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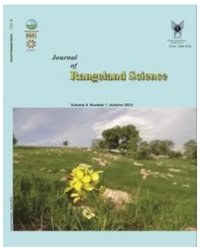

Full Length Article:

Vulnerability Analysis of Flood in Rangelands Using Multi Criteria Decision Analysis and Geographic Information System (Case Study: Gilard Basin, Damavand, Iran)

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Abstract. Flood disaster is considered as a major natural hazard due to its devastating effects on the affected areas. Determining the flood vulnerable areas is important for decision makers in order to perform planning and management activities. Geographical Information System (GIS) is integrated with Multi Criteria Decision Analysis (MCDA) used to analyze the flood vulnerable areas. The aim of this research was to provide more flexible and accurate decisions to evaluate the causative factors for planning and management of rangelands of Gilard, Damavand. So, effective factors influencing flood occurrence in the study area was first surveyed. Some of the causative factors for flood in the watershed such as mean annual precipitation, basin area, basin slope, drainage density, land uses and soil type were taken into account. Then, through assembling spatial and descriptive information related to the study area and using Analytic Hierarchy Process (AHP), the criteria have been grouped and weighted. At the end, as regards of ultimate weight, the basin was classified into five classes. Results of this research show that mean annual precipitation and Sedimentation Rate with the average values of 26.5% and 2.01% had maximum and minimum effects on flood occurrence in rangeland of Gilard in Damavand, respectively.

Key words: Flood, Multi criteria decision analysis, Geographical information system, Analytical hierarchy process

Introduction

Decision analysis looks at the paradigm in which an individual decision maker (or decision group) contemplates a choice of action in an uncertain environment. Theory of decision analysis is designed to help the individual make a choice among a set of pre-specified alternatives. The decision making process relies on information about the alternatives. The quality of information in any decision situations can run the whole gamut from scientifically-derived hard data to subjective interpretations, from certainty about decision outcomes (deterministic information) to uncertain outcomes represented by probabilities and fuzzy numbers. This diversity in type and quality of information about a decision problem call for methods and techniques that can assist in information processing. Ultimately, these methods and techniques may lead to better decisions (Bojórquez-Tapia *et al.*, 2001).

Our values, beliefs and perceptions are the forces behind almost any decision-making activity. They are responsible for the perceived discrepancy between the present situation and a desirable state. Values are articulated in a goal which is often the first step in a formal (supported by decision-making techniques) decision process. This goal may be put forth by an individual (decision- maker) or by a group of people. The actual decision boils down to select "a good choice" from a number of available choices. Each choice represents a decision alternative. In the Multi Criteria Decision-Making (MCDM) context, the selection is facilitated by evaluating each choice in the set of criteria. The criteria must be measurable even if the measurement is performed only at the nominal scale (yes/no; present/absent) and their outcomes must be measured for every decision alternative. Criterion outcomes provide a basis for the comparison of choices and consequently, they may facilitate the selection of one, satisfactory choice (Sani, 2008). Many nations experience fatalities and injuries, property damage and economic and social disruption resulting from natural disasters. Natural disasters such as earthquakes, hurricanes, flash floods, volcanic eruptions and landslides have always constituted a major problem in many developing and developed countries. The natural hazards kill thousands of people and destroy billions of dollars' worth habitat and property each year (Mendoza and Martins, 2006). The rapid growth of the world's population has escalated both the frequency and severity of the natural disasters. Flood disaster has a very special place in natural hazards (Thomas, 2002). Floods are the costliest natural hazard in the world and account for 31% of economic losses resulting from natural catastrophes. Especially, river flooding has been a major natural hazard worldwide in recent events for example, Cleveland in 2006, Bolivia in January 2007, Namibia in February 2007 and Australia in March 2007. Millions of people were affected in socio-economic life, thousands of people died and it caused the physical losses of over 20 billion USA Dollars (UN-EU, 2007). Multi-Criteria Evaluation (MCE) methods have been applied in several studies. Since 80% of data used by decision makers is geographically related to each other (Malczewski, 1999), Geographical Information System (GIS) may provide more information about decision making situations. GIS allows the decision maker to identify a list meeting a predefined set of criteria with the overlay process (Aurora, 2003) and the multi-criteria decision analysis within GIS may be used to develop and evaluate alternative plans that may facilitate compromise among interested parties (Malczewski, 1996).

MCA method was used to analyze and find the flood vulnerable areas in west of black sea in northern Turkey (Yalcin, 2002). In this study, GIS was integrated with MCE. This study has used seven spatial criteria and each criterion was presented and stored in a layer using Arc View 8.2 and their values were generated. The criterion maps are converted into grids and the mathematical processes were applied to the criteria with Map Calculator. Ranking Method was used to rank every criterion under consideration in the order of the decision maker's preference and Pairwise Comparison Method (PCM) which is designed as a user interface has been utilized to calculate the weights from input preferences with Visual Basic Application (VBA) program embedded in ArcGIS 8.2. At the end of the application, composite maps were created by the use of Boolean Approach, Ranking Method and Pairwise Method. Another study in south of Thailand presented a GIS-based multi-criteria analysis approach to assess flooding risk analysis (Pramojanee *et al.*, 2001). It has applied the multi-criteria analysis framework to determine flood vulnerable areas with GIS to give the overall flooding areas. Ologunorisa and Abawua (2005) investigated GIS techniques in the evaluation of flood risk occurrence in the world and showed that criterion of rainfall, run off and land uses are the most important factors in flood occurrence. Antonie *et al.* (1997) presented an example application on the integration of multi-criteria evaluation technique with GIS for sustainable land uses in Kenya; maximizing revenues from crops and livestock production, food output and district self-reliance in agricultural production and minimizing environmental damages from the erosion.

The objective of this study was to determine flood vulnerable areas in rangelands of Gilard basin in Damavand, Iran using Spatial Multi-criteria Evaluation technique (Analytical Hierarchy Process-AHP) and Ranking Method.

Materials and Methods

Study area

Gilard Basin lies in the eastern corner of Tehran province (lat 35˚- 37′-12″ to 35˚-43′-00″ N and long 51˚-51′-00″to 52˚-04′-06″E) and is one of the sub basins of Damavand River (Fig. 1).This basin is limited from east and south to Damavand River, from north to Chenar-e-Gharb Village and its highlands and from west to Abbas Abad Village and its highlands. Perimeter of basin is 51km. Altitudinal range is from 1330 m to 2365 m a.s.l. Mean annual rainfall is 381.7 mm and mean annual temperature is 20.7 °C (natural resource office documents of Damavand). The basin is known as a source for grazing but persistent incidences of flood have mitigated the effective utilizations of this basin by the populace of this region resulted in the underutilization of these resources.

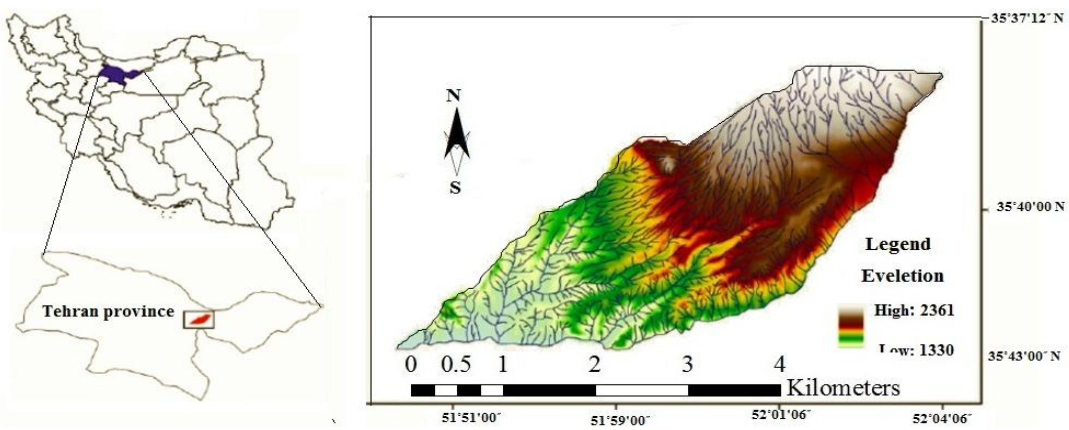


Fig. 1. Geographic location of study area

Selection and evaluation of criteria

The selection of criteria that has a spatial reference is an important step in multi criteria decision analysis (Malczewski, 1996). The criteria used in this study were selected due to their relevance in the study area listed below:

- Mean annual rainfall (precipitation) -which has a direct relationship with flood incidences.
- Drainage network of the river basin - which has a converse relationship with flood incidences.
- Slope of the basin- which has a converse relationship with flood incidences.
- Soil hydrologic group types- soils with heavy textures has a high flood incidence probability as compared to soils with light textures.
- Land use-which urban and settled areas has a high flood incidence probability as compared to the parks and gardens.
- Time of concentration- which has a converse relationship with flood incidences.
- Miller coefficient- which has a direct relationship with flood incidences.
- Basin area- which has a direct relationship with flood incidences.

Materials

Data and materials that used in this study consist of:

- Topography map of study area in 1:50000 scale,
- Digital Elevation Models (DEM) layer of study area,
- Soil texture map of study area in 1:50000 scale,
- Land use map of study area in 1:50000 scale,
- Meteorological data of study area for preparation of annual rainfall layer,
- Geologic map of study area in 1:50000 scale and
- Assemblage other researches of study area and field visit.

Methods

Basically, two phases were applied in this study to analyze the flood vulnerability structure: 1-) to determine effective factors causing flood and 2-) to apply several approaches to conduct Multi Criteria Evaluation (MCE) in a GIS environment in order to evaluate and find the flood vulnerable areas. This study provides useful ways to examine the alternatives and evaluate the specific criteria to reduce uncertainty for the decision solutions. Spatial Multi Criteria Decision Making Method (MCDM) aims to achieve solutions for spatial decision problems derived from multiple criteria. These criteria also called attributes must be carefully identified to achieve the objectives and final goal. The performance of an objective is measured with the help of these attributes. Generally, for the determination of flood vulnerable area, after appointment of flood interference factors to flood occurrences, these factors based on their priority have been sorted and weighted. Then, effective sub-factors of criteria were determined and weighted and at last, from the multiplication of them, the total weight of each criterion that interferes in flood was extracted. Minimum and maximum limits of criteria weights are determined as the amounts of flood risk in the study area presented in the maps.

Multi criteria analysis

Multi criteria analysis is applied in producing and combining spatial data describing the causing factors. Multi criteria analysis techniques are known as suitable tools to support the decision making in complex problems with regard to technical, socio-economic and environmental aspects. Multi criteria analysis method is a multi-variable deciding method which consists of three principals: analysis, judgment, and comparison and priority combination. The analysis principals need to breakdown decision making problems into various elements in the form of hierarchy i.e. making a tree structure for a criterion and a sub-criterion. The judgment principal's emphasis is on twin comparison of criteria based on the elements of each level for calculating the relative significance. This weight can be calculated in an individual sense or from expert's opinions and the resulted twin comparison may be presented in a matrix framework named priority matrix (Qodsipor, 2005). For the determination of accuracy rate and weighting uses, consistency coefficient is defined as (Equation 1):

$$CR = CI / RI \quad \text{(Equation 1)}$$

Where

CR is consistency ratio and RI is the mean adaptation index. CI is the adaptation index extracted directly from priority matrix (Equation 2):

$$CI = (\lambda_{max} - n)/(n-1) \quad \text{(Equation 2)}$$

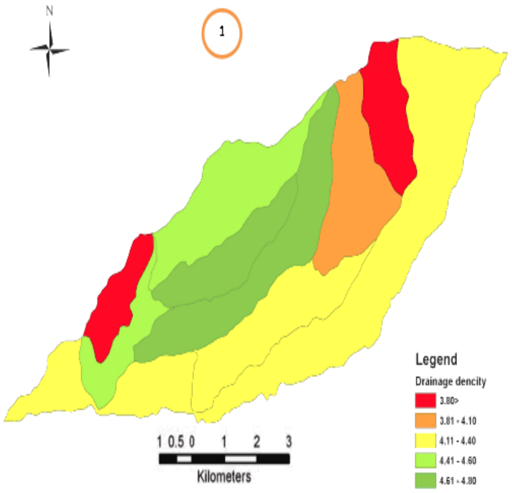
λ_{max} is the greatest amount of priority matrix and n is the degree of matrix. Generally, if CR is lesser or equal to 0.1, system adaptation will be acceptable; otherwise, initial values must be reviewed. Analytical Hierarchical Process (AHP) is a multi-criteria decision making technique which provides a systematic approach for assessing and integrating the impacts of various factors involving several levels of dependent or independent, qualitative as well as quantitative information (Rafikul, 2003). It is a methodology to evaluate often conflicting and qualitative criteria systematically (Saaty, 1980). Like other multi-attribute decision models, AHP also attempts to resolve conflicts and analyze judgments through a process of determining the relative importance of a set of activities or criteria by pairwise comparison of these criteria on a 9-point scale. In order to do this, a complex problem is first divided into a number of simpler problems in the form of a decision hierarchy (Erkut and Moran, 1991). AHP is often used to compare the relative preferences of a small number of alternatives concerning an overall goal. AHP is becoming popular in decision-making studies where conflicting objectives are involved. Recently, a new method known as Spatial – AHP has been introduced to identify and rank the areas that are suitable for a landfill using knowledge-based user preferences and data contained in GIS layers.

Classification of criteria values

Based on research review of similar works about flood vulnerability analysis through MCDA methods and GIS, the most important criteria for this intension are mean annual precipitation, basin area, basin slope, drainage density, soil hydrologic group, miller coefficient, time of concentration, land use and sedimentation rate. Each of these criteria regarding their importance in flood incidence has been broken into subclasses for the preparation of related maps (Fig. 2). In (Fig. 2), Shapes No 1, 2, 3, 4, 5, 6, 7, 8 and show categorical maps of drainage density, slope classes, annual rainfall, land cover, time of concentration, soil hydrological types, sediment rate, Miller coefficient and the basin area, respectively. Then, such as for AHP ranking values (values from 1 to 9), each subclass was ranked. Normalization of flood occurrence criteria showed that Mean Annual Rainfall (26.5%) and Sedimentation Rate (2.01%) had higher and lower values in flood incidence vulnerability (Table 1). These values have been extracted by multiplying the values of normal weight column of (Table 1).

Table 1. Criteria and sub criteria effects on flood occurrence in Gilard basin

Criterion	Sub Criterion Classes	Value	Normal Weight
Mean annual rainfall (mm)	258-274	1	0.2651
	274-325	2	
	325-351	3	
	351-377	5	
	377-428	7	
	428-480	9	
Basin area(km^2)	3.99-6.84	1	0.2273
	6.84-9.87	3	
	9.87-12.88	5	
	12.88-20.22	7	
	20.22-40.18	9	
Basin slope(degree)	21-35	1	0.1457
	15-21	2	
	11-15	3	
	7-11	5	
	4-7	7	
	0-4	9	
Drainage density(km/km^2)	>4.8	1	0.1236
	4.6-4.8	2	
	4.4-4.6	3	
	4.2-4.4	5	
	3.8-4.2	7	
	3.8>	9	
Soil hydrologic group	A	1	0.0776
	B	5	
	C	7	
	D	9	
Miller coefficient	0.16>	1	0.0651
	0.17-0.29	3	
	0.30-0.37	5	
	0.38-0.52	7	
	0.53-0.60	9	
Time of concentration(hours)	1.82-3.58	1	0.0413
	1.30-1.82	3	
	1.02-1.30	5	
	0.65-1.02	7	
	0.61-0.65	9	
Land use	Rangelands(A)	1	0.0341
	Gardens(B)	2	
	Cropland(C)	3	
	Flood plains(D)	5	
	Urban area - Abandonment lands(E)	7	
	Residential lands (F)	9	
Sedimentation rate	Negligible(I)	1	0.0201
	Rather low(III)	3	
	Medium(IV)	5	
	Rather high(V)	9	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1
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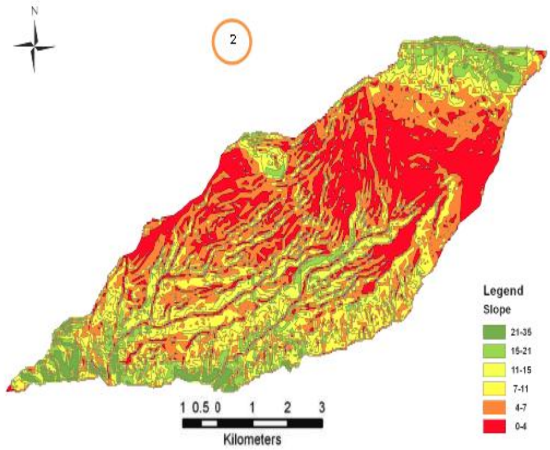
4.11 - 4.40
4.41 - 4.60
4.61 - 4.80
1 0.5 0 1 2 3
Kilometers


N
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7-11
4-7
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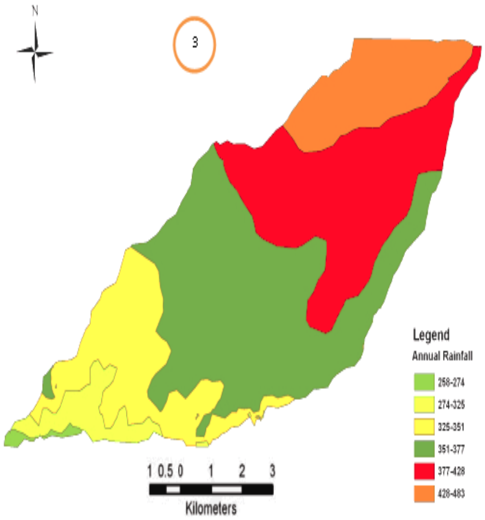
Kilometers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274-325
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351-377
377-428
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1 0.5 0 1 2 3
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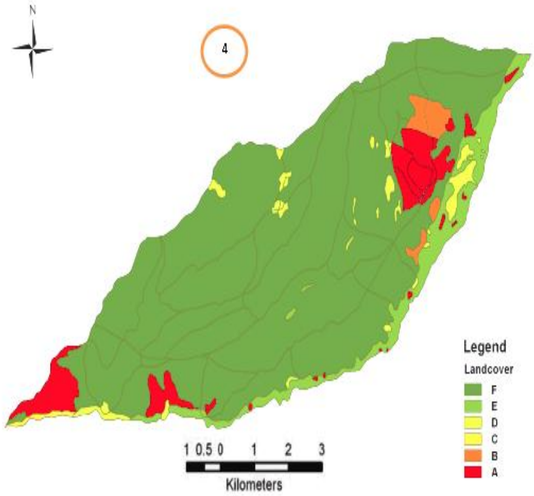
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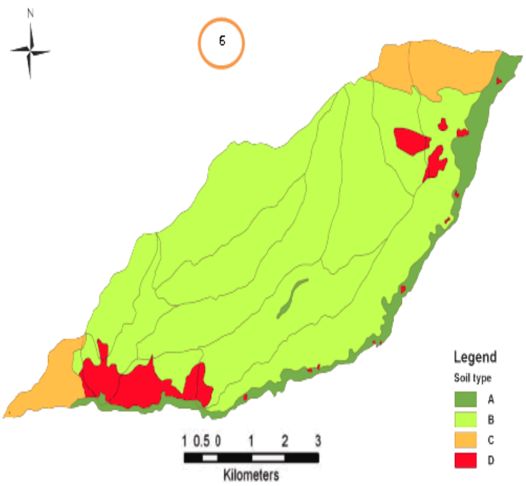
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Soil type
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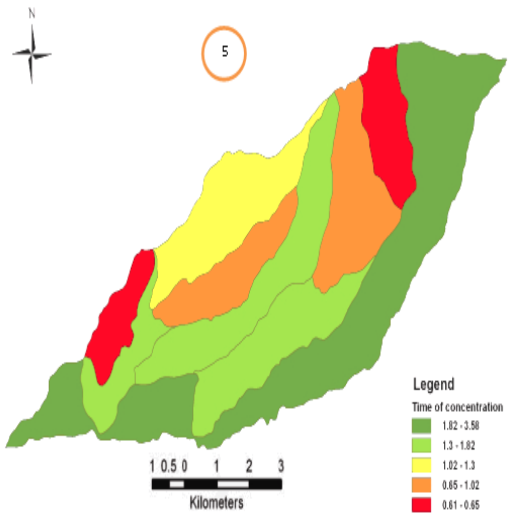
B
C
D
1 0.5 0 1 2 3
Kilometers


N
5
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Time of concentration
1.82 - 3.58
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0.65 - 1.02
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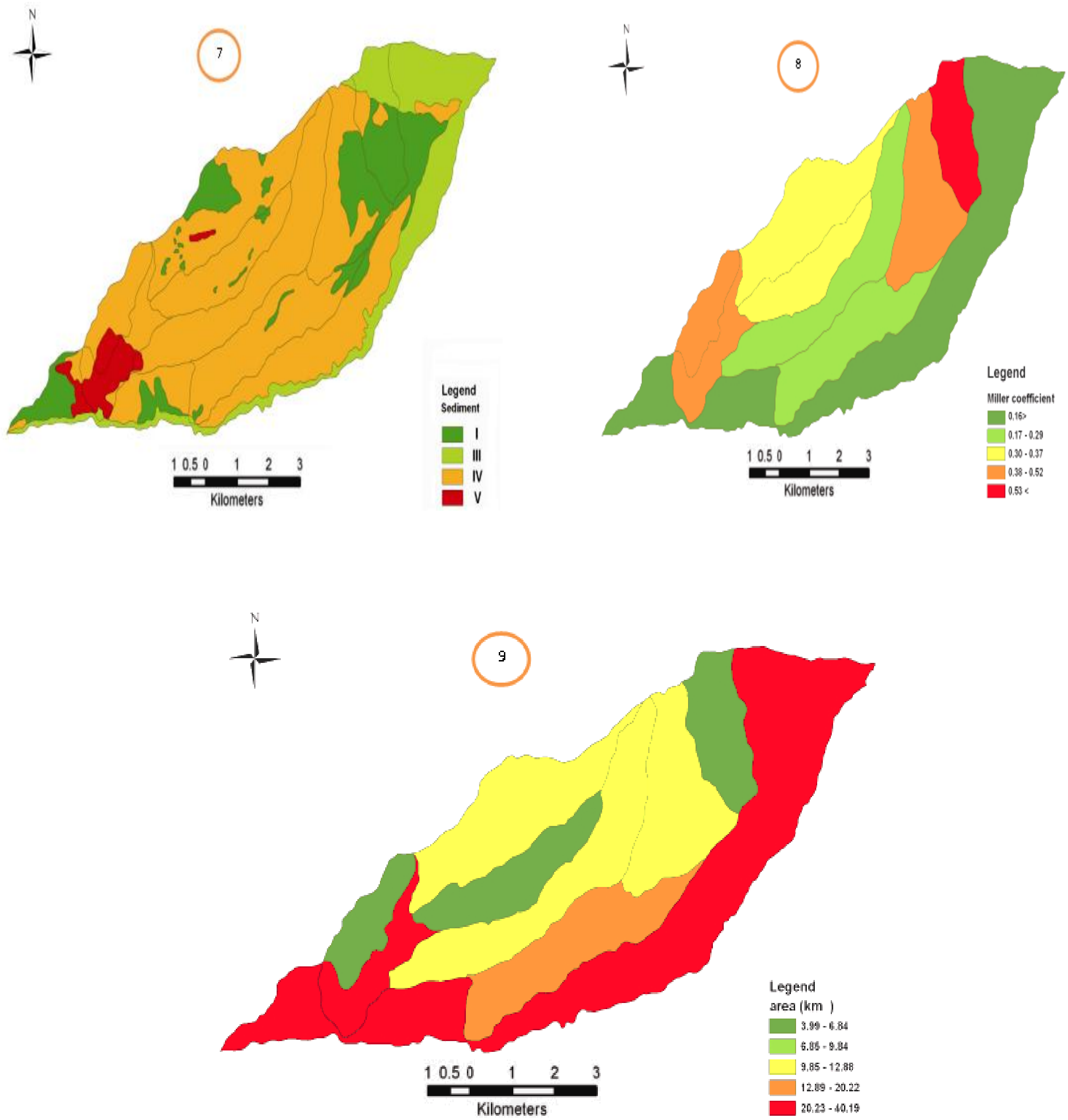

Fig. 2. Resulted layers from weighting the criteria of flood occurrence of Gilard basin

Results

After the determination of causes and criteria that affected flood occurrence in Gilard basin, these causing factors have been sorted and weighted based on multi variable analysis. Then, the given layers were weighted and combined in GIS environment and the classified map of flood occurrence probability was produced (Fig. 3). Final composite map showing the flood vulnerable areas has been created using multi criteria evaluation methods with GIS (Fig. 4). In this research, range numbers are designated as Very High, High, Medium, Low and No Risk on the output map depicting the levels of flood vulnerability of the study area. Percentages of the related zones concerning flood vulnerability were also calculated as 7%, 32%, 42%, 17% and 2%, respectively.

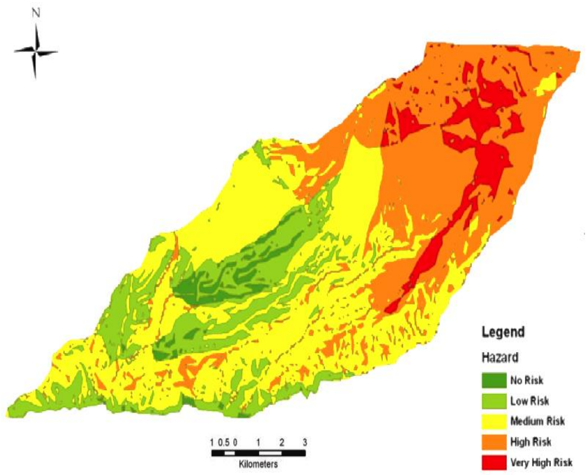

Fig. 3. Classified flood occurrence probability map of Gilard using AHP method

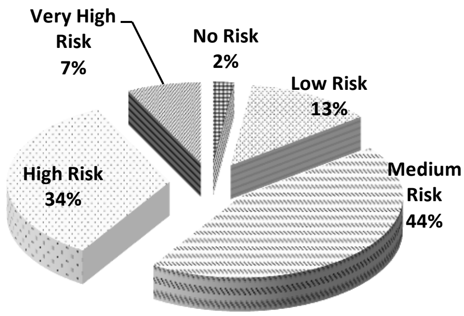

Fig. 4. Class percent of flood risk probability in Gilard basin

Discussion and Conclusion

The flood vulnerable map can give planners, insurers and emergency services a valuable tool for assessing flood risk (Sanders and Tabuchi, 2000). Each of them needs to assess risk for more than one scenario. A project including these vulnerability maps should be used for land planning and management alternatives (Barroca *et al.*, 2006). The study also reviewed the role of GIS in decision making and then outlined the evaluation approach for many criteria in decision process. The design of multi criteria environment attempted to use a variety of evaluation techniques for specific data from GIS and present them in a manner that is familiar to decision makers. By integrating the evaluation techniques with GIS, it was intended that the effective factors would be evaluated more flexibly and thus, more accurate decisions would be made during a short period by the decision makers. By evaluating the criteria, the values of the criteria were classified to explain the opinions and preferences.

The results of this study indicated that dominant study areas (Gilard basin) have moderate to very high flood vulnerabilities. Field visit of study area confirmed the results of this research; thus, land uses, land cover types and erosion conditions have a good correlation with high risk areas. At the same time, results of this study confirmed the results of other studies about factors affecting flood vulnerability. For the rangelands, some of range condition factors must be added to factors used in such studies.

Due to the effects of flood, there is a need to look for the ways to mitigate it. Some arrangements must be developed and evaluated to deal with the problems. Considering the study, the following recommendations are made to tackle the problem of flood and for further studies:

- Developmental projects on flood prone areas should be critically analyzed on the basis of effective factor causing flood in order to mitigate the hazard.
- Afforestation and plant restoration should be encouraged on the areas liable to flood; this is a measure to reduce the risk inherent.
- More studies should be undertaken to establish new techniques for evaluating the criteria.

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ارزیابی آسیب پذیری سیلاب در اراضی مرتعی حوزه آبخیز گیلارد دماوند، با استفاده از روش آنالیز چند معیاره و سیستم اطلاعات جغرافیایی

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چکیده. در میان بلایای طبیعی، سیلاب‌ها به دلیل اثرات مخربی که ایجاد می‌نمایند (بخصوص در اراضی مرتعی) از اهمیت فراوانی برخوردار هستند. تعیین اولویت مناطق آسیب‌پذیر به خطر سیل گرفتگی برای تصمیم‌سازان (با توجه به زمان و هزینه) به منظور انجام برنامه‌ریزی و مدیریت دقیق بسیار مهم و ضروری است. سیستم‌های اطلاعات جغرافیایی (GIS) در ترکیب با شیوه‌های آنالیز چند متغیره (MCDA)، برای ارزیابی مناطق آسیب‌پذیر به سیلاب بکار گرفته می‌شوند. هدف از این تحقیق، فراهم نمودن شرایط صحیح‌تر تصمیم‌گیری در زمینه ارزیابی عوامل موثر بر وقوع سیلاب در اراضی مرتعی کوهستانی می‌باشد. بدین منظور، ابتدا عوامل موثر برای وقوع سیل در منطقه بررسی شد و مهم‌ترین آن‌ها شامل میزان بارندگی سالانه، مساحت حوزه، شیب حوزه، شبکه زهکشی، کاربری اراضی و نوع خاک شناسایی و ارزیابی شدند. سپس با گردآوری اطلاعات مکانی و توصیفی عوامل یاد شده در حوزه گیلارد و با استفاده از فرآیند تحلیل سلسله مراتبی (AHP)، اقدام به دسته‌بندی و وزن‌دهی این عوامل گردید. در پایان بر حسب وزن نهایی به دست آمده، میزان خطرپذیری حوضه در مقابل سیلاب‌ها، دسته‌بندی گردیده و نتایج به صورت نقشه و نمودارهای آماری ارائه شد. نتایج این تحقیق نشان داد که از میان عوامل مذکور، میزان بارندگی سالانه (۲۶/۵ درصد) و کاربری اراضی (۳/۴ درصد) به ترتیب، بیشترین و کمترین تاثیر را در وقوع سیلاب دارا بودند.

کلمات کلیدی: سیلاب، آنالیز چند معیاره، سیستم اطلاعات جغرافیایی، فرآیند تحلیل سلسله مراتبی