran's population (Jazirehi, and Ebrahimi Rastaghi, 2003). Characterized by a semi-Mediterranean climate, they are of the most important and sensitive ecosystems in Iran. Zagros forests and rangelands play an important role in soil and water conservations. About 40% of water supply in the country comes from Zagros region (Ghazanfari *et al.*, 2004) and this fact makes clearer the role of forests and rangelands. Farming in understory, fuel wood extraction, livestock grazing, increasing population, high dependence of local people on forest resources for primary livelihood needs resulted in degradation of Zagros forests and rangelands (Borzoie *et al.*, 2014; Ghazanfari *et al.*, 2004; Jazirehi and Ebrahimi Rastaghi, 2003). Along with these factors, since the last decade, climate change has been becoming an important issue in the world, particularly in semi-arid natural areas of Iran. Drought is one of the climate change symptoms that had affected this region and caused some degradation in forest and rangelands of Zagros. Drought as a climate change phenomena can also effect on rangelands. Droughts can reduce the total annual rangelands forage production (Badri Pour, 2012; Nakhaee Nezad Fard *et al.*, 2013) and its consequences are one of the most threats for rangelands exploitation (Sharifyan Bahraman *et al.*, 2014). Drought also has negative impacts on forest hydrology and productivity (Sun *et al.*, 2015). Even when mortality is not realized, severe droughts can have long lasting effects on forests (Anderegg *et al.*, 2015). Many studies investigated severity or consequences of droughts (Esper *et al.*, 2007; Damavand *et al.*, 2016; Safari Shad *et al.*, 2017), but few studies tried to determining vulnerable area to droughts. Determining and mapping of the vulnerable areas to drought can be considered as the first and main step in drought management planning (Pandey *et al.*, 2010; Stone & Russel, 2011; Pasho *et al.*, 2011; Shahabfar *et al.*, 2012). A more structured, systematic approach to assessing the vulnerability could help policy makers and managers develop more realistic approaches (Joyce *et al.*, 2013). This phenomenon can be affected by some different factors including forest structure, land use, irrigation conditions, land cover, species types, annual and seasonal rainfall, standard precipitation index, watershed geography, soil type, water resources positions (surface and sub-surface) and land properties (Allen *et al.*, 2010; Pandey *et al.*, 2010; Pasho *et al.*, 2011; Núñez *et al.*, 2011; Shahabfar *et al.*, 2012; Fang *et al.*, 2012; Liu *at al.*, 2013). This problem needs to be considered by the managers. Managers should prepare suitable precautions to deal with this problem.

However, numerous affecting factors make drought management planning as complex task. Thus, there should be proper tools that can be used to determine affecting factors and zoning vulnerable areas to drought. Multi-Criteria Decision Making (MCDM) methods are decision analysis tools that have been developed in order to support complex decision making (Kangas and Kangas, 2002; Colantoni *et al.*, 2016).

The multi-criteria analysis techniques can greatly reduce the cost and time and increase accuracy in decision-making. Analytical Hierarchy Process (AHP) as a multi-criteria decision making method, has been extensively used in natural resources management. AHP is a quantitative method that uses paired comparisons for weighting criteria and sub-criteria. Along with the rapid progress of GIS and computer technology, this technique has been broadly used in research projects. Nowadays, using in evaluation, providing ecological capability map, management and planning of lands are the most important applications of GIS (Bocco *et al.*, 2005; Liu *et al.*, 2007; Akhzari *et al*, 2013; Karimi *et al.*, 2014; Rostami *et al.*, 2014; Noorollahi *et al.*, 2016). In recent years, AHP as a multi-criteria decision making method was combined with GIS as a method to analyzing spatial data. This combined method facilities combination of experts' opinions to spatial data (Borzoie *et al.*, 2014). This integrated method was used in several studies to deal with situation in which multi criteria decisions were assessed via spatial data (Karimi *et al.*, 2014). Integrating GIS with AHP has many advantages for the assessment of the area vulnerability to different destructive factors including droughts.

Zagros is located in the arid and semi-arid regions and has high vulnerability to drought. In 2001 and 2002, the amount of damages of droughts in Iran was 2.5 and 1.7 billion dollars, respectively (Damavand *et al.*, 2016). Thus, drought management strategies must try to damage prevention programs. Determining of vulnerable area to drought is a concern to the planners or decision makers. Many of studies or programs focused on consequences of droughts in Iran, while as mentioned, mapping of vulnerable area to drought must be considered as main and the first step of drought management program. This research was trying to develop an integrated method for mapping vulnerable natural resources to drought in Kashkan Basin, Lorestan province, Iran.

Materials and Methods

Study area

This study was conducted in 2015, in Kashkan Basin. Kashkan river basin is located in Lorestan province with an area of 9287.39 km^2. The major cities in this river basin are Khorramabad, Koohdasht, Alashtar, Pol-e-Dokhtar and Dowre. It is a mountainous region in the Zagros Mountains. This watershed is one of the main sub basins of large Karkheh river basin in western of Iran. The annual precipitation of the basin is about 460 mm, and its mean elevation is 1600 m abve sea level.

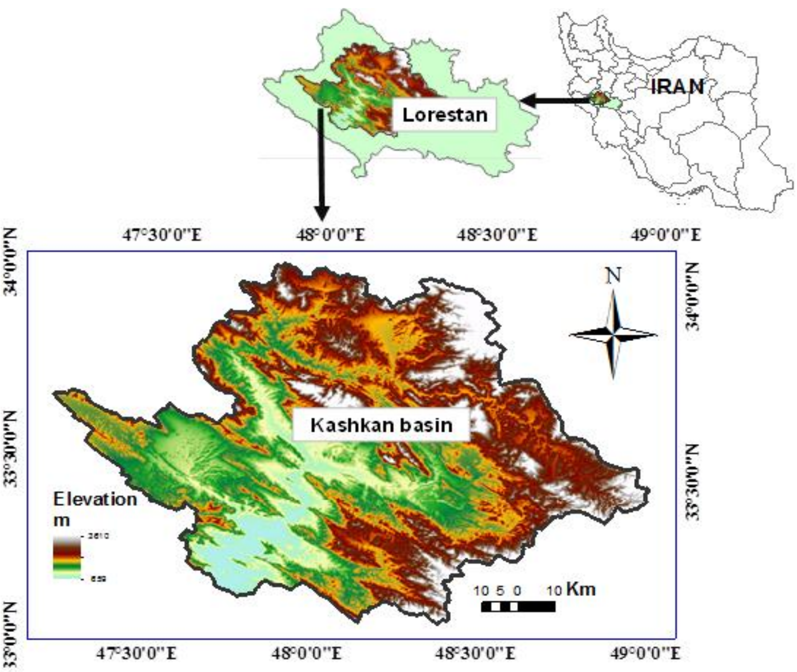

Fig. 1. Location of the study area in Lorestan province

Methods

Weighting of criteria and sub-criteria was carried out using AHP method. In fact AHP and the Geographic Information System (GIS) in an integrated technique were used for mapping vulnerable areas to the droughts. This process was done in three main steps:

a) Identification and weighting of criteria and sub criteria

In the first step, the most important criteria and sub criteria that effect on vulnerability to droughts were determined. Initial criteria and sub criteria were selected based on conditions of the study area, experts' opinions and literature review (Allen *et al.,* 2010; Pandey *et al.*, 2010; Pasho *et al.,* 2011; Núñez *et al.,* 2011; Shahabfar *et al.,* 2012; Fang *et al.*, 2012; Liu *et al.*, 2013). 6 criteria (hydro climate, soil, physiography, land use, vegetation cover and population) and 19 sub-criteria were selected and weighted using AHP. Pairwise comparison was used to allocate weights to criteria and sub criteria and Consistency Ratio (CR) also was calculated to verify the coherence of the judgments, which must be about 0.10 or less to be accepted (Satty, 2008).

For weighting criteria and sub criteria, a questionnaire was provided. Criteria and sub criteria were compared by group of experts. Group consists of 23 experts including members of universities and scientific centers who were familiar with natural resources on Zagros and drought concept. Experts used pairwise comparisons and Saaty’s scale (Table 1) to assess the importance of criteria and sub criteria (Satty, 2008). Data of 23 pairwise comparisons were analyzed using the Expert Choice Professional software (Borzoie *et al.*, 2014; Karimi *et al.,* 2014). Relative weights for the functions were calculated based on input from the experts.

Table 1. Saaty’ scale and their context in comperwise

Value	1	3	5	7	9	2, 4, 6, 8
Oral priority	Equal	Moderate	Strong	Very strong	Extreme	Intermediate values

b) Map generation

In this step, maps of sub-criteria were produced using ArcGIS 10 software. Every map represents one sub-criterion and used as a thematic layer or data layer in raster format. Digital Elevation Model (DEM) map extracted from NASA Shuttle Radar Topographic Mission (SRTM) 90 m was provided from Lorestan Watershed Management Department for study area. This map was projected using Lambert conformal conic coordinate system. Some required maps including slope, aspect and altitude with the same resolution (90 m) were extracted DEM map. These maps were prepared using surface tool available in Spatial Analyst tools in Arc Toolbox of ArcGIS. Soil and land use maps were obtained from department of natural resources. Precipitation and temperature data were obtained from department of applied Meteorology of Lorestan and were interpolated using geo-statistical techniques available in ArcGIS 10. Surface and sub-surface water maps were collected from Lorestan regional water company, and population data were obtained from Lorestan statistical center. As it was mentioned, classification maps were conducted based on the natural conditions of study area i.e. uniformity or irregularity and the range of data, previous studies and experts' opinions.

c) Final map creation

In this step, maps were combined with their corresponding weights using Weighted Linear Combination (WLC) technique in GIS environment. The site vulnerability to drought was identified based on the obtained scores. In this method, the value of each criterion was calculated by the following (Equation 1):

$$A = \sum_{i=1}^{n} Wi \times Xi \qquad \text{(Equation 1)}$$

Where:
n= the number of factors
Wi= the weight of "i th" factor
Xi = a rating given for the defined class of the "i th" factor found on the factor map.

Result

Results of pairwise comparisons are presented in Table 2. Hydro climate criterion with final weight of 0.268 was the most important criterion which followed by physiography, vegetation cover, land use, population and soil characters. The Table 2 also, indicates final weights of sub criteria. Precipitation gains the highest weight among sub-criteria of hydro climate factors. The weights of other sub-criteria are shown in this Table too. Land use and slope maps of the study area are shown in Figs. 2 and 3, respectively. Major natural resources in the area consist of forest and rangeland. All man made land uses was categorized as other land use. Four slope classes were used for the slope map.

Table 2. Final weights of criteria and sub criteria used in this study

No	Main criteria	Final weight	Sub criteria	Final weight
1	hydro climate	0.268	Precipitation	0.541
			Temperature	0.234
			Surface water	0.129
			Sub surface water	0.096
2	Soil	0.108	Clay	0.205
			Clay loamy	0.180
			Clay loamy sandy	0.213
			Gravel loamy	0.193
			Sandy gravel loamy	0.209
3	Physiography	0.193	Aspect	0.396
			Altitude	0.307
			Slope	0.297
4	Land use	0.127	Water body	0.293
			Forest	0.493
			Pasture	0.214
5	Vegetation cover	0.192	Forest type	0.297
			Canopy cover	0.703
6	Population	0.112	Urban	0.497
			Rural	0.503

Slope classification shows that about 46% of the study area are located in 0-15 degrees class (Table 3 and Fig. 2). Slope classes of 25-45, 15-25 and more than 45 degrees cover 22.25, 20.56 and 10.74% of the area, respectively. Result of land use map indicates that forests cover more than 48% of study area (Table 4 and Fig. 3). Non natural resources area, rangeland and water bodies with 40.44, 9.9 and 1.2% cover the rest of the area, respectively.

Table 3. Area of slope classes of the study area

Class	Slope (degree)	Area (%)
1	0-15	46.45
2	15-25	20.56
3	25-45	22.25
4	>45	10.74

Table 4. Area of land use classes of the study area

Class	Land use	Area (%)
1	Forest	48.56
2	Rangeland	9.90
3	Water bodies	1.10
4	Other land uses	40.44

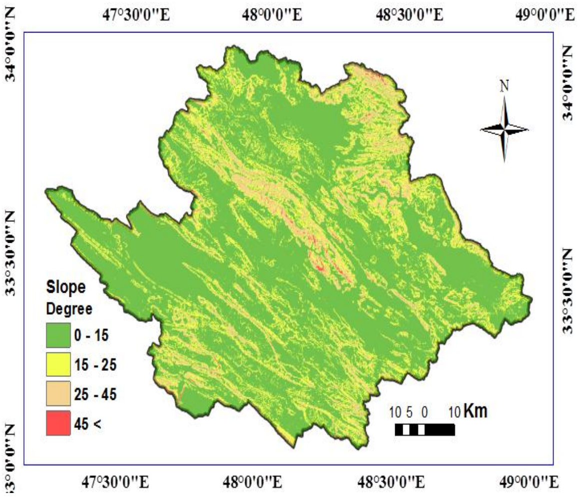

Fig. 2. Slope map of the study area

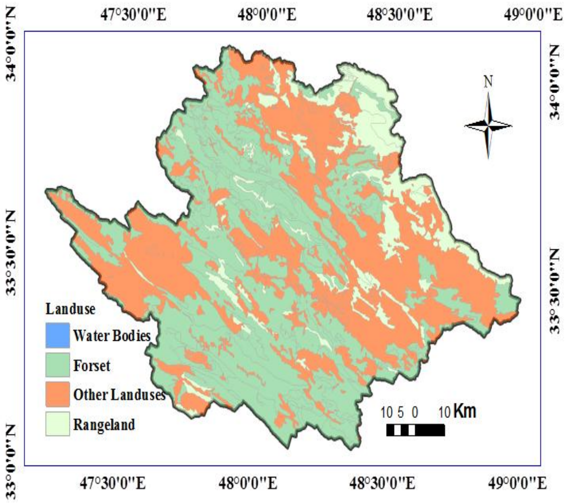

Fig. 3. Land use map of the study area

Classification of groundwater showed that more than 61% of the area was classified as semi-deep that followed by deep and shadow classes with 24.15 and 14.30%, respectively (Table 5 and Fig. 4). Vulnerability to droughts map indicates that 26.28% of the area was classified as moderately vulnerable (Table 6 and Fig. 5). Low vulnerable and vulnerable areas cover 17.11 and 7.67% of the study area, respectively. Extremely vulnerable to droughts class includes 8.50% of the studied area.

Table 5. Underground water classes

Class	Depth	Area (%)
1	Shallow	14.30
2	Semi deep	61.55
3	Deep	24.15

Table 6. Vulnerability to drought in Kashkan

Class	Vulnerability	Area (%)
1	Extremely Vulnerable	8.50
2	Vulnerable	7.67
3	Moderately Vulnerable	26.28
4	Low Vulnerable	17.11
5	Other land uses	40.44

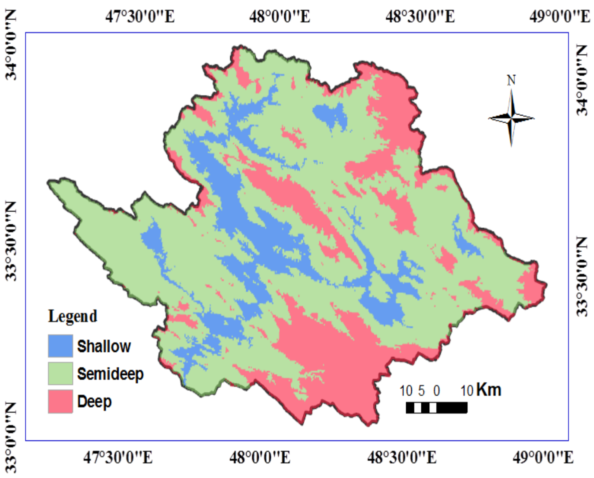

Fig. 4. Groundwater classification

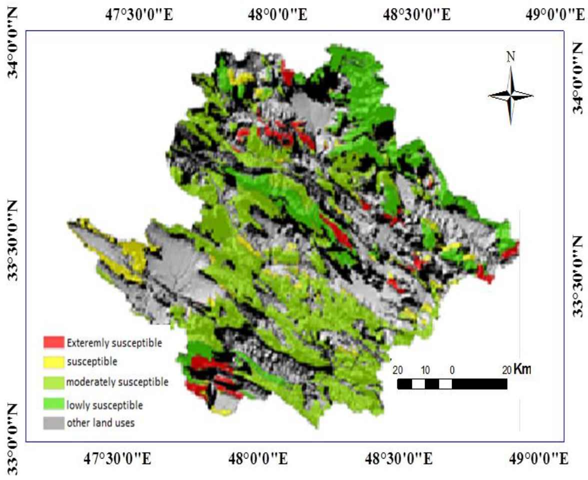

Fig. 5. Vulnerability to drought map in Kashkan basi Vulnerability

Discussion

This study was carried out to develop an integrated approach for combining expert's opinions and GIS tools for mapping vulnerable natural areas to droughts. Results of study indicated that different factors have different importance in vulnerability to droughts. This fact also represented in some related studies (Gu *et al.,* 2008; Allen *et al.,* 2010; Guo *et al.,* 2016). Based on the results, hydro climate factor played the most important role in the drought sensitivity followed by physiography and land cover. This fact showed that annual rainfall and temperature can be considered as the most important indicators. Since these factors are natural and cannot be controlled, managers need to monitor these factors carefully and make proper plans for different situations. This fact can be described by nature of study area which is a semi-arid region. In this kind of natural resources, rainfall and physiography can play an important role in occurrence of droughts. Rainfall is considered as one of the most factors for detecting drought events in arid regions (Guo *et al.,* 2016). Physiography also, can amplify the effect of rainfall decline. Aspect was considered as the most important factor of physiography criterion which has great effect in water and soil cycles and dynamics. Pandey *et al.* (2010) also found that upper and steeper slope are more vulnerable to droughts.

Among vegetation cover criteria, canopy cover was much more important than forest type. This fact can be related to the nature of Zagros forests. These forests consist of Oak trees, and there is no remarkable different among Zagros forest sites. But, canopy cover is considerably different along Zagros Mountains due to variable factors including land use, slope, aspect, altitude and even human factors like population (Fattahi *et al.,* 2000). Therefore, this sub-criterion obtained higher weight. Canopy covers can effects on forest soil. In open or less dense forests, forest soil receives more light and heat in return. This stream of light and heat can evaporate more water from forest soil and leads in more vulnerability to droughts. Since, soil moisture is a critical component in land surface-atmospheric processes and prolonged soil moisture deficits due to open vegetation cover often lead to drought-induced vegetation stress (Gu *et al.,* 2008). Studies showed that vegetation indices alone cannot fully describe the severity of drought conditions. Intensity, severity and spatial patterns of drought depend on many factors (Caparrini & Manzella, 2009).

Findings of this research indicated that 26.28% of the area is moderately vulnerable to droughts. Low vulnerable and vulnerable areas cover 17.11 and 7.67% of the study area, respectively. 8.50% of the area was classified as extremely vulnerable to droughts. These findings illuminate the requirement of proper planning to confront against probabilistic droughts. The most important factors, are natural and must be considered by managers. However, human factors including land use and population also can influence on vulnerability to drought. These factors must be controlled. Avoiding land use change, reducing local people pressures on forests and rangelands, are the measures that must be considered. Exploitation of ground water and surface water are main human related process that can induce drought (Loon *et al.,* 2016). Vulnerability to drought can be affected by lack of infrastructural capacity, insufficient socioeconomic capacity to manage the impacts of drought events (Carro *et al.,* 2016). So, it is necessary to try for improvement in socioeconomic and infrastructural capacities in Zagros. Low level of development and high dependence of local people on natural resources for primary livelihood needs resulted in degradation of Zagros forests and rangelands (Ghazanfari *et al*., 2004). This degradation can make forests and rangelands more vulnerable to drought.

This study tried to develop an integrated method using combining AHP as a multi criteria decision making method and GIS to predict vulnerability to droughts. Although, this integrated method has been applied in different areas of research including wind power plant site selection (Atici *et al.,* 2015), land capability for recreation (Borzoei *et al.,* 2014; Karimi *et al.,* 2014) and wind farm site selection (Latinopoulos and Kechagia, 2015) but, there are few researches which in the vulnerability of natural resources to droughts have been investigated. So, this research can be considered as initial work in this area and need to be improved by a list

For conclusion, identifying and monitoring of vulnerable areas to drought must be considered as a vital task by managers during the time. For this goal, natural resource's managers need to consider important factors that can help to determine these areas. Results of this study about affecting factors can be used to mapping vulnerable natural land areas to drought. Map of vulnerable area can be used as a tool to plan preparation actions to manage this natural disaster.

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تعیین حساسیت منابع طبیعی به خشکسالی با استفاده از تصمیم‌گیری چند معیاره و سیستم اطلاعات جغرافیایی (مطالعه موردی: حوزه آبخیز کشکان، استان لرستان، ایران)

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چکیده. کوه‌های زاگرس دارای پوشش منحصر به فردی از جنگل و مراتع می‌باشند. افزایش جمعیت، توسعه‌یافتگی پایین و وابستگی شدید مردم به منابع طبیعی برای نیازهای خود، باعث تخریب این منابع طبیعی شده است. در دهه گذشته و در کنار این عوامل، تغییر اقلیم و خشکسالی‌های شدید تبدیل به یکی از فاکتورهای مهم تخریب در مناطق نیمه خشک و مخصوصا زاگرس شده است. این تحقیق در سال ۱۳۹۴ با هدف ایجاد یک روش تلفیقی با ترکیب AHP به عنوان یک روش تصمیم گیری چند معیاره و GIS برای پهنه بندی حساسیت به خشکسالی در حوزه کشکان در استان لرستان انجام شد. با استفاده مرور منابع، شرایط منطقه و دیدگاه متخصصان شش معیار اصلی و ۱۹ معیار فرعی تهیه شدند. این لیست اولیه با استفاده از مقایسات جفتی و توسط متخصصان مقایسه و وزن هر کدام تعیین گردید. سپس نقشه-های مربوط به هر کدام از این زیر معیارها با استفاده از وزن‌های محاسبه شده در محیط GIS تحلیل شدند. نتایج نشان داد که معیارهای هیدرو اقلیم، ویژگی‌های فیزیکی و پوشش گیاهی به ترتیب بیشترین وزن را داشتند. هیدرواقلیمی، آب، ویژگی‌های فیزیکی، کاربری، پوشش گیاهی و جمعیت، بارندگی، درصد تاج پوشش و دما نیز مهمترین زیر معیارهای مربوط بودند. نتایج نشان داد که ۱۷/۱۱، ۲۸/۲۶۶ و ۷/۶۷ درصد به ترتیب دارای حساسیت کم، متوسط و حساس می‌باشند. همچنین ۸/۵ درصد از منطقه به حساسیت شدید به خشکسالی پهنه بندی شد. این یافته‌ها می‌تواند به مدیران برای برنامه‌ریزی در مناطق حساس به خشکسالی کمک کند.

کلمات کلیدی: زاگرس، خشکسالی، تحلیل سلسله مراتبی، مرتع، جنگل