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Original Article

Evaluating the Vulnerability of Agricultural Land Use to the Landslide Risk in Rural Areas (Case Study: Tarom County)

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Abstract

Purpose- Landslides are major hazards to human activities, which often wreak havoc on economic resources, damaging properties and facilities in rural areas. The present study, considering that a perquisite of any development and planning is the recognition of the geographical features in an area, investigated the risk of landslide due to the expansion of agricultural land uses in rural areas.

Design/Methodology/Approach- This is an applied research that sought to examine the research background and select the most appropriate methods. Accordingly, it adopted a mixture of quantitative methods (fuzzy Delphi and fuzzy best-worst method), GIS and remote sensing techniques to achieve the research goal.

Findings- According to the research findings, with increasing height, slope and vicinity to the fault lines, the risk of landslides rises in the study areas. These areas are mostly located in the highlands and the eastern and western regions, where rural areas are chiefly distributed. However, the majority of rural areas are distributed in the middle areas, which have better access to water resources and are in more favorable conditions due to topographic factors. Meanwhile, agricultural lands, due to the use of river water resources, have been distributed in the middle areas, which are classified as low risk areas in terms of landslides. In contrast, due to the limited flat lands in highlands, agricultural gardens have developed in highlands with a moderate slope, which subsequently pose the risk of landslide. Therefore, the regular monitoring of land use development to increase the safety factor in new housing construction and agricultural lands is one of the planning requirements for land use development in mountainous rural areas.

Keywords: Environmental Hazards, Landslide, Fuzzy Best-Worst Method, Tarom County.

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1. Introduction

According to research conducted by the Center for Epidemiology, landslides account for about 17% of all deaths related to natural hazards worldwide (Kanungo et al., 2012; Pourghasemi et al., 2012). Landslides are often recognized as one of the most devastating and widespread natural disasters in the world and a leading cause of death and economic losses (Achour et al., 2017; Chen et al., 2018; Das et al., 2012; Pourghasemi et al., 2012). As Petley (2012) points out, landslide-associated losses and its destructive effects are more prominent in less developed countries, which is mainly rooted in the misconception of landslide hazards and the lack of appropriate resources (Razak & Mohamad, 2015). Landslides are more prevalent in mountainous areas and every year a host of landslides are reported in these areas (Lin et al., 2017; Shahabi et al., 2014). Given the future trends of these regions, as well as growing urbanization and unplanned development, deforestation and growing regional rainfall due to climatic changes, especially in earthquake-prone areas, this natural phenomenon in expected to be intensified in the future (Goetz et al., 2011; Kanungo et al., 2012). It would be of great concern, especially to mountain dwellers.

As regards mountainous areas, it is obvious that the spatial deployment of rural areas in these areas is more affected by natural factors such as access to water, flat land and fertile soil, and therefore scant attention has been paid to factors such as natural hazards. As such, many rural areas are developed in areas that are vulnerable to natural disasters. In this regard, and shown by the research, most of the rural settlements in Tarom city are deployed in mountainous areas (Table 1). In this context, during the past years, due to the prosperity of agricultural activities and the favorable environment of Tarom city for these activities, many agricultural activities and gardens have developed in valleys and the foothills. In some rural areas (Tahm, Chavarzagh, etc.), the sudden onset of landslides wreaks havoc on these agricultural uses. Accordingly, this study, recognizing the importance of land study prior to any planning for land use, investigates the development of agricultural land uses in rural areas of Tarom city with respect to the risk of landslides in these areas.

Table 1. Distribution of residential areas (rural and urban) of Tarom city in natural types
(Source: Statistic Center of Iran, 2011 & field observations, 2020)

Area	District	County	SUM	Frequency	Plain	Frequency	Mountainous	Frequency
Rural	Chavarzagh	Chavarzagh	30	%19.9	3	%10	27	%90
		Dastjerdeh	19	%12.6	6	%31.6	13	%68.4
	Central	Abbar	17	%11.3	8	%47.1	9	%52.9
		Deram	41	%27.2	5	%12.2	36	%87.8
		Gilvan	42	%28.8	10	%23.8	32	%76.2
Urban			2	%1.3	1	%50	2	%50
SUM			151	%100	33	%100	118	%100

Apart from zoning areas for landslides, the importance of addressing this issue is linked to the inadequate development of agricultural land uses, which are one of the main assets of rural households.

2. Theoretical foundations of research

Agricultural lands, which make up 40% of rural areas worldwide (Lesiv et al., 2019) are of the main land uses that have received growing attention due to the rising population and the need for food supply, development and exploitation of lands in rural areas. Meanwhile, despite the importance of land development and exploitation for agriculture in rural areas, it is necessary to recognize the use of land to mitigate the vulnerability of agricultural lands to natural disasters, particularly in mountainous areas that are prone to natural hazards. Landslides are one of the most prevalent natural disasters in mountainous areas. "Slide" is the motion of a mass under the impact of gravity, which is seen as a random process owing to the interaction of complex and unknown geographical, environmental and physical factors (Das et al., 2012). Landslides, unpredicted and destructive, are often considered as a natural hazard. Regarding landslides, risk assessment and zoning are the main measures in disaster risk management (Ambrosi et al., 2018) and one of the essential tools in any program. the main purpose of which is to mitigate the impact of natural disasters in the future (Skilodimou et al., 2019).

Over the past few decades, considering the importance of risk assessment of natural hazards such as landslides, a variety of methods have been developed for hazard mapping worldwide (Achour et al., 2017), among which GIS and remote sensing techniques have been widely utilized to assess areas more susceptible to landslide (Pirasteh & Li, 2017; Pirasteh et al., 2018; Shahabi et al., 2015). GIS (Kayastha et al., 2013; Wan et al., 2010), logistic regression models (Bui et al., 2016; Chen et al., 2019; Das et al., 2010), bivariate and multivariate methods have been introduced in many studies as a suitable method for determining landslide susceptibility (Choi et al., 2012; Meinhardt et al., 2015; Regmi et al., 2014; Zhang et al., 2016). Moreover, one way of evaluating a new approach is using the multivariate decision making methods, which is frequently used in research in combination with GIS method (Feizizadeh & Blaschke, 2014; Kayastha et al., 2013; Trinh et al., 2016). About Iran, this issue has been studied by Arab Ameri et al. (2018), Saffari & Hashemi (2017), Mansouri et al. (2016), Saffari (2014), and Moghimi et al. (2012). The Fuzzy Delphi decision making, AHP, ANP, Boolean logic and entropy methods have been employed to assess landslide risk. However, as the review of these studies suggests, they have primarily focused on zoning areas at the risk of landslide and scant attention has been paid to risk assessment relative to land use development. With this in mind, the present study, by reviewing the research background and selecting the most appropriate methods, aimed at assessing the risk of landslide with respect to the development of agricultural land uses in rural areas.

3. Research Methodology

3.1 Geographical Scope of the Research

The study area was Tarom County in Zanjan province, Iran. According to the latest political divisions of the country, this county comprises two central districts, Central and Chavarzagh. The Central districts comprises three villages of Abbar, Gilvan and Darram and Chavarzagh districts also includes two villages of Chavarzagh and Dastjerdeh. According to the last census (2016), this county had a population of 46641 people, of which 21% lived in urban areas and 79% in rural districts of the county. In addition to the great geographical distribution of rural areas, the topographic type of rural and urban settlements in this city indicates that most settlements are located in mountainous and uneven areas. As regards employment and economic activities, considering the climatic and environmental conditions, horticulture, agriculture, services and industry sectors are the main source of employment, respectively. Figure 1 shows the geographical location of Tarom city.

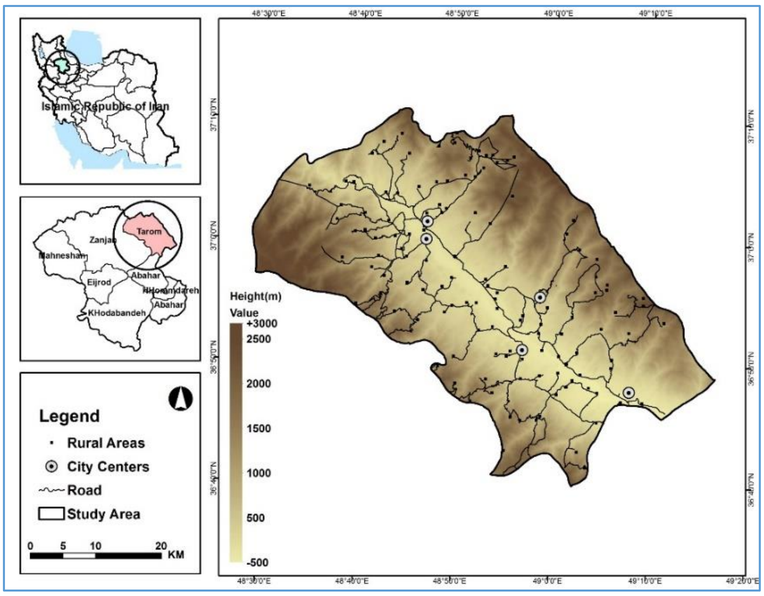

Figure 1. Geographical location of the study area

3.2. Methodology

The adoption of appropriate criteria for the intensity and susceptibility of landslides is a key step in its hazard analysis, on which the accuracy of research results is dependent. Accordingly, in the first step of the research, the criteria affecting the risk of landslides are determined based on similar studies and climatic conditions of the study area, Table 2.

Table 2. Criteria influencing landslides

Factor	Conditions of the study Area	Background of the Research
Height	Highlands in most of study areas	(Blahut et al., 2010; Chen et al., 2017; Ghimire, 2011; Kornejady et al., 2018; Zhang et al., 2015; Akgun, 2012; Bălteanu et al., 2010; Blahut et al., 2010; Chen et al., 2017)
Slope		
Slope directions		
Distance from river	The Ghezel Ozan river running through the study area and natural river flowing in some regions	
Distance from fault	The fault extending across the study area as well as Rudbar and Tarom earthquakes in 1990	(Blahut et al., 2010; Akgun, 2012; Chen et al., 2017; Zhang et al., 2015)
Geology	Geological formation in most of studied areas, low permeability to rainfall	(Bălteanu et al., 2010; Chen et al., 2017; Ghimire, 2011; Zhang et al., 2015)
Rain	Rainfall and high relative humidity in the study area due to highlands and the Ghezel Ozan River	(Bălteanu et al., 2010; Chen et al., 2017; Zhang et al., 2015)
Relative humidity		
Land Use	Most of lands in the study areas are barren and arid lands. Also, highlands in the study areas are devoid of vegetation due to soil erosion	(Bălteanu et al., 2010; Blahut et al., 2010; Ghimire, 2011; Kornejady et al., 2018)
Vegetation		(Blahut et al., 2010; Chen et al., 2017; Ghimire, 2011; Singh et al., 2014)
Distance from road		(Akgun, 2012; Chen et al., 2017)

To screen the criteria, the experts' opinion in fuzzy Delphi method was used. It was intended to draw on experts' consensus regarding the selection of appropriate criteria as the research basis, and to analyze experts' stances more precisely in a fuzzy space. The instrument was a researcher-made questionnaire based on fuzzy Delphi spectrum (Table 3). A total of 10 university professors with a relevant educational background were randomly selected from the target population. The questionnaire first explained the main purposes of the research as well as the importance of accuracy in answering questions. Then, respondents were asked to state another factor related to the research goals besides the specified criteria.

Table 3. Range of linguistic terms and numerical scale of fuzzy Delphi method

Linguistic Terms	Very Low	Low	Median	High	Very High
Fuzzy numbers	(0, 0, 0.25)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1)	(0.75, 1, 1)

Appropriate screening criteria were selected and then based on the type of information obtained from each criterion, the zoning maps were drawn in ARC GIS, ENVI. These criteria were weighted using the best-worst method (BWM). This is one of the most effective methods for weighting the criteria, which was first proposed by Rezaei (2015). This method is superior to the AHP hierarchical method due to the compatibility ratio between the evaluation criteria. Given that this method has a lower pairwise comparison, it provides more reliable results (Rezaei, 2015). In this method, first the most and least important criteria and sub-criteria in terms of the highest and lowest scores were determined using fuzzy Delphi method. Then, a pairwise comparison questionnaire was developed (Table 4). The specialized questionnaire was filled out by 15 university professors acquainted with the research subject.

Table 4. Range of linguistic terms and numerical scale of the best-worst fuzzy method

Linguistic terms	Equal importance (EI)	Low importance (WI)	Fair importance*(FI)	Very important (VI)	Absolutely important (AI)
$\tilde{a}_{BW}$	(1, 1, 1)	(2.3, 1, 3.2)	(3.2, 2, 5.2)	(5.2, 3, 7.2)	(7.2, 4, 9.2)

After collecting the questionnaires, the data was fuzzily merged and its codes were weighed in the LINGO. After controlling the adjustment rate, the final weight of the criteria and sub-criteria was calculated. Then, by applying the weight of each criterion to the zoning map, the landslide risk map in the study area was drawn. However, to design a land use map for a 15-year period, Landsat 8 and 7 images were obtained for the study area. After pre-processing the images and enhancing the spatial separation and mosaicization of the satellite images, the land use map was identified using the maximum probability classification method for 6 land uses. After classification, for the verification and calculation of error matrix with terrestrial data, a comparison was drawn between samples of land use map and terrestrial data (GPS) (Figure 2). Finally, after overlapping landslide hazard map and land uses, residential areas and land use development were identified as landslide risk.

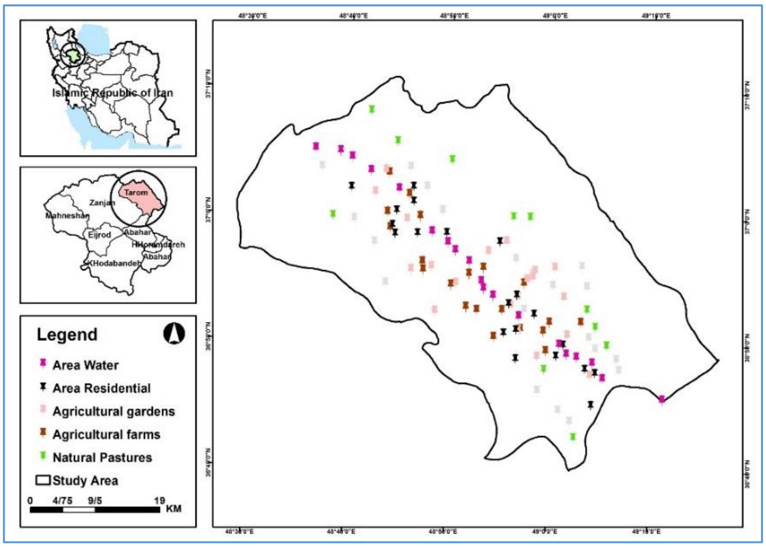

Figure 2. Land harvested points for validation of land use classification map

4. Research Findings

The target population was selected from among academic experts using fuzzy Delphi method. In this method, the questionnaire data was defined as triangular fuzzy numbers for each criterion and then the responses to the questionnaires were integrated according to Equation 1

.

$$a_j = \min\{a_{ij}\} \quad , \quad b_j = \frac{1}{n}\sum_{i=1}^{n} b_{ij} \quad , \quad c_j = max\{c_{ij}\} \quad , \quad Crisp = \frac{a_j + b_j + c_j}{3}$$

Equation 1. Fuzzy Delphi method

The median fuzzy value was set at 0.500 as the minimum fuzzy value to confirm the appropriateness of the criteria Accordingly, only the criterion of distance from main roads was removed as an inappropriate criterion (Table 5). Moreover, in the suggestions section, the experts approved the study criteria without offering any parameter.

Table 5. Fuzzy value of expert opinions and the appropriateness of each criterion

Factor	Answer 5	4	3	2	1	SUM	Fuzzy value		Review	Consensus
Height	1	9	-	-	-	10	(0.5, 0.77, 1)	0.757	Suitable	%90
Slope	1	7	2	-	-	10	(0.25, 0.71, 1)	0.654	Suitable	%70
Slope directions	-	2	8	-	-	10	(0.25, 0.54, 1)	0.597	Suitable	%70
Distance from fault	2	7	1	-	-	10	(0.25, 0.76, 1)	0.671	Suitable	%70
Rain	2	5	3	-	-	10	(0.25, 0.70, 1)	0.651	Suitable	%70
Relative humidity	-	3	7	-	-	10	(0.25, 0.56, 1)	0.605	Suitable	50/.
Distance from river	1	2	7	-	-	10	(0.25, 0.58, 1)	0.610	Suitable	70/.
Vegetation	2	2	6	-	-	10	(0.25, 0.62, 1)	0.624	Suitable	60/.
Geology	-	4	6	-	-	10	(0.25, 0.59, 1)	0.613	Suitable	60/.
Land Use	-	2	7	1	-	10	(0, 0.51, 1)	0.502	Suitable	70/.
Distance from main roads	-	-	-	-	2	10	(0, 0, 0.75)	0.250	Unsuitable	40/.
SUM	9	43	51	5	2	-	-		-	-

The highlands are characterized with steep slope and instable foothills. Hence, in mountainous areas, mass displacements, especially landslides, are more probable. In terms of final weight, the physical criterion and land cover were determined as the most and the least important criterion, respectively. As regards physical criterion, the sub-criterion of height and slope directions were the most and the least important sub-criteria, respectively. As for hydrological criterion, rainfall and the distance from the river and as for land cover criterion, vegetation and land use were determined as the most and the least important sub-criteria for the landslide risk, respectively (Table 6).

Table 6. Fuzzy Delphi final weight and determination of the most and the least important criteria by BWM method

Method BWM	Row	Final Delphi fuzzy weight	Sub-criterion	Method BWM	Final Delphi fuzzy weight	Factors
Important	1	0.117	Height	Important	0.424	Physical
-	3	0.107	Slope			
Least important	9	0.091	Slope directions			
-	2	0.110	Distance from fault			
Important	4	0.107	Rain	-	0.298	Hydrogeology
Least important	8	0.092	Relative humidity			
-	6	0.100	Distance from river			
Important	5	0.102	Vegetation	Least important	0.278	Land cover
-	7	0.093	Geology			
Least important	10	0.082	Land Use			
-	-	1	-	-	1	SUM

After identifying important and irrelevant criteria, the paired questionnaire was prepared by the BWM method and filled out by 15 university professors, as shown in Figure 3.

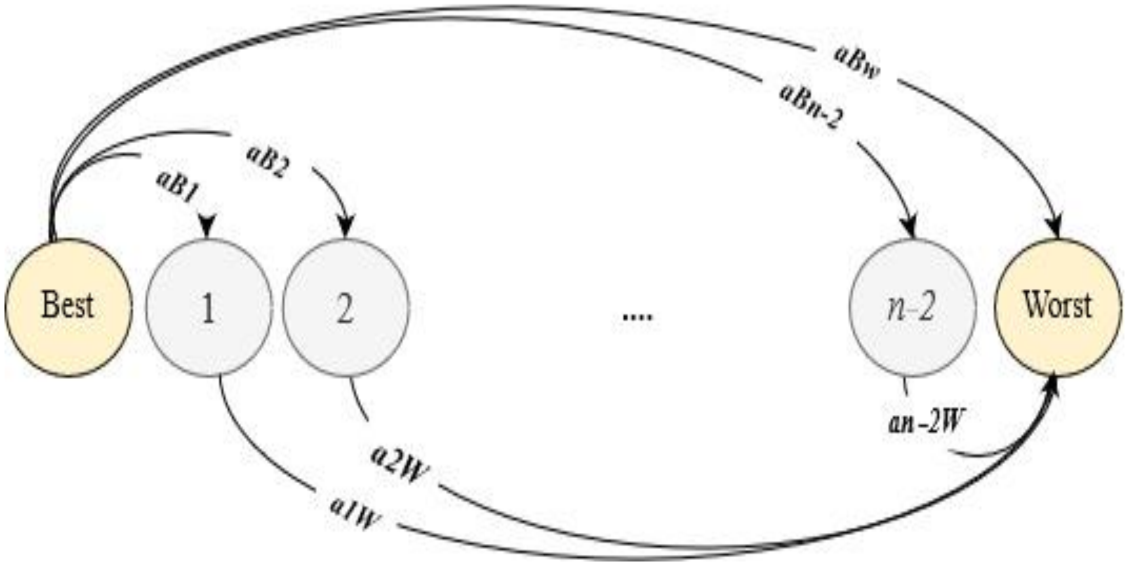

Figure 3. Paired comparison of the best and worst alternatives using the BWM method

From a gender perspective, the majority of experts were male. They were chiefly in the age group of 40-60 years and held the position of assistant professors. As for the field of study, most respondents were specialized in natural geography, as shown in Table 7.

Table 7. Demographic characteristics of the participants in the BWM

Gender	Frequency	Percent	Field of Education	Frequency	Percent
Man	11	%73.3	Rural planning	3	%20
Female	4	%26.7	Geomorphology	4	26.7%
SUM	15	%100	Climatology	4	%26.7
Age Group	Frequency	Percent	Geology	4	%26.7
More than 60 years	4	%26.7	SUM	15	%100
40 to 60 years	7	%46.7	Education	Frequency	Percent
20 to 40 years	4	%26.7	Professor	2	%13.3
Less than 20 years	0	%0	Associate	4	%26.7
Not stated	0	%0	Assistant Professor	6	%40
SUM	15	%100	PhD	3	%20
			SUM	15	%100

Pairwise comparison judgments of criteria and sub-criteria were merged in the form of fuzzy numbers, based on the most and the least important parameters, as shown in Table 8. Then, according to Equation 2, in the LINGO program, the fuzzy value of each criteria and sub-criteria is obtained.

Table 8. Fuzzy integration of criteria and sub-criteria based on Pairwise Comparison of the most and the least important criteria

Factors	Important	Fuzzy integration	Least important	Fuzzy integration
Physical	Physical	(1, 1, 1)	Land cover	(0.67, 3, 4.5)
Hydrogeology		(0.67, 2, 4.5)		(0.67, 1, 2.5)
Land Cover		(0.67, 3, 4.5)		(1, 1, 1)
Sub-criteria	Important	Fuzzy integration	Least important	Fuzzy integration
Height	Height	(1, 1, 1)	Slope directions	(1.5, 3, 4.5)
Slope		(0.67, 1, 2.5)		(0.67, 2, 3.5)
Slope directions		(1.5, 3, 4.5)		(1, 1, 1)
Distance from fault		(0.67, 1, 1.5)		(0.67, 2, 3.5)

Factors	Important	Fuzzy integration	Least important	Fuzzy integration
Rain	Rain	(1, 1, 1)	Distance from river	(0.67, 2, 4)
Relative humidity		(0.67, 1, 2.5)		(0.67, 1, 2.5)
Distance from river		(0.67, 2, 4)		(1, 1, 1)
Vegetation	Vegetation	(1, 1, 1)	Land Use	(0.67, 1, 2.5)
Geology		(0.67, 1, 2.5)		(0.67, 1, 2.5)
Land Use		(0.67, 1, 2.5)		(1, 1, 1)

$$
s.t.\begin{bmatrix}
\min k \\
\left|\dfrac{(l_B^w, m_B^w, u_B^w)}{(l_j^w, m_j^w, u_j^w)} - (l_{Bj}, m_{Bj}, u_{Bj})\right| \le (k^*, k^*, k^*) \\
\left|\dfrac{l_j^w, m_j^w, u_j^w}{l_B^w, m_B^w, u_B^w} - (l_{jW}, m_{jW}, u_{jW})\right| \le (k^*, k^*, k^*) \\
\sum_{j=1}^{n} R\left(\widetilde{W}_j\right) = 1 \\
l_j^w \le m_j^w \le u_j^w \\
l_j^w \ge 0 \\
j = 1, 2, \cdots, n
\end{bmatrix}
$$

Equation 2. The best-worst method

$$
\begin{bmatrix}
\min = k; \\
l_{B1}^w - 0.67 * u_{j2}^w \le = k;\, l_{B1}^w - 0.67 * u_{j2}^w \ge = -k; \\
m_{B1}^w - 1 * m_{j2}^w \le = k;\, m_{B1}^w - 1 * m_{j2}^w \ge = -k; \\
u_{B1}^w - 2.5 * l_{j2}^w \le = k;\, u_{B1}^w - 2.5 * l_{j2}^w \ge = -k; \\
l_{B1}^w - 0.67 * u_{j3}^w \le = k;\, l_{B1}^w - 0.67 * u_{j3}^w \ge = -k; \\
m_{B1}^w - 1 * m_{j3}^w \le = k;\, m_{B1}^w - 1 * m_{j3}^w \ge = -k; \\
u_{B1}^w - 2.5 * l_{j3}^w \le = k;\, u_{B1}^w - 2.5 * l_{j3}^w \ge = -k; \\
l_{j2}^w - 0.67 * u_{B3}^w \le = k;\, l_{j2}^w - 0.67 * u_{B3}^w \ge = -k; \\
m_{j2}^w - 1 * m_{B3}^w \le = k;\, m_{j2}^w - 1 * m_{B3}^w \ge = -k; \\
u_{j2}^w - 2.5 * l_{j3}^w \le = k;\, u_{j2}^w - 2.58 * l_{j3}^w \ge = -k; \\
0.167 * l_1 + 0.668 * m_1 + 0.167 * u_1 + 0.167\ * \\
l_2 + 0.668 * m_2 + 0.167 * u_2 + 0.167\ * l_3 + 0.668 * \\
m_3 + 0.167 * u_3 = 1; \\
l_1 \le m_1;\ m_1 \le u_1;\ l_1 \ge 0; \\
l_2 \le m_2;\ m_2 \le u_2;\ l_2 \ge 0; \\
l_3 \le m_3;\ m_3 \le u_3;\ l_3 \ge 0;
\end{bmatrix}
$$

Equation 4. Land Cover sub-criteria in LINGO

$$
,\begin{bmatrix}
\min = k; \\
l_{B1}^w - 0.67 * u_{j2}^w \le = k;\, l_{B1}^w - 0.67 * u_{j2}^w \ge = -k; \\
m_{B1}^w - 2 * m_{j2}^w \le = k;\, m_{B1}^w - 2 * m_{j2}^w \ge = -k; \\
u_{B1}^w - 4.5 * l_{j2}^w \le = k;\, u_{B1}^w - 4.5 * l_{j2}^w \ge = -k; \\
l_{B1}^w - 0.67 * u_{j3}^w \le = k;\, l_{B1}^w - 0.67 * u_{j3}^w \ge = -k; \\
m_{B1}^w - 3 * m_{j3}^w \le = k;\, m_{B1}^w - 3 * m_{j3}^w \ge = -k; \\
u_{B1}^w - 4.5 * l_{j3}^w \le = k;\, u_{B1}^w - 4.5 * l_{j3}^w \ge = -k; \\
l_{j2}^w - 0.67 * u_{B3}^w \le = k;\, l_{j2}^w - 0.67 * u_{B3}^w \ge = -k; \\
m_{j2}^w - 1 * m_{B3}^w \le = k;\, m_{j2}^w - 1 * m_{B3}^w \ge = -k; \\
u_{j2}^w - 2.5 * l_{j3}^w \le = k;\, u_{j2}^w - 2.5 * l_{j3}^w \ge = -k; \\
0.167 * l_1 + 0.668 * m_1 + 0.167 * u_1 + 0.167\ * \\
l_2 + 0.668 * m_2 + 0.167 * u_2 + 0.167\ * l_3 + 0.668 * \\
m_3 + 0.167 * u_3 = 1; \\
l_1 \le m_1;\ m_1 \le u_1;\ l_1 \ge 0; \\
l_2 \le m_2;\ m_2 \le u_2;\ l_2 \ge 0; \\
l_3 \le m_3;\ m_3 \le u_3;\ l_3 \ge 0;
\end{bmatrix}
$$

Equation 3. Main criteria in LINGO

$$
\begin{bmatrix}
\min = k; \\
l_{B1}^w - 0.67 * u_{j2}^w \le = k;\, l_{B1}^w - 0.67 * u_{j2}^w \ge = -k; \\
m_{B1}^w - 1 * m_{j2}^w \le = k;\, m_{B1}^w - 1 * m_{j2}^w \ge = -k; \\
u_{B1}^w - 2.5 * l_{j2}^w \le = k;\, u_{B1}^w - 2.5 * l_{j2}^w \ge = -k; \\
l_{B1}^w - 0.67 * u_{j3}^w \le = k;\, l_{B1}^w - 0.67 * u_{j3}^w \ge = -k; \\
m_{B1}^w - 2 * m_{j3}^w \le = k;\, m_{B1}^w - 2 * m_{j3}^w \ge = -k; \\
u_{B1}^w - 4 * l_{j3}^w \le = k;\, u_{B1}^w - 4 * l_{j3}^w \ge = -k; \\
l_{j2}^w - 0.67 * u_{B3}^w \le = k;\, l_{j2}^w - 0.67 * u_{B3}^w \ge = -k; \\
m_{j2}^w - 1 * m_{B3}^w \le = k;\, m_{j2}^w - 1 * m_{B3}^w \ge = -k; \\
u_{j2}^w - 2.5 * l_{j3}^w \le = k;\, u_{j2}^w - 2.5 * l_{j3}^w \ge = -k; \\
0.167 * l_1 + 0.668 * m_1 + 0.167 * u_1 + 0.167\ * \\
l_2 + 0.668 * m_2 + 0.167 * u_2 + 0.167\ * l_3 + 0.668 * \\
m_3 + 0.167 * u_3 = 1; \\
l_1 \le m_1;\ m_1 \le u_1;\ l_1 \ge 0; \\
l_2 \le m_2;\ m_2 \le u_2;\ l_2 \ge 0; \\
l_3 \le m_3;\ m_3 \le u_3;\ l_3 \ge 0;
\end{bmatrix}
$$

Equation 5. Hydrogeology sub-criteria in LINGO

$$\left[\begin{array}{c} \min = k\,; \\ l_{B1}^{w} - 0.67 * u_{j2}^{w} \leq = k\,; l_{B1}^{w} - 0.67 * u_{j2}^{w} \geq = -k; \\ m_{B1}^{w} - 1 * m_{j2}^{w} \leq = k\,; m_{B1}^{w} - 1 * m_{j2}^{w} \geq = -k\,; \\ u_{B1}^{w} - 2.5 * l_{j2}^{w} \leq = k\,; u_{B1}^{w} - 2.5 * l_{j2}^{w} \geq = -k\,; \\ l_{B1}^{w} - 1.5 * u_{j3}^{w} \leq = k\,; l_{B1}^{w} - 1.5 * u_{j3}^{w} \geq = -k\,; \\ m_{B1}^{w} - 3 * m_{j3}^{w} \leq = k\,; m_{B1}^{w} - 3 * m_{j3}^{w} \geq = -k; \\ u_{B1}^{w} - 4.5 * l_{j3}^{w} \leq = k\,; u_{B1}^{w} - 4.5 * l_{j3}^{w} \geq = -k; \\ l_{B1}^{w} - 0.67 * u_{j4}^{w} \leq = k\,; l_{B1}^{w} - 0.67 * u_{j4}^{w} \geq = -k; \\ m_{B1}^{w} - 1 * m_{j4}^{w} \leq = k\,; m_{B1}^{w} - 1 * m_{j4}^{w} \geq = -k\,; \\ u_{B1}^{w} - 1.5 * l_{j4}^{w} \leq = k\,; u_{B1}^{w} - 1.5 * l_{j4}^{w} \geq = -k\,; \\ l_{j2}^{w} - 0.67 * u_{B3}^{w} \leq = k\,; l_{j2}^{w} - 0.67 * u_{B3}^{w} \geq = -k; \\ m_{j2}^{w} - 2 * m_{B3}^{w} \leq = k\,; m_{j2}^{w} - 2 * m_{B3}^{w} \geq = -k; \\ u_{j2}^{w} - 3.5 * l_{j3}^{w} \leq = k\,; u_{j2}^{w} - 3.5 * l_{j3}^{w} \geq = -k\,; \\ l_{j4}^{w} - 0.67 * u_{B3}^{w} \leq = k\,; l_{j4}^{w} - 0.67 * u_{B3}^{w} \geq = -k; \\ m_{j4}^{w} - 2 * m_{B3}^{w} \leq = k\,; m_{j4}^{w} - 2 * m_{B3}^{w} \geq = -k; \\ u_{j4}^{w} - 3.5 * l_{j3}^{w} \leq = k\,; u_{j4}^{w} - 3.5 * l_{j3}^{w} \geq = -k\,; \\ 0.167 * l_1 + 0.668 * m_1 + 0.167 * u_1 + 0.167 * l_2 + 0.668 \\ * m_2 + 0.167 * u_2 + 0.167 * l_3 + 0.668 * m_3 + 0.167 * u_3 \\ +0.167 * l_4 + 0.668 * m_4 + 0.167 * u_4 = 1; \\ l_1 \leq m_1;\ m_1 \leq u_1;\ l_1 \geq 0; \\ l_2 \leq m_2;\ m_2 \leq u_2;\ l_2 \geq 0; \\ l_3 \leq m_3;\ m_3 \leq u_3;\ l_3 \geq 0; \\ l_4 \leq m_4;\ m_4 \leq u_4;\ l_4 \geq 0; \end{array}\right]$$

Equation 6. Physical sub-criteria in LINGO

The comparisons between criteria and sub-criteria using the BWM are more consistent than other decision-making methods. The study of its value in our research method indicates its greater desirability.

Table 9. Fuzzy numerical value and compatibility of main criteria and sub-criteria

Factors	Fuzzy Weigh	£	CR	Row	Sub-criterion	Fuzzy Weight	£	CR
Physical	0.290 0.495 0.855	0.045	0.045	1	Height	(0.268, 0.323, 0.323)	0.045	0.045
				2	Slope	(0.147, 0.291, 0.332)		
				3	Slope directions	(0.082, 0.123, 0.209)		
				4	Distance from fault	(0.185, 0.291, 0.332)		
Hydrogeology	0.200 0.225 0.496			5	Rain	(0.344, 0.344, 0.757)	0.068	0.068
				6	Relative humidity	(0.275, 0.275, 0.585)		
				7	Distance from river	(0.207, 0.207, 0.514)		
Land Cover	0.180 0.180 0.367			8	Vegetation	(0.247, 0.356, 0.461)	0.026	0.059
				9	Geology	(0.195, 0.356, 0.409)		
				10	Land Use	(0.174, 0.330, 0.330)		

Physical criteria had the highest weight for landslide risk zoning. Among the sub-criteria, height and distance from the fault were the most important and slope and land use had the least significance for zoning the risk of landslides in the regions (Table 10).

Table 10. Standard weight and sub-criteria affecting the landslide risk

Factors	Weight	Row	Sub-criterion	Weight	Final Weight
Physical	0.521	1	Height	0.314	0.164
		2	Slope	0.274	0.143
		3	Slope directions	0.131	0.068
		4	Distance from fault	0.281	0.146
Hydrogeology	0.267	5	Rain	0.415	0.111
		6	Relative humidity	0.327	0.087
		7	Distance from river	0.258	0.069
Land Cover	0.212	8	Vegetation	0.356	0.075
		9	Geology	0.338	0.072
		10	Land Use	0.306	0.065
SUM	1	-	-	-	1

For landslide riskoning, the final weight of the sub-criteria was applied to the zoning map of each and areas exposed to landslide risk were identified (Figure 4).

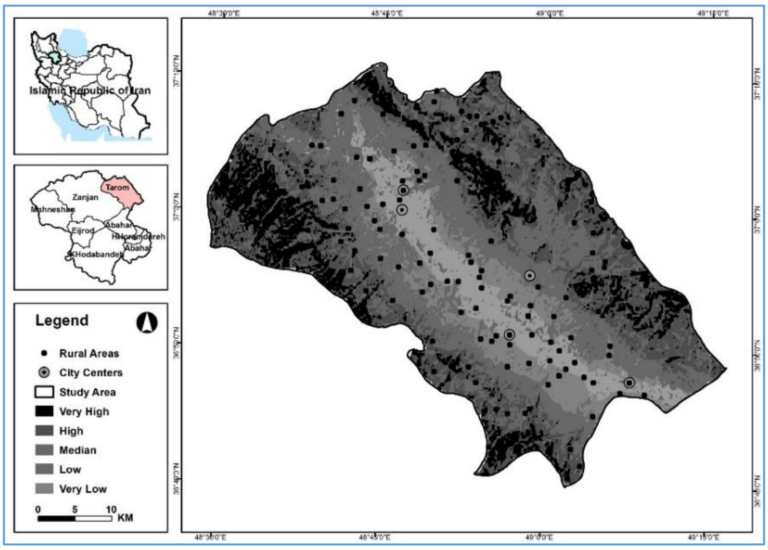

Figure 4. Landslide risk zoning

In rural areas, a larger portion of land uses were dedicated to agriculture. Naturally, these land uses thrive in areas with a desirable access to water resources. Since the Ghezel Ozan river runs through the study area, most of the water areas are located in the middle areas. Residential areas, which are built in low and flat lands, and agricultural lands, due to the convenient access to river water resources, have been developed in the middle areas with a lower height and slope. However, the use of agricultural gardens (mostly olive) in the study period (2005-2009) was more prevalent in areas with medium and steep slopes (Table 11).

Table 11. Land use area of areas classified by the maximum probability method

Land Use	Area (Hec)				Changes	
	2005		2019			
Area Water	245.1	%1.2	1890.9	%0.9	-0.28	Low
Residential Areas	4039.5	%2	4145.2	%2	+0.05	High
Gardens of Agriculture	10647.1	%5.2	11785.8	%5.8	+0.56	High
Agriculture Farmer	16423.1	%8.1	17005.7	%8.4	+0.29	High
Natural Pastures	136936.1	%67.5	132085.1	%65.1	-2.39	Low
Barren Lands	32454.6	%16	36038.8	%17.8	+1.77	High
SUM	202951.5	%100	202951.5	%100	-	-
-	Kapa coefficient: %84		Kapa coefficient: %87.6		-	

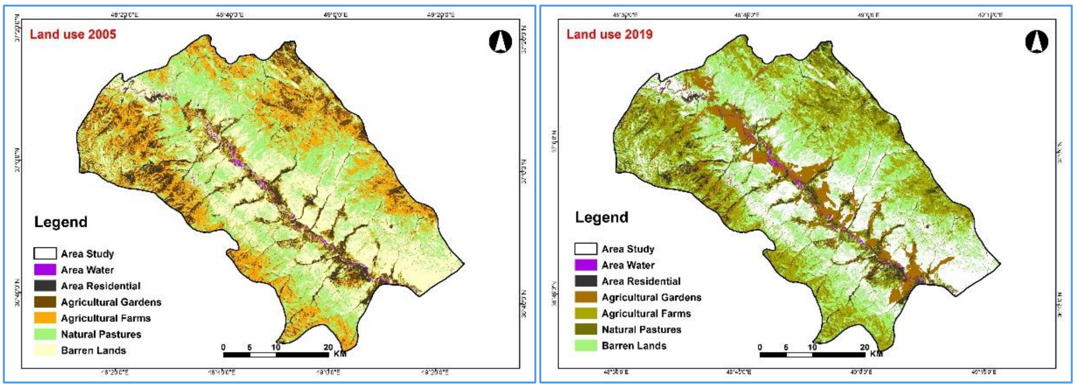

Figure 5. Land use in the study area

Given the overlap between the landslide risk and land use, the residential and agricultural land uses mainly developed in areas with a low landslide risk. The agricultural gardens primarily developed in areas with high risk of landslides, despite the fact that a landslide would damage these areas.

Table 12. Land use development matrix in areas exposed to landslide risk over 2005-2019

Landslide hazard	Area Water	Residential Areas	Gardens of Agriculture	Agriculture Farmer	Natural Pastures	Barren Lands
Very Low	➡	*	*	*	*	*
Low	*	➡	*	➡	*	*
Median	*	*	⬇	*	*	*
High	*	*		*	➡	*
Very High	*	*	*	*	*	➡

5. Discussion and Conclusion

Residents of rural areas in highlands often pursue a location-based biological pattern; however, due to the nature of their residence, they have to deal with a plethora of natural disasters in these areas. The rural areas under study sit in a mountainous area and landslides, as one of the natural hazards in rural areas, have always debilitated economic and infrastructural capacities of these areas. Considering that any development and planning requires knowledge and awareness of the geographical features of the region, which is a prerequisite for development, especially in rural areas, this study investigated the risk of landslides in light of the expansion of land uses. Given the purpose of the present study and as stated by Zumpano et al. (2018), this risk is largely ignored despite the fact that rural communities are vulnerable in terms of economic resilience and natural disaster losses. The present study adopted a combination of quantitative methods (fuzzy Delphi and best-worst fuzzy), GIS and remote sensing techniques to pursue the research goals by reviewing research background and selecting the most appropriate methods for zoning landslide risk. According to the results, physical criteria and sub-criteria of height, distance from the fault and slope were the major landslide criteria for the risk of landslides (Arab Ameri et al., 2018; Saffari & Hashemi, 2017; Mansouri et al., 2016; Basharat et al, 2016). That is, with increased height, slope and proximity to fault lines, the risk of landslides surges (Skilodimou et al, 2018). These areas are located to the east and west of the study area. Since most of these areas are highlands, pastures and barren lands are the most common land. Moreover, the distribution of rural and residential areas in these areas is constrained and often temporary. In this context, considering that rural settlements usually develop around flat lands, with favorable soil and water sources, most rural areas have been distributed in the middle areas with a better access to river water resources (Ghezel Ozan) and most favorable topographic factors. Agricultural lands, due to the importance of access to river water, are distributed in the middle areas, which run a lower risk of landslide. In contrast, agricultural gardens, due to constraints related to flat and even lands in rural areas, have usually expanded in high and medium-slope areas. However, given that the analysis and identification of areas for any development and planning is one of the key steps to hamper financial losses on land use in the event of hazards, it is important to allocate a greater attention to this issue. Therefore, some practical ways are suggested to reduce losses and financial losses associated with landslides for agricultural gardens in rural areas:

- Considering the economic value of agricultural lands and proper development of these land uses in areas with the risk of landslide,
- Evaluating and identifying arable lands in areas with a lower risk of landslides.
- Regular monitoring of land use development to enhance safety in new housing construction and agricultural lands.
- Providing the necessary infrastructure to raise awareness of rural residents about the dangers of landslides.
- Developing rural infrastructure services in low and flat areas to diminish landslide susceptibility.

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بررسی آسیب‌پذیری کاربری‌های کشاورزی از خطر وقوع زمین‌لغزش در نواحی روستایی شهرستان طارم

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چکیده مبسوط

۱. مقدمه

آن چه در ارتباط با مناطق کوهستانی بدیهی است، استقرار مکانی-فضایی مناطق روستایی در این مناطق، بیشتر متأثر از عوامل طبیعی مانند دسترسی به آب، زمین هموار، خاک مساعد بوده و لذا کمتر به عواملی مانند مخاطرات طبیعی توجه شده است. به طوری که بسیاری از نواحی روستایی در مناطقی استقرار یافته‌اند که در صورت وقوع هرگونه بلایای طبیعی می‌توانند آسیب‌پذیر باشند. این امر همواره مورد غفلت قرار می‌گیرد و این در حالی است که جوامع روستایی به لحاظ تاب‌آوری اقتصادی و زیان‌های ناشی از بلایای طبیعی از جوامع آسیب‌پذیر هستند. بنابراین، با توجه به خطر وقوع زمین‌لغزش در مناطق کوهستانی، توسعه و برنامه‌ریزی برای کاربری‌ها، نیازمند شناخت و بررسی است.

۲. مبانی نظری تحقیق

زمین‌های کشاورزی که در سراسر جهان تا ۴۰ درصد از مناطق روستایی را اشغال می‌کنند، یکی از کاربری‌های مهم زمین بوده که امروزه به دلیل فراوانی جمعیت و نیاز تأمین مواد غذایی، توسعه و بهره‌برداری از آن را در مناطق روستایی ضروری کرده است.
در این میان اما به رغم اهمیت توسعه و بهره‌برداری از زمین برای کشاورزی در مناطق روستایی، این امر نیازمند شناخت استفاده از زمین برای کاهش آسیب‌پذیری زمین‌های کشاورزی از بلایای طبیعی است که ضرورت پرداختن به آن در مناطق کوهستانی به دلیل رخ دادن بسیاری از مخاطرات طبیعی در این مناطق است.

یکی از این بلایای طبیعی که اغلب در مناطق کوهستانی رخ می‌دهد، زمین لغزش‌ها هستند. "لغزش" حرکت یک جرم تحت تأثیر گرانش زمین بوده که به دلیل اثر متقابل عوامل پیچیده و ناشناخته جغرافیایی و محیطی و فیزیکی، به عنوان یک روند تصادفی مورد توجه قرار می‌گیرد. در ارتباط با زمین لغزش‌ها ارزیابی و پهنه‌بندی خطر، یکی از مهمترین اقدامات در مدیریت ریسک فاجعه و یکی از ابزارهای ضروری در هر برنامه‌ای بوده که هدف اصلی آن نیز کاهش تأثیر بلایای طبیعی در آینده است.

۳. روش تحقیق

معیارهای مؤثر بر خطر وقوع زمین لغزش براساس قضاوت خبرگان به روش دلفی فازی(FDELPHI) و نقشه پهنه‌بندی هر کدام از آن‌ها نیز در ARC GIS, ENVI انجام شد. وزن‌دهی این معیارها در روش بهترین و بدترین فازی(FBWM) که گروه‌های تصمیم‌ساز آن خبرگان دانشگاهی بودند و در برنامه LINGO وزن‌دهی شدند. برای تهیه نقشه کاربری اراضی برای یک دوره ۱۵ ساله نیز از تصاویر ماهواره‌ای لندست ۸ و ۷ برای منطقه مورد مطالعه تهیه شد. نقشه کاربری به روش طبقه‌بندی حداکثر احتمال در ۶ کاربری اراضی شناسایی و برای صحت‌سنجی آن از نمونه‌های برداشت شده زمینی(GPS) استفاده شد. در پایان نیز پس از همپوشانی نقشه خطر زمین لغزش، توسعه کاربری‌های کشاورزی، در خطر وقوع زمین لغزش شناسایی شدند.

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۴. یافته‌های تحقیق

وجود ارتفاعات نقش مهمی در افزایش زاویه شیب و ناپایداری دامنه‌ها دارند، لذا مناطقی که در ارتفاعات بلند قرار دارند، در آن مناطق تعدد وقوع حرکات توده‌ای به ویژه زمین لغزش‌ها خواهد بود. برحسب وزن نهایی، معیار فیزیکی به عنوان مهم‌ترین معیار و پوشش زمین به عنوان کم‌اهمیت‌ترین معیار تعیین گردید. در معیار فیزیکی، زیرمعیار ارتفاع و جهات شیب به عنوان مهمترین و کم‌اهمیت‌ترین زیرمعیار و همچنین در معیار هیدرولوژی، زیرمعیار بارش و فاصله از آبراهه و در معیار پوشش زمین نیز، زیرمعیارهای پوشش گیاهی و کاربری اراضی به عنوان مهم‌ترین و کم‌اهمیت‌ترین زیرمعیار برای تعیین مناطق برای وقوع خطر زمین لغزش تعیین گردیدند. همچنین با توجه به یافته‌های تحقیق و تهیه نقشه خطر وقوع زمین‌لغزش، کاربری باغات کشاورزی(اغلب بهره‌برداران زیتون) در دوره مورد بررسی(۱۳۹۸- ۱۳۸۳) بیشتر در مناطق با شیب متوسط و تند توسعه یافته که بالتبع با توجه به همپوشانی نقشه توسعه کاربری‌ها و خطر وقوع زمین‌لغزش، این کاربری‌ها در خطر وقوع زمین‌لغزش قرار دارند.

۵. بحث و نتیجه‌گیری

با توجه به آن که نقطه پیداش یک سکونتگاه روستایی دسترسی مناسب به زمین‌های هموار، خاک مساعد و آب بوده، بدیهی است که بخش بیشتری از کاربری‌های کشاورزی نیز در مناطقی توسعه می‌یابند که دسترسی مناسب‌تری به منابع آب داشته باشند. در نواحی مورد مطالعه بیشتر مناطق روستایی در نواحی میانی که دسترسی مناسب‌تری به منابع آبی رودخانه(قزل اوزن) و با توجه به عوامل توپوگرافی در شرایط مساعدتری قرار دارند، توزیع شده‌اند. زمین‌های کشاورزی به دلیل استفاده از منابع آبی رودخانه در نواحی میانی که به لحاظ خطر وقوع زمین‌لغزش به عنوان مناطق کم خطر هستند، توزیع شده‌اند و در مقابل باغات کشاورزی به دلیل محدودیت داشتن زمین هموار در مناطق روستایی، غالباً در مناطق مرتفع و با شیب متوسط توسعه یافته‌اند. بدین‌ترتیب بدیهی است که توسعه این کاربری‌ها در مناطق خطر وقوع زمین‌لغزش موجب آسیب‌رساندن به این کاربری‌ها خواهد شد، لذا توجه به ارزش اقتصادی زمین‌های کشاورزی و توسعه مناسب این کاربری‌ها در زمین‌هایی که خطر کمتری برای وقوع زمین‌لغزش دارند و همچنین بررسی منظم توسعه کاربری‌ها به منظور افزایش ضریب ایمنی در ساخت و سازهای جدید مساکن و زمین‌های کشاورزی در مناطق روستایی مورد مطالعه از مهم‌ترین فعالیت‌ها خواهد بود.

کلید واژه‌ها: مخاطرات محیطی، زمین‌لغزش، روش بهترین بدترین فازی، شهرستان طارم.

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