Assessment of Areas Vulnerable to Natural Hazards: A Case Study on Rural Areas of Azna County, Iran

Hamed Abbasi[1], Siyamak Sharafi[1], Zohreh Maryanaj[2]

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Original Article

Abstract

INTRODUCTION: Rural areas, usually when compared to other human settlements in terms of natural events, have the greatest vulnerability. The aim of this study was to evaluate natural hazards such as earthquakes, landslides, floods and identify high-risk zones in rural areas of the central township of Azna County, Iran.

METHODS: Topographic and geology maps, elevation digital model, and seismic and meteorological data along with field studies were used to investigate the location of villages in terms of earthquakes, landslides, and floods. Then, factors effective in each of the hazards were identified and grouped in separate layers. The Arc geographic information system (GIS) software was used to develop and integrate maps; AHP model and paired comparison method were used to weight effective factors in the possibility of any of the natural hazards, and to compare the criteria one by one. The fuzzy logic model was used to standardize the layers in Arc GIS software. Moreover, the overlay model index was used to integrate final layers of natural hazards and determine high-risk zones.

FINDINGS: It was found that 49% of villages, due to their placement on major and minor faults, were in the high-risk earthquake zone. The risk of landslides in areas where rural areas were based is very low due to the low slope, and only 10% of the villages are at risk of landslides. In addition, 14% of the villages, due to their placement on major rivers beds, were in the high-risk and very high-risk flooding categories. Prioritization of rural areas in terms of natural hazards using the AHP model shows that eight villages were located in high-risk areas.

CONCLUSION: Providing maps of potential natural hazards can be helpful in crisis management and identification of high-risk settlements.

Keywords: Natural Hazards; Rural Areas; Seismicity; High-Risk Areas; Iran

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Introduction

Natural hazards have existed throughout human existence; however, due to the rapid growth of the human population and density in all areas of life, especially in high-risk areas, today, human beings are experiencing major disasters such as tsunamis, tornadoes, and earthquakes with significant casualties even in developing countries (1,2). Natural hazards occur abruptly and cause damage to humans and the environment; in other words, natural hazards are environmental physical elements that are harmful to humans and are created by external forces superior to human power (3). Due to their unforeseen nature, these risks often cause numerous financial and human losses (4,5). The available evidence suggests a continuous increase in the intensity and frequency of various natural hazards (6,7). Natural hazards are identifiable before they can be defined (8).

In many cases, these hazards have devastating impacts on human communities, both urban and

1- PhD, Department of Geography, Lorestan University, Lorestan, Khorramabad, Iran
2- PhD, Department of Geography, Seyyed Jamaleddin Asadabadi, Asadabad, Iran
Correspondence to: Hamed Abbasi, Email: abbasi.h@lu.ac.ir

rural, and their consequences on the environmental, social, economic, and psychological dimensions of human settlements have been evident for many years (9). In fact, these types of hazards create a wide range of unforeseen threats to human beings and human habitats (10). Human settlements, and particularly rural ones, are vulnerable to degradation at certain times due to being located in areas with a naturally hazardous infrastructure (11-13).

Geological evidence indicates that the Earth has been severely threatened throughout its life by natural forces, with the earthquake perhaps being the most destructive of these forces (14). Floods and landslides are also among the most devastating natural hazards (15-17).

Iran has experienced more natural disasters throughout the history of natural disasters, especially earthquakes and floods, due to its position in the Alpine-Himalayan orogenic belt, as well as due to its varying climate and temporary and transient instabilities (18). Lorestan Province, located in Western Iran and in the Zagros mountainous region, has witnessed numerous natural disasters and floods in the past few years, with the earthquakes, landslides, and floods being the most notable of them. The diversity of hazards in this province is due to its different geological and climatic characteristics as well as its topography. Examples of natural hazards in the area in recent years include earthquakes and landslides in Borujerd and Dorud in 2006, flood in Kouhdasht City in 2015, and devastating flood in April 2019 that caused many financial and life casualties in the province. The city of Azna in the eastern part of the province has also experienced a variety of natural hazards, especially geological hazards, which can cause devastation and financial loss, particularly in less strong rural areas.

Geographical research on natural hazards has a long history, beginning with a focus on physical processes and the study of its evolutionary trend through increasing understanding of the interaction between the physical and human environment (19). Today, with the advancement of science and technology, and the use of quantitative and qualitative models in natural hazard assessment, a variety of studies have been carried out regarding the types of hazards nationally and internationally, with a particular emphasis on hazard assessment and its impact on human settlements.

Numerous studies have been conducted in different parts of Iran in this regard. Negaresh and Yari performed an analysis on risk and crisis management in environmental and natural hazards (13). Faraji-Sabokbar et al. performed a spatial analysis of the impacts of natural hazards in rural areas using a geographically weighted principal component analysis (PCA) model (5). Farhadinejad et al. examined landslides using remote sensing data (20). Souri et al. performed landslide risk zoning using artificial neural network (ANN) (10). Fazelnia et al. carried out zoning of risks in rural areas using a geographic information system (GIS) with an emphasis on landslides (21). Pourtaheri et al. examined the role of capacity creation in reducing the effects of natural hazards (earthquakes) in rural areas (9). Sadeghloo and Sajasi Gidari studied risk management strategies in rural areas using the SWOC-TOPSIS model (22). Nasrinnejad et al. carried out flood potential zoning using fuzzy hierarchy analysis method (23). Salahshouri and Vafaeinezhad surveyed the changes of floods in the plains of the Karkheh River due to the construction of Karkheh Reservoir dam using remote sensing and GIS (24). In all the above studies, it was concluded that flood and landslide risks are higher in Iran. In addition, the human factor is the most important factor in the extent of landslide damage, and the existing potential for reducing earthquake impacts and vulnerability is not sufficient.

Natural hazards are a major challenge in rural areas and these areas are usually the most vulnerable areas with the least self-consideration in natural events (25-28), and predicting the exact time of natural hazards is beyond the reach of current human sciences. Therefore, identifying vulnerable and susceptible areas of natural hazards can partially prevent the consequences of these disasters. Accordingly, this study was performed with the aim to identify the potential of natural hazards (earthquakes, floods, and landslides) and villages exposed to natural hazards in the central township of Azna County in Lorestan Province, Iran. This city contains 2 rural districts and 49 villages with a population of about 21123 people. The lowest and highest points of the study area were, respectively, 1703 and 4040 m high with an average height of 2790 m. The mean annual precipitation and the mean annual temperature of the region are about 415 mm and 12.5 °C, respectively.

Methods

The present study was conducted in several stages. In the first stage, field studies were carried out to investigate the location of the villages under study in relation to the potential for earthquakes, landslides, and floods. In the second stage, factors affecting the occurrence of natural hazards (earthquake, landslide, and flood) were determined using the results of previous studies and expert opinions. These factors include faults, earthquakes taken place and earthquake accelerographs, topography (slope, slope direction, and elevation), geological formations, drainage network (river), mean monthly and annual rainfall, maximum 24-hour rainfall, land use, access roads, and soil (Table 1). Then, vector layers such as geology, soil, and land use were converted into raster layers using the Spatial Analyst tool in Arc GIS software environment. The other layers were provided as raster using the Distance, Topo to raster, Density, and Kriging tools.

In the third stage, after preparing the layers with a raster format, fuzzy standardization was applied to each raster map to define effective ranges in flood risk and landslide in numerical distance between 0 and 1. In addition to unifying the maps, this method specifies the role of specific ranges in each of the factors. Linear fuzzy standardization functions (relations 1 and 2) were employed to define effective ranges between 0 and 1.

In the fourth stage, the importance of each of the factors effective in the landslides and floods was determined using the opinions of experts. At this stage, by generating a matrix, a pairwise comparison was made on the factors effective on these hazards using AHP tool in Arc GIS environment. After generating the matrix of each hazard and calculating the final weight of the effective factors, using the AHP tool in Arc GIS, the final weight of each factor was multiplied by the final raster layer of the associated factor in the environment of the Spatial Analyst tool. In this way, the final map of the landslide and flood hazards was prepared. It should be noted that earthquake hazard zoning was conducted using a map provided by the International Earthquake Research Institute, fault layers, and seismicity history database. After preparing the final map of the earthquake, landslide, and flood hazards, the layers were integrated using the index overlay model and the final map of natural hazards was prepared. It should be noted that the classification of the final maps of natural hazards into four classes was performed based on expert theories and field studies. In the fifth step, the position of the rural areas was overlaid on each of the final layers of natural hazards. Then, using the Sample command, the position of each village relative to the cell value of the zone located on it was determined. Subsequently, prioritization of the villages was assessed in terms of each of the natural hazards and the high-risk villages were identified.

Findings

Investigation of high-risk zones in terms of earthquake and determination of at-risk villages: Examination of the faults in the study area indicated that the longest faults were extended from northwest to southwest as a strip with a length of 10 to 18 km. Since long faults mainly coincide with mountain strips, fewer habitats are found around faults corresponding to layers with a high and very high seismic risk.

Table 1. Factors used in identifying areas prone to earthquakes, landslides, and floods

Factors \ Risk type	Landslide	Flood	Earthquake	Scale	Layer preparation method
Distance from fault	✓	-	✓	1:100000	Distance tool
Distance from road	✓	-	-	1:150000	Distance tool
Distance from waterway	✓	-	-	1:25000	Distance tool
Precipitation	✓	✓	-	1:50000	Kriging method
Slope	✓	✓	-	1:25000	Topo to raster tool
Slope direction	✓	✓	-	1:25000	Topo to raster tool
Geology	✓	✓	-	1:100000	Map digitization
Soil	-	✓	-	1:50000	Map digitization
Maximum 24-hour precipitation	-	✓	-	1:50000	Kriging method
Land use	-	✓	-	1:50000	Map digitization
Earthquake acceleration	-	-	✓	1:50000	Map digitization
Seismicity	-	-	✓	1:50000	Density method

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The faults located on the middle fault layers are located in the central areas towards the northwest. Within the boundaries of these faults, rural areas have not been formed due to the rough and steep slope. On the northeast side of the study area, there are faults ranging from 17 to 3700 m. Most of the urban and rural settlements of the study area have been formed in this area.

The overlay of the faults on the earthquake hazard map revealed that the earthquake hazard rate in the study area was proportional to the direction of the main faults of the area that were stretched from northwest and southeast, and the earthquake hazard rate decreased from west to northeast. Areas of high earthquake risk in the mountainous and high areas that are close to the Zagros Fault covered approximately 6956 hectares of the study area. The high risk and medium risk categories comprised 28820 and 37496 hectares of the study area, respectively (Figure 1).

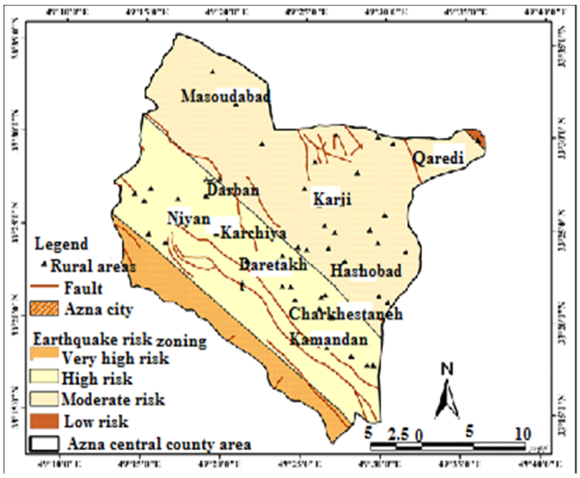

Figure 1. Earthquake risk zoning and risk percentage of villages in the central township of Azna, Iran

The zoning of the villages in terms of earthquake risk indicated that there were 1, 24, 24, and 0 villages in the low-risk, medium-risk, high-risk, and very high-risk category, respectively. Moreover, 49% of the villages were in the high-risk category in terms of earthquake risk.

Investigation of high-risk zones in terms of landslides and identification of at-risk villages: Examining the factors effective in the occurrence of landslides showed that geological and topographic formations have had the highest contribution to the occurrence of landslides (Table 2).

Landslide hazard assessment and zoning indicated that areas with a very high potential of landslide were located on high and steep slopes and on uneven terrains with less surface area compared to other regions, covering 1362 hectares. These areas consisted mainly of calcareous formations. The areas in the high-risk category were located at heights and covered 14937.75 hectares of the study area. Other areas that had mostly lower slope with a medium to low risk of landslides covered a surface area of approximately 57000 hectares. The residential and urban areas of the study area were located mainly in the category of low risk of landslides (Figure 2).

Classification of rural areas based on landslide risk level revealed that 32, 12, 5, and 0 villages were in the low-risk, medium-risk, high-risk, and very high-risk category, respectively. Moreover, in terms of risk, about 10% of the villages were at risk of landslides, so it can be concluded that the probability of landslides is high in areas with almost no rural settlements. However, due to the heavy rainfall in April 2019 and multiple landslides, one village was evacuated as a result of the landslide (shown in figure 2, with an arrow).

Table 2. Final weight of each layer and their importance relative to each other in terms of landslide risk zoning

Factors used	Geology	Slope	Slope direction	Distance from fault	Precipitation	Distance from waterway	Distance from road	Final weight
Geology	1	2	3	4	5	6	7	0.36
Slope	0.5	1	2	3	4	5	7	0.24
Slope direction	0.33	0.5	1	2	3	4	5	0.15
Distance from fault	0.25	0.33	0.5	1	2	3	5	0.10
Precipitation	0.2	0.25	0.33	0.5	1	2	4	0.06
Distance from waterway	0.14	0.2	0.25	0.33	0.5	1	2	0.04
Distance from road	0.12	0.14	0.2	0.2	0.25	0.5	1	0.03

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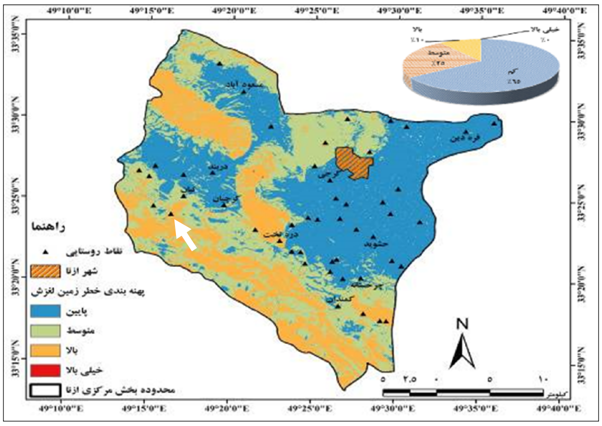

Figure 2. Landslide hazard zoning and risk percentage of villages in the central township of Azna, Iran

Investigation of high-risk zones in terms of floods and identification of at-risk villages: Based on the flood risk-zoning map, the areas exposed to a very high risk of flooding were in the riverbed, covering 1043.75 hectares of the study area. Most parts of the study area were not at risk of flooding (55450 hectares). The surface area of the regions with low flood risk was about 5545.75 hectares. The category with a moderate flood risk can be observed over the apexes and mountains of the area (Figure 3).

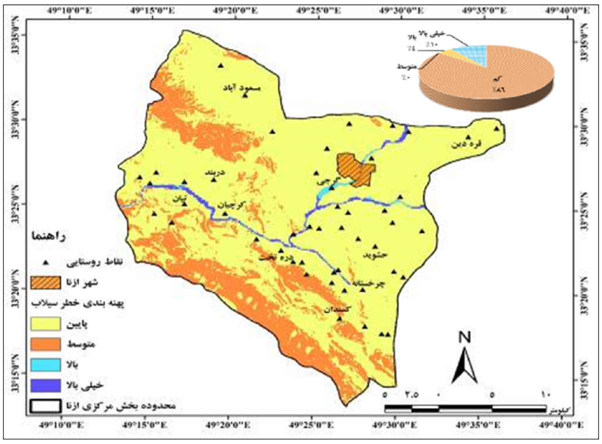

Figure 3. Flood hazard zoning and risk percentage of villages in the central township of Azna, Iran

Evaluation of the position of the villages relative to the flood-prone zones indicated that 2 and 4 villages were in the high-risk and very high-risk categories, respectively. Other villages were positioned in the low-risk category. The flood risk for the villages showed that 86% of the villages were not at risk of floods because high-risk areas are in the mountainous regions where no village is formed.

Identification of areas prone to natural hazards and at-risk villages: After integrating the effective factors in the event of earthquakes, landslides, and floods, in order to prepare the final layer of natural hazards in the central township of Azna city, the final layers of hazards were weighted, and then, the final layer of natural hazards was prepared using the index overlay model (Table 3).

Table 3. Weight of layers used to identify areas prone to natural hazards

Factor	Flood	Earthquake	Landslide	Final weight
Flood	1	3	3	0.44
Earthquake	0.33	1	2.5	0.24
Landslide	0.33	0.4	1	0.20

According to table 3, flood had the highest weight among the three hazards, because in the flood risk-zoning layer, 5 villages were in the very high-risk category, while none of the villages were located in the very high-risk category in terms of earthquakes or landslides.

Evaluation of natural hazards and overlay of the villages on it showed that 2, 9, 34, and 4 villages were in the low-risk, medium-risk, high-risk, and very high-risk category, respectively (Figure 4). The villages with a very high risk were those placed around the banks of the main rivers and were prone to the risk of flooding.

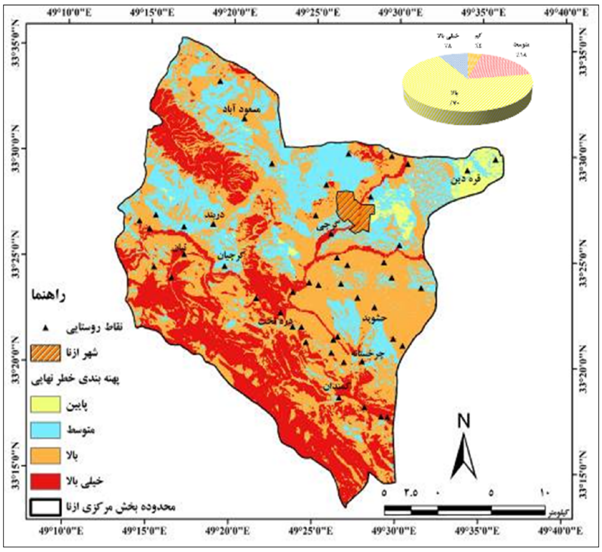

Figure 4. Natural hazard zoning and risk-taking percentage of villages in the central township of Azna, Iran

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Table 4. Prioritization and identification of villages at risk of natural hazards

Row	Village name	Earthquake	Landslide	Flood	Row	Village name	Earthquake	Landslide	Flood
1	Shahpasand	1	1	0	26	Baghmouri	0	0	0
2	Shengan	1	0	0	27	Bavki Mirbakhtyar	0	0	0
3	Aliabad	0	0	0	28	Borjaleh	0	0	0
4	Qasemabad	0	0	0	29	Bidestaneh	1	1	0
5	Qaziabad	1	0	1	30	Pazardalou	0	0	0
6	Qaredin	0	0	0	31	Tombak	0	0	0
7	Kaleh Rustam	1	1	0	32	Tiyan	1	0	0
8	Karchian		0	0	33	Jouy Asiyab	0	0	0
9	Kalkaleh	1	0	0	34	Charkhestaneh	1	0	0
10	Kamry	1	0	0	35	Cheshmeh Soltan	0	0	0
11	Kamandan	0	0	0	36	Chagazal	0	0	0
12	Gorji	1	0	1	37	Cham Zaman	1	0	1
13	Lamis	0	0	0	38	Hashouyad	0	0	0
14	Mahmoudabad	0	0	0	39	Khosromireh	0	0	0
15	Hosseinabad	1	0	0	40	Darband	1	0	0
16	Masoudabad	1	0	0	41	Darreh Takht	1	1	0
17	Miyanroudan	0	0	0	42	Dalyan	0	0	1
18	Nosratabad	1	0	0	43	Zolqadr	0	0	0
19	Hendar	1	0	1	44	Doboloukan	1	0	1
20	Vazmdar	0	0	0	45	Dodahak	0	0	0
21	Ahmadabad	1	0	0	46	Dolatabad	0	0	0
22	Ashrafabad	1	0	0	47	Deh Darvishan	1	1	0
23	Babadineh	0	0	0	48	Zarnan	0	0	0
24	Siyavashabad	1	0	0	49	Soltanabad	0	0	0
25	Sivaleh	1	0	0					

Risk-taking of the villages against natural hazards indicated that 4%, 18%, and 70% of the villages were, respectively, at low, medium, and high risk; in addition, 8% of the villages were at the highest level of risk.

After overlaying of the villages on the earthquakes, landslides, and floods layer, the villages in the high-risk and very high-risk categories were identified as high-risk villages. In addition, 8 villages were considered as high-risk villages in terms of natural hazards (Table 4).

Conclusion

The study findings showed that the flood risk was the highest risk in the study area, because the area was surrounded by high mountains and uneven terrains leading the runoff to the lower parts where the beds of the main rivers and most of the villages were located. Moreover, in terms of the three hazards studied, 5 villages were in high-risk flood zones. However, there was no village in the very high-risk category of earthquakes and landslides; this can be explained by the fact that the areas with very high rate of earthquake and landslide events mainly coincided with the high and uneven areas where favorable conditions for the establishment of rural areas were not provided. The study by Riyahi and Zamani regarding the geographical factors affecting flooding in rural areas of Sarvabad city, Iran, showed that about 50% of the city area, 39 out of 77 villages, and 48% of the population of rural settlements were in the high-risk flood category (4).

The prioritization of villages in terms of earthquake risk and identification of at-risk villages indicated that 24 villages were in the high-risk earthquake category; however, based on the history of seismicity of the central township of Azna since 1900, 7 earthquakes have been recorded, with the magnitude of the largest of them being 4.7 Richter. Earthquakes with magnitudes of greater than 4 occurred along the main fault paths, so although about half of the villages are in high-risk zones, due to the lack of accurate and adequate information on the seismicity status of the area, these villages cannot be considered as high-risk villages. The results of the study by Negaresh and Yari showed that the distribution of the cities of Nourabad, Selseleh, Borujerd, Khorramabad, and Dorud in seismic areas and high faults in Lorestan Province are among the most important weaknesses of this province (13). The results of the study by Alavi et al. on the zoning of rural settlements in Talesh, Iran, using the VIKOR model suggested that 49% of the villages were exposed to earthquakes (29). Assessment of major and minor faults indicated that landslide had the lowest risk among the three hazards in the Azna Township, as most of the villages were in the low-risk and medium-risk categories.

Due to the rainfall in April 2019 and the resulting landslide, Kaleh Rostam village was evacuated. This village was located in the high-risk zone in the investigation of the landslide potential in the study area. Therefore, providing maps of potential natural hazards can be helpful in crisis management and identification of high-risk settlements.

Conflict of Interests

Authors have no conflict of interests.

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