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Miyandoab flood risk mapping using dematel and SAW methods and DPSIR model

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ABSTRACT

It is essential to assess flood risk mapping for sustainable development. The present study aimed to identify the causes of flooding and predict the extent of damage caused in the area of Miyandoab, Iran. The Driver, Pressure, State, Impacts, response (DPSIR) conceptual framework model was used to analyze the factors affecting flooding in the region. DPSIR is a system approach that identifies key relationships between humans and the environment, and its combination with the simple additive weighting (SAW) model identifies a new strategy for achieving sustainable development. The DPSIR method for flood susceptibility analysis in the region, examined the social, economic, physical, and environmental factors as the driving force. The flood risk level was then determined for the region by preparing the driving force map and mapping the region. For this purpose, the decision-making trial and evaluation laboratory (Dematel) and SAW models were used to investigate the causal relationship between the factors and calculate the weight of layers; Matlab software was used to implement the models. Finally, based on the weights extracted from the SAW method, risk mapping was performed in the geographic information system (GIS) environment. The results showed that out of the total area of the study area, about 78,462 hectares have a high risk, 91,542 hectares have medium risk, and 2,952 hectares have a low risk of flood. The results from combining the models of decision support systems and GIS indicated high efficiency in determining the areas with a high risk of flood.

1. Introduction

A system's ability to sustain itself inevitably depends on the success of its relation to the environment. But the need for sustainable communication with the environment requires the distribution of resources and work responsibility among the components of the system in such a way that internal elements accept their position and role together with other elements to continue the operation and stability of the system in a changing environment. In this case, stability is divided into two main parts: internal stability and external stability [1]. Sustainable development can be defined as "the management of the relationship between human systems and ecosystems in order to sustainably use resources to ensure the well-being of the present and the future of humans and ecosystems." [2]. Today, cities and settlements are mostly built in places exposed to natural disasters in terms of natural hazards or man-made disasters due to technological advances [3]. The development of settlements along river banks and beds as well as the margins of floodplains without recognizing the hydrological and dynamic conditions of rivers and upstream parts of watersheds will face development problems, which increases the risk of flooding that results in human, financial, and infrastructure losses [4]. The increasing development of urban communities affected by uncontrolled population growth and migration has led to the uncontrollable expansion of cities. Hence, for the targeted guidance, the criteria should be defined to lead to sustainable urban development. In this way, a city's sustainability is ensured from ecological and environmental perspectives [5]. Most settlements are built in the outlet of

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basins [6]. Given that settlements have sometimes been developed in Iran's flood-prone areas, substantial damage is incurred annually to people's lives, their properties, and the natural ecosystems. The study of flood control and reduction of damages and losses in a limited way at the national level is essential to achieve sustainable development [7]. Flood mapping is one method of flood management. The maps obtained from this method provide valuable information about the nature and effects of flooding on floodplain lands and a river's riparian zone [8]. As a result, it is possible to issue the appropriate warnings in the event of a flood and facilitate the relief and rescue operations [9]. In flood mapping, to control flooding in land use and development, the flood-prone areas are divided into different hazards parts [10]. By identifying the areas at high risk of flooding, the development in these areas can be prevented. If development is needed in these areas, management strategies can be implemented from the beginning of construction in these areas [11]. Flood risk mapping for the planning and management of flood control has not been considered in this study area. Therefore, to identify the causes of flooding and predict the extent of resulting damages in different conditions for the economic and social justification of flood control programs, the factors affecting flooding in the region are analyzed with the DPSIR conceptual model. Then, with the identification and spatial distribution of the driving forces, the flood risk mapping is performed. Flood risk can be systematically assessed in the form of this model. This model relates the driving forces, pressures, states, impacts, and responses [12]. In this study, the SAW method was used to give weight to the factors due to the existing various related factors. For this purpose, the Dematel technique was first used to examine the relationships between the factors. The following are some examples of flood risk assessment in spatial planning issues. Hammond et al. (2018) proposed the modified DPSIR model to enable policymakers to assess some approaches for urban flood resilience. In this way, the authorities can take some measures to deal with the scenarios in the future in order to well appreciate the flood impacts. They demonstrated the effectiveness of this model in assessing and improving flood resilience in cities, despite the existence of restrictions [13]. Wang et al. (2018) examined the application of a new hybrid method by combining the multi-criteria decision-making analysis with GIS to assess flood susceptibility mapping. It was developed by a combination of Dematel, interval rough numbers, weighted linear combination, and analytical network process techniques in Shangyou County, China, as a case study [14]. Sepehri et al. (2020) carried out a study for preparing flood susceptibility maps in the northwestern part of Hamadan Province in Iran. In this way, six criteria associated with flooding were selected: check dam, topographic wet index, land use, soil texture, elevation, slope, and distance to discharge channel. Afterward, they weighted the criteria according to its role played in the flood susceptibility assessment. The weighting was performed in two cases of outer criteria: interval rough Analytic Hierarchy Process (AHP) and inter weighting (fuzzy logic). They prepared the flood susceptibility maps of the area under study with the combination of the primary weights and the GIS-based weight overlay technique [15]. Chakraborty and Mukhopadhyay (2019) reviewed some authentic and effective methods to prepare the map of flood risk in the region of Cooch Behar according to vulnerability and hazard concepts. They employed the AHP method to weight the criteria that define vulnerability and hazard based on their research. The results showed that the flood-prone areas were located in the east, southeast, south, center, and north central regions. In addition, the flood vulnerability level was specifically high in the southern, southeastern, and southwestern parts of the area along the international border between Bangladesh and India, along with some remote regions in the center and north center [16]. In April 2019, a huge flood occurred in Miyandoab due to heavy and continuous rain. As the water level rose to several meters, it caused severe damage to houses, agricultural products, roads, gardens along rivers, and bridges. For sustainable development purposes and to improve the city's resilience to natural hazards, especially floods, it is necessary for people and city managers to have the necessary preparations in place. In this regard, the present study aimed to assess the risk of flooding in Miyandoab; the importance, relationship, impact, and ranking of each factor in this issue were separately assessed and examined.

2. Methodology

2.1. Geographical location of the study area

Miyandoab County (Figure 1) is located in West Azerbaijan province (Uremia) in Iran. It has a geographical longitude of eastern 64°, 6′ of Greenwich meridian and geographical latitude of Northern 36°, 58′ of the equator, at the southern part of the Uremia Lake, southeast of West Azerbaijan, and in the East and West Azerbaijan provinces' intersection. The county has an area of 164 square km and covers 4.18% of the province; it is 1314m from sea level. The average rainfall is 289 mm. Also, 33.11% of the county's area is covered with hills, and the remaining 67.88% is composed of plain and flowages. The weather is variable, with relatively hot summers and moderately cold winters. The geographical conditions of the area have resulted in relatively good agriculture growth and industrial development. The county's economy mostly relies on agriculture and animal husbandry; important crops such as wheat, sugar beet, apples, and grapes are produced in abundance. Livestock and livestock products are among the export products of the area.

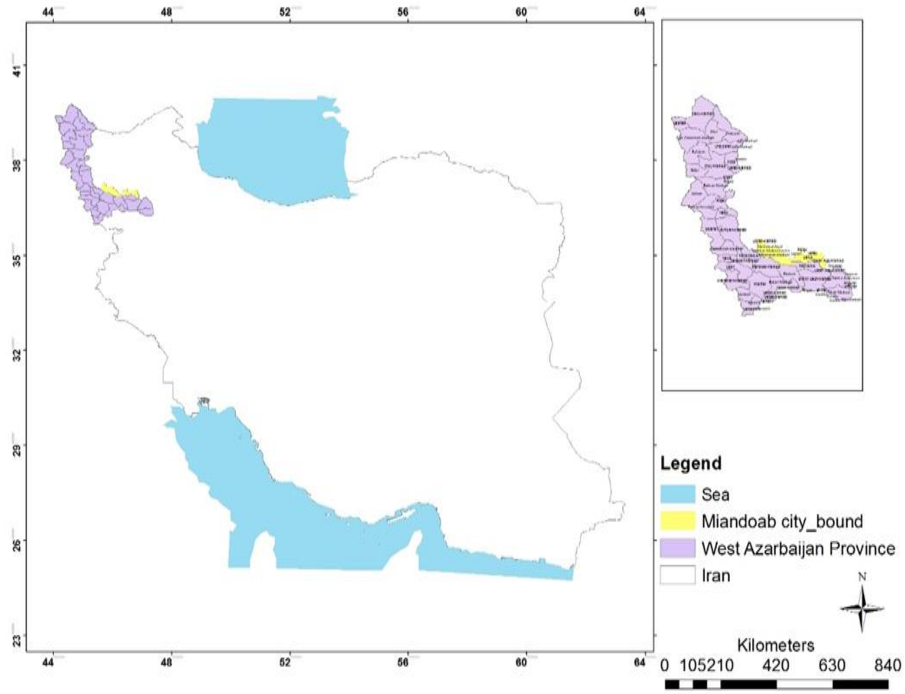

Fig. 1. Geographical location of Miyandoab county in West Azerbaijan and Iran.

The agricultural system of the county is traditional, and it is possible to increase product output several times through modernization and mechanization. According to the latest census, the city has a population of about 240,000 people [17].

What seems to be important in flood risk assessment is scoring to prioritize and rank indicators in a way that can be cited in mitigation programs. The goal is to rank, sort, arrange the data, and rate the indicators. In many cases, there is ambiguity and uncertainty in the ranking of the indicators. In this research, with the help of DPSIR and combining it with multi-criteria decision-making methods, the flood incidence index system was determined to manage the risk of this phenomenon.

2.2. DPSIR model

The United Nations Environment Program (UNEP) developed the DPSIR conceptual model to study and evaluate natural and human structures and functions [18]. This model is a conceptual framework based on the causal chain of data analysis that connects environmental information through various indicators, determines their leads and lags, and explains appropriate responses and solutions applicable to different components of the chain [19]. In this conceptual model, the drivers are human and biophysical forces that cause changes in biophysical and human processes and patterns. The driving forces lead to pressures on the quality of the environment. The pressures include natural and human factors that directly affect the state of the ecosystem and cause positive and negative changes in the state of the environment. The impacts are the changes in human and ecological conditions that result from such interactions. The elements of the DPSIR model framework are as follows:

1- Driving force: Driving force is a necessity. Examples of driving force for people are shelter, food, and water.

2- Pressure: The driving force leads to human activities such as transportation or food production. These human activities put pressure on the environment due to production or consumption processes.

3- Status: The state of the environment is affected as a result of pressures. State changes in ecosystems can be described based on biophysical processes.

4- Impact: Changes in status may have environmental and economic impacts on ecosystem performance and the ecosystems' ability to support life

5- Response: A response by society or policymakers is the result of unintended effects and can affect any sector.

Therefore, for analyzing the flood susceptibility of the region by the DPSIR method, the physical, social, economic, and environmental factors were examined as driving forces. Then, by preparing the driving force map and mapping the region, the flood risk level was determined [20].

2.3. Dematel method

The Dematel method was developed using the principles of graph theory for creating the system structure in the form of directed graphs and the constituent elements based on the opinion of experts, hierarchical structure, and the

relationships between the given and received effects on the factors. It is made up of the following steps.
Step 1 (formation of direct communication matrix): In this step, 15 flood-related experts were asked to prioritize the parameters according to Table 1.

Table 1. Importance of comparisons based on Dematel method.

Preferences	NO impact	Very little	Low impact	High impact	Very high
Numerical values	0	1	2	3	4

Step 2: Calculate relative intensity matrix governing direct relationships. In this step, we first multiply each variable by the inverse of the maximum row sum (k). Also, k is calculated by Equation (1).

$$K = \frac{1}{\max \sum_{j=1}^{n} a_{ij}} \quad (1)$$

Step 3: Calculate possible relative intensity matrix from all direct and indirect relationships. This step is calculated using Equation (2), where I is a unit matrix. In the unit matrix, the value 1 is assigned to all the main diameter entries.

$$M \times (I - M) - 1 \quad (2)$$

J is the received effect of each factor, which is obtained from the column sum of numbers, and R is the given effect of each factor, which is obtained from the row sum of the final matrix numbers. R+C is the priority vector, and the higher the value, the greater the interaction it has with other factors. R-C is the relation vector, which represents the net effect of each factor in the system. One of the various types of causal diagrams showing the degree of dependence is the net causal diagram T or network relationship map (NRM), which is obtained based on the table of zero and one related to NRM table, which was coded in Matlab software.

2.4. SAW method

In this method, the final rank of each option is estimated by the weighted sum of all values of each parameter: 1) normalization of the data matrix, 2) determination of weight (W), and 3) calculation of the total rank of each parameter.
1. The original data should be converted to a comparable value using a conventional method.
2. Give weight to indicators: This step is done through the entropy method. In this method, the higher the distribution of variables in an indicator, the more important the indicator. To calculate the weights in this method, we first need to calculate k and Ln(m). It should be noted that here, m is the number of options.

$$E_J = -K \sum_{i=1}^{n} [n_{ijln}](n_{ij})] \rightarrow \begin{cases} \forall_j = 1,2,3,\dots,n \\ k = \frac{1}{Ln(m)} \end{cases} \quad (3)$$

Thus, k is obtained by Equation (4).

$$k = \frac{1}{Ln(m)} \quad (4)$$

To calculate the degree of standard deviation, we use the following relation (5):

$$d_j = 1 - E_j \quad (5)$$

To calculate the weight of each indicator, we use the following relation (6):

$$W_j = \frac{d_j}{\sum_{i-1}^{n} d_j} \quad (6)$$

Select the best alternative (S_i) (7):

$$S_i = \sum_{j}^{n} = 1\ W_j \times r_{ij} \quad (7)$$

where S_i is the final weight of each factor, Wj is the weight of each criterion, and r_{ij} is the normalized weight of each variable in each criterion. In this method, an option is selected whose S_i is higher than the other options [20].
The general research process is shown in Figure 2.

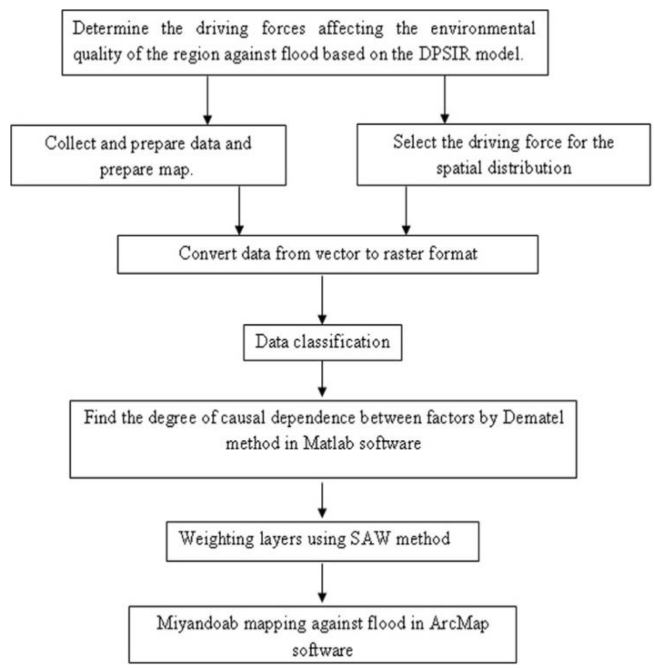

Fig. 2. Research process.

3. Results and discussion

Since there are different decision problems, relevant sustainability indicators are needed to solve these problems [21]. Floods are one of the most natural disasters that threaten people and property around the world and cause severe damage to communities, economic activity, agricultural land, dams, bridges, and roads [22]. An expert survey among 15 flood-related experts and academic scholars was conducted using the SAW method to determine and select the driving forces affecting the flooding in the area while reviewing the literature and considering the conditions of the region. As mentioned earlier, according to the DPSIR conceptual model, the driving forces are human and biophysical forces that cause the changes in the biophysical and human processes and patterns. The demographic factors such as gross population density (as it affects the construction process) and levels of education and employment were selected as the driving forces for influencing the level of participation and awareness to improve the quality of the environment. In this study, the data processing and analysis were performed based on the parameters of slope, geology, river discharge, rainfall, land use, and population density. According to the characteristics of this region, the DPSIR model is plotted in Figure 3. After preparing the data layers, the SAW method (Table 2) was used to determine the weight of the criteria. The weights were calculated with Matlab software. The Dematel method also examined the degree of dependence of the options (Tables 3 to 5), their ranking (Figure 4), and relationship (Figure 5). The final flood risk map was produced by overlaying the maps resulting from the driving forces (Figure 6). For this purpose, the weight of the criteria was multiplied by the relevant layers, and besides, the layers were combined; thus, the final raster map was obtained in three classes (from high risk to low risk). Table 6 shows the area of the three classes in hectare and percent. To solve the problem of different rankings, the rank averaging method was used.

Table 2. The weight of factors based on SAW method.

Index	S_i	Score
River discharge	0/2165	1
Land use	0/1875	2
Rainfall	0/1792	3
Population density	0/1533	4
Slope	0/1176	5
Geology	0/1165	5

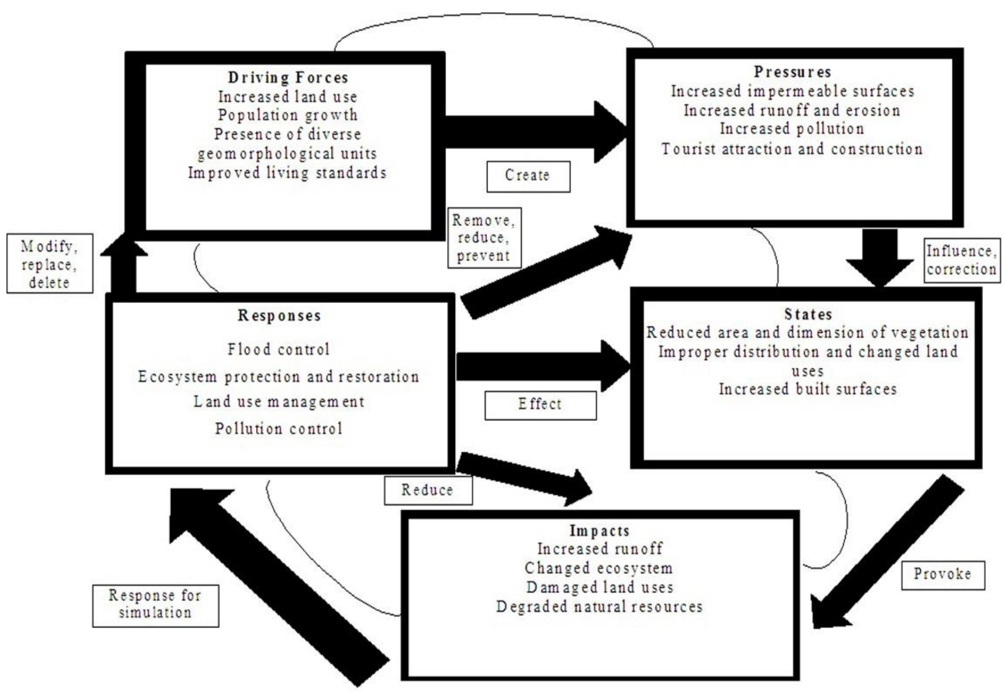

Fig. 3. Understand the characteristics of the area based on the DPSIR model.

Table 3. Primary direct relation matrix.

	Slope	Land use	Geology	Rainfall	River discharge	Population density
Slope	0	2	2	1	1	3
Land use	1	0	1	3	3	2
Geology	2	1	0	1	1	2
Rainfall	1	3	1	0	4	2
River discharge	2	3	1	4	0	2
Population density	1	2	1	1	3	0

Table 4. Matrix of given and received effect of each factor.

	Slope	Land use	Geology	Rainfall	River discharge	Population density	R
Slope	0/39	0/76	0/48	0/67	0/77	0/79	3/88
Land use	0/55	0/78	0/48	0/95	1/06	0/85	4/69
Geology	0/46	0/58	0/27	0/55	0/63	0/62	3/13
Rainfall	0/60	1/05	0/51	0/83	1/19	0/91	5/11
River discharge	0/68	1/10	0/54	1/12	0/99	0/96	5/42
Population density	0/47	0/77	0/40	0/69	0/89	0/57	3/81
J	3/17	5/05	2/71	4/83	5/55	4/73	3/88

Table 5. The weight of factors based on Dematel method.

	R	J	R+J	R-J	Score
Slope	3/88	3/17	7/06	3/17	5
Land use	4/69	5/05	9/74	5/05	2
Geology	3/13	2/71	5/84	2/71	6
Rainfall	5/11	4/83	9/95	4/83	3
River discharge	5/42	5/55	10/97	5/55	1
Population density	3/81	4/73	8/55	4/73	4

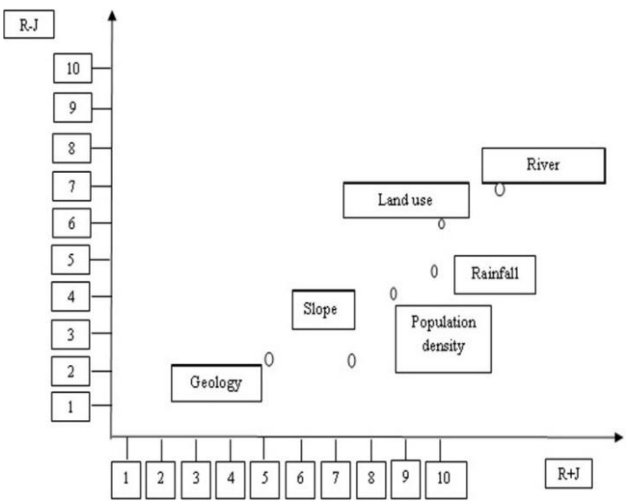

Fig. 4. Final graph.

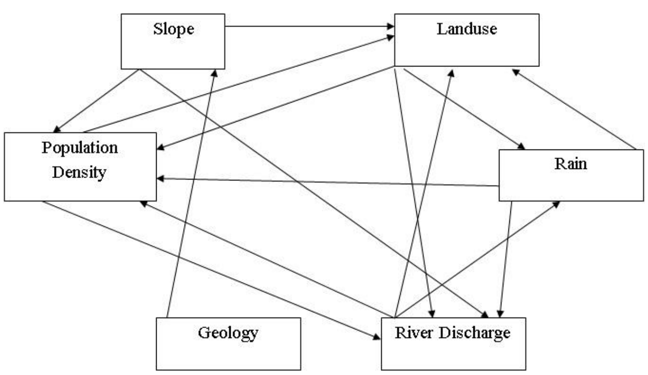

Fig. 5. T Net causal diagram or network NRM relationship map.

Table 6. Area of classes from high to low risk in hectare and percent.

Risk Classes	Area (hectare)	Area (percent)
High	78462	36/1
Moderate	91542	42/1
Low	2952	1/3

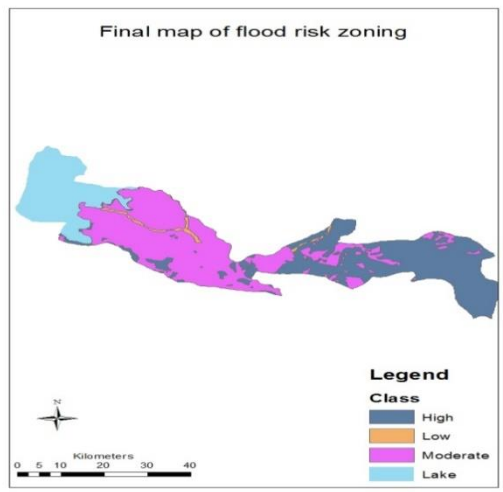

Fig.6. Final Map of flood risk mapping in Miyandoab city.

Considering the characteristics of the area for flood risk management and achieving reasonable solutions to reduce flood damage and also limiting the spread of flooding in Miyandoab, three steps for the flood risk management process can be considered as follows:

-Activities before flooding: analysis of various options (structural, non-structural) for the implementation while minimizing the damages.

-Activities during flooding: rational assessment of the flooded state during the flooding and short-term management of the operation of flood control facilities.

-Activities after flooding: a variety of decisions that return the flooded area to normalcy.

For optimal planning from environmental aspects and for the issues related to flood risk assessment according to all the studies conducted, the following suggestions are presented:

- Due to the accurate, fast, and operational nature of GIS, the study in the field of flood risk assessment and mapping without the use of these systems will be time-consuming and purely theoretical.
- To increase the efficiency of the practical studies in the field of flood risk assessment and management, it is suggested to use new methods of multi-criteria decision-making systems such as ANP.
- Considering the location and proximity of rivers and flood-prone areas to settlements, the relevant authorities are requested to prevent the spread and influence of urbanization in flood-prone areas.

4. Conclusions

Flooding is a natural phenomenon and any region is prone to this event. What makes this phenomenon unnatural and catastrophic is human interference in nature. Making decision about the measures to protect against flooding involves many decision-makers and managers, because the issue brings about many criteria and complexities. One of the most important factors in reducing the flood risk is a community's readiness and planning to deal with the flood. The readiness refers to having a specific plan in advance. The recent floods in several cities in Iran, including Miyandoab, have caused great human and financial losses due to poor management and lack of proper response. The present study aimed to identify high-risk areas in land use planning and management that face flood disasters every year. This study identified the causes of flooding with the DPSIR conceptual model, assessed the risk of factors and data layers using the Dematel and SAW methods with MATLAB software, and mapped the study area in terms of flood risk in ArcMap software. The results from combining the models of the decision support systems and GIS showed high efficiency in determining the areas with high flood risk. About 13 villages in the region are located in high-risk zones, 37 villages are in medium-risk zones, and three villages are in low-risk zones, which suggests a kind of flood risk ranking. It is therefore necessary to consider ranking in the management and planning process, especially risk management, and adopt a special strategic plan. As such, flood management should give priority to villages in high risk zones. In this study, unlike other studies that only used GIS and socio-economic criteria, the effective factors were first analyzed with the DPSIR model to assess flood risk; a set of economic, social, physical, and environmental factors, as a force, were used as the driving forces affecting the flood risk. Also, the Dematel and SAW methods, which are multi-criteria decision-making methods, were used to determine the importance of factors and criteria due to clarity and simplicity. Given that the factors of river discharge, rainfall, land use, slope, population density, and geology are more important in the Dematel method, but the factors of river discharge, land use, rainfall, population density, slope, and geology are more important in the SAW method. In this paper, the weights combined using the mean rank method. The final result indicated the high risk of flood in the southeast of the region and small portions in the southwest of the region.

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