J. Appl. Environ. Biol. Sci., 7(8)102-109, 2017
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ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
www.textroad.com

Environmental Risk Analysis of Zarivar Wetland Using Bayesian Networks

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Received: March 19, 2017
Accepted: June 12, 2017

ABSTRACT

By the increase in rate of population and industrial growth, loss of wetlands in both developed and developing countries occurred. Zarivar wetland in Kurdistan province is one of the richest ecosystems on the west of Iran which has been exposed to many setbacks and environmental risks. This study has been conducted to evaluate the environmental risks assessment of Zarivar wetland. To this purpose, in the first step, the most important risk factors and risks, using field studies and expert judgment were identified. In the second step, a graphical Bayesian network was drown using Netica software and applied to characterize risks. With the development of Bayesian network model, the probability of each of these risks in three states including: high, medium and low was determined, and in the third step, by identifying the degree of importance to each of states, risks were prioritized. The results show that risk of increasing pollution is the serious threat to the wetland. Finally, management strategies were presented to reduce and control risks.
KEYWORDS: Risk assessment, Wetland, Bayesian Networks, Zarivar wetland

1. INTRODUCTION

Generally, wetlands are aquatic ecosystems that have many important role in removing impurities, reducing the volume of flood water, preserving wildlife habitats, groundwater recharge, erosion control and other important ecosystem services (Cappiella and Fraley-McNeal 2007). The initial focus and development of human civilization 6000 years ago occurred in areas such as wetlands, river valleys and coastal plains. Wetlands with their rich and abundant resources have a vital role in the development and survival of human communities (Ramsar Convention Secretariat 2007). Sustainable and multilateral use of wetland ecosystem services are beneficial for both human and non-human communities. Ecosystem services are a concept to represent the real value of wetlands and other ecosystems. These services must be considered in decision-making processes to development regions and countries (Malekmohammadi and Rahimi Blouchi 2014).

Todays, due to various reason, natural resources and environments have undergone remarkable degradation (Abdelkader and Khéloufi 2017). Although wetlands are important ecosystems on the earth and provide irreversible services for nature and human society, more than half of them have been dried or vanished over the time (Qu et al. 2011). In recent decades, wetlands have been exposure risks and a lot of stressful factors. Application of environmental risk assessment leads to better understanding of chemical, physical and biological factors which affect wetlands, and it also is important to provide an effective management program to protect wetlands (Malekmohammadi and Rahimi Blouchi 2014). It is necessary to notice that risk is an unavoidable and inevitable part of life (Rizwana et al. 2017), and to assess each of factors that pose the environment to threats and get an optimum condition, risks should be identified and controlled (Perdana and Karnaningroem 2017). Environmental risk assessment is a quantitative and qualitative assessment of the risks which are caused by exposure to chemical and physical hazardous factors. Risk assessment of a specific site means identifying potential threats and hazards to that site which are in contact with human and environmental health. These threats can be created and transferred by contaminants in underground and surface water, air pollution, soil leaching, accumulation of poison and pollution in food chains and so on (Kibria 2014).

Many studies about environmental risk assessment of wetlands have been done. In 2007 Pollino and his colleagues carried out some studies to identify and evaluate Bayesian networks criteria to assess ecological risks. They found that watershed managers, due to diversity and complexity of environmental components and also considerable uncertainty related to quantifying the threats and risks, are facing great challenges in the management of ecosystems. They showed that Bayesian approach is an accurate and suitable method to assess and model environmental threats (Pollino 2007). Qu and et al in 2011 conducted a study to ecological risk assessment of pesticides into the Taihu wetland in China. In this study, the ecological risks of eight pesticides in wetland

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identified and evaluated. Pesticides which were used to destroy weeds had a particularly large impact on wetland vegetation, insects, fish, and zooplanktons. In general, it was found that pesticides cause serious risks in wetlands and these risks and threats must be reduced (Qu et al. 2011). Ayer et al in 2012 applied Bayesian approach for ecological risk assessment of the Upper Grande Ronde watershed. They provided a Bayesian network model to assess potential effects of fire, grazing, forest management practices and insect outbreaks on habitats and resources (Kimberley and Landis 2012). Yet et al in 2016 conducted a study in the case of agricultural development in order to present a Bayesian network framework regarding risk analysis of project cost and benefit. They used dynamic and hybrid Bayesian networks in a framework containing continues and discrete variables. They showed that their model can be used to assess different projects (Yet et al. 2016).

Zarivar wetland is a rich ecosystem which has remarkable fauna and flora. Unfortunately, due to natural phenomena and human activities such as agriculture, livestock and urbanization it has been affected and suffered drastically. Human activities in the area generally include agriculture, horticulture and animal husbandry that due to wrong decisions and plans, these activities are intensified at around of the wetland. Since there is no comprehensive study associated with identifying these threats in Zarivar wetland, the purpose of this study is to identify and show its potential risks. Due to the uncertainty in occurrence and assessment of risks, Bayesian networks as a graphical model has been used for risk assessment and then proper solutions to manage and reduce risks and their effects have been presented.

2. MATERIAL AND METHODS

To environmental risk assessment of Zarivar wetland and determination of risks that have endangered the availability and stability of the wetland, library and field studies of Zarivar wetland were conducted. Firstly, natural and ecological aspects of the wetland (physical, chemical and biological) and the relationships among elements of the wetland were identified and then risk factors and main risks that disrupt functions and processes of the wetland were determined. At the later stage to characterize these risks and threats, Bayesian network framework were drawn (the framework of the Bayesian network is composed of nodes (variables), links (relationships between nodes) and conditional tables of variables) by Netica software. In the next stage, risks of Zarivar wetland were prioritized, and finally, appropriate management strategies to reduce and control the risks were presented. Figure 1 shows steps of this study.

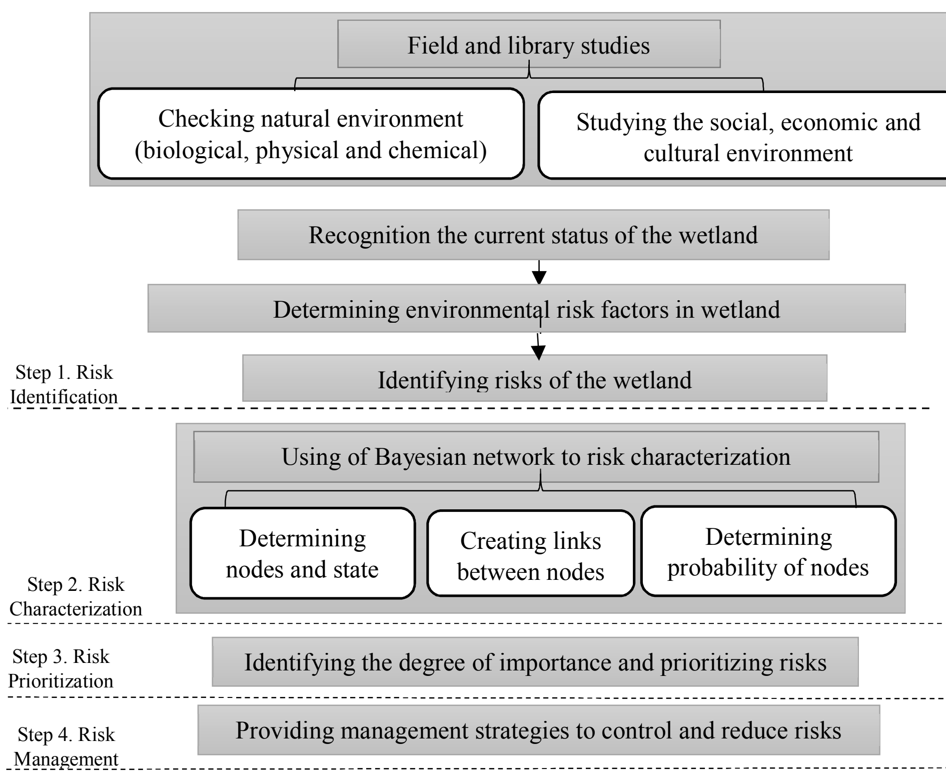

Figure 1. The process of environmental risk assessment of Zarivar wetland

2.1. Study area

Zarivar wetland is a freshwater ecosystem that situated in the west of Marivan in Kurdistan province with longitude from 46°03' to 46°10' east, and latitude from 35°30' to 35°37' north. Agricultural activities by modern and traditional systems have been done in vast areas of the basin. Zarivar wetland is one of the unique freshwater wetlands in Iran that was created as a result of chutes of the ground. This wetland from the west, east and north is surrounded by mountains and covered with forests and has an important role in control floods and runoff. The wetland is recharged by a series of springs that lay down the floor of the wetland, precipitation and runoff, and a channel that diverted from Ghezelcheso basin. Ghezelcheso basin is located in the north of Zarivar wetland. Figure 2 shows the location of Zarivar wetland.

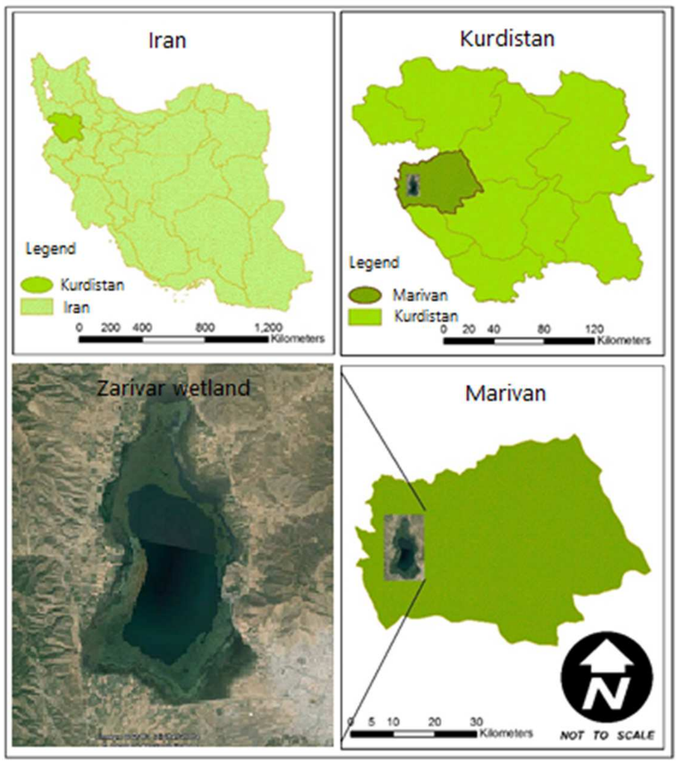

Figure 2. Location of Zarivar wetland

2.2 Bayesian networks

Bayesian networks are based on Bayes' rules that can be used as a coherent approach to managing uncertainties using dependencies among variables. Bayesian networks are graphical models to inference and describe the probabilistic relationships among large numbers of variables (Kabir et al. 2015), and they have been used in a wide range of problems from the analysis of textual data to medical diagnosis. These networks provide appropriate conditions and framework for combining data with expert knowledge (Uusitalo 2007). Utilization of these methods have led to an easy understanding of cause and effect relationships among variables and can be combined with other analytical and decision-making tools (Marcot et al. 2001). Bayesian networks are able to use the subjective judgment of experts. Subjective judgment of experts is the only source of information when events and studies are new and are under investigation, or historical data about them is scant (Hart and Pollino 2009). Bayesian networks consist of the following three parts,

1- A set of nodes (variables) and direct links between them
2- Set of states of variables
3- Conditional probability tables for each variable

Nodes and links draw the structure of the Bayesian network. The nodes represent variables and each variable is shown by a node so that the number of nodes represents the number of variables. Nodes that are before a specific node are known as parent nodes, and those that are after specific nodes are known as child nodes. The relationship among these variables is created through links. The direction of the links represents a causal relationship between two variables. For each node, different states of the variable can be defined by the user. Each node has a probability function. Primary nodes (without parent nodes) represent prior probability (or unconditional probability), and each child node contains a conditional probability table. In fact, the distribution of conditional probability which is the

marginal distribution of child nodes is determined within these tables. The states of each variable and conditional probability distribution can be determined through available information, field and laboratory research, modeling and expert judgment (Kabir et al. 2015).
In figure 3, A and B are nodes (variables). A is a parent node and b is a child node, and the arrow shows the direction of the relationship between these two variables. So, A is a primary node which has no parent node. By considering 3 states: High, Medium and Low, node A has an unconditional probabilities. Node B is a child which can be affected by node A, and it contains a conditional probability table.

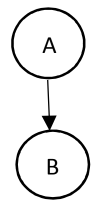

Fig. 3. Nodes and links in structure of Bayesian network

Table 1 shows unconditional probability and states of variable A.

Table 1. Unconditional probability and states of variable A

Variable A	Probability
H	**$P(A_1$=H)**
M	**$P(A_1$=M)**
L	**$P(A_1$=L)**

So, the conditional probability distribution of node B can be calculated. Table 2 shows conditional probability distribution of node B.

Table 2. Conditional probability table and states of node B

Variable A	Variable B		
	States		
States	**H**	**M**	**L**
H	P(B=H|A=H)	P(B=M|A=H)	P(B=L|A=H)
M	P(B=H|A=M)	P(B=M|A=M)	P(B=L|A=M)
L	P(B=H|A=L)	P(B=M|A=L)	P(B=L|A=L)

Bayesian networks basically represent a continuous probability distribution of all variables of a system. Based on the Pearl chains, if $X = \{x_1, x_2, \dots, x_n\}$ be a set of variables, so the joint probability distribution of $x_1, x_2, \dots, x_n$ can be determined by the conditional distribution of any variable which is given to each of the nodes in a Bayesian network, function 1 (Troldborg et al. 2013).

$$P(X) = P(x_1, x_2, \dots, x_n) = \prod_{t=1}^{n} P(x_i | Pa(x_i)) \qquad (1)$$

Where x_i represents i value in a random variable, $P(x_1, x_2, \dots, x_n)$ is joint probability values of$(x_1, x_2, \dots, x_n)$, and $pa(x_i)$ represents the parents of x_i node.
The marginal distribution of any variable in the Bayesian networks can be found by summing over all other variables, function 2,

$$P(X_i) = \sum_{U \setminus \{X_I\}} P(U) \qquad (2)$$

Probabilistic inference is one of the main merits of Bayesian networks, so that the posterior probability distribution is calculated using Bayesian networks based on observed evidence such as observed changes in some variables in the network. Inference through Bayesian networks includes predictive and diagnosis inference. Predictive inference can be achieved by applying different scenarios in parent nodes, this means that by observing changes in the status of parent nodes, occurred changes in child nodes be predicted. Diagnosis inference takes place through applying scenarios in child nodes (Norsys 2017).

3. RESULTS

To environmental risk assessment of Zarivar wetland, natural and ecological aspects of the wetland and potential impacts of risk factors on biological, chemical and physical condition of the wetland were investigated. Finally, to assess the wetland using Bayesian Network, 18 nodes (variable) were determined. These nodes include 12 risk factor nodes, 6 risk nodes. Risk factor nodes are primary or root nodes with unconditional probabilities that are the main cause of risk to the wetland and expose the wetland to risk. In fact, these nodes create risks to the wetland. Risk factors include overexploitation of water, unmanaged tourism development, destruction of vegetation, increase in agricultural land use changes, increase in residential construction, changes in water temperature, discharge of domestic sewage, entrance agricultural waste into the wetland, wildfire in marshes, Zarivar dam, Qezelcheso Channel, and increase the level of constructing roads. Risk nodes are child nodes with conditional probabilities that are consequences of risk factor nodes and are the main risks to the wetland. Risk nodes including, increase in land use changes, increase in sedimentation of wetland, loss of biodiversity, increase in pollution of the wetland, occurrence eutrophication in the wetland and excessive exploitation of water resources. All of these nodes are linked together through 21 links. In this study, states for each node were determined based on field studies and expert opinions. Table 3 shows each of nodes and states.

Table 3. Nodes and States

Nodes		State of nodes	Type of node
A1	Overexploitation of water	High, Low	Risk factor nodes (main causes of risks in the wetland)
A2	Unmanaged tourism development	True, False	
A2	Destruction of vegetation	High, Medium, Low	
A4	Increase in agricultural land use changes	High, Medium, Low	
A5	Increase in residential construction	High, Low	
A6	Changes in water temperature	Spring, Summer, Winter	
A7	Discharge of domestic sewage	High, Medium, Low	
A8	Entrance of agricultural waste into wetland	High, Low	
A9	Occurrence of wildfire	High, Low	
A10	Zarivar dam	True, False	
A11	Qezelcheso channel	True, False	
A12	Increase in the level of constructing roads	High, Medium, Low	
A13	Overexploitation of wetland resources	High, Medium, Low	Risk nodes (main risks in the wetland)
A14	Occurrence of Eutrophication	High, Medium, Low	
A15	Increase the volume of pollution	High, Medium, Low	
A16	Decrease of biodiversity	High, Medium, Low	
A17	Increase in sedimentation	High, Medium, Low	
A18	Increase in the level of land use changes	High, Medium, Low	

Due to the uncertainty in determining and occurring of risks, Bayesian networks was used to environmental risk assessment of Zarivar wetland. Many software and programs were designed to do Bayesian calculations. Netica is a powerful software for working with belief networks and influence diagrams. It has been programmed to draw advanced Bayesian belief networks, create an environment to identify different states of variables and to do conditional probability calculations between variables (Norsys 2017). So, in this study, Netica was used to the risk assessment of Zarivar wetland. Figure 4 shows a graphical diagram of environmental risk assessment of Zarivar wetland. States and probability tables for each of these variables were identified through field studies and expert judgment. After the construction of the network in the Netica software, the model was run; figure 4 shows the graphical diagram of environmental risk assessment of Zarivar wetland.

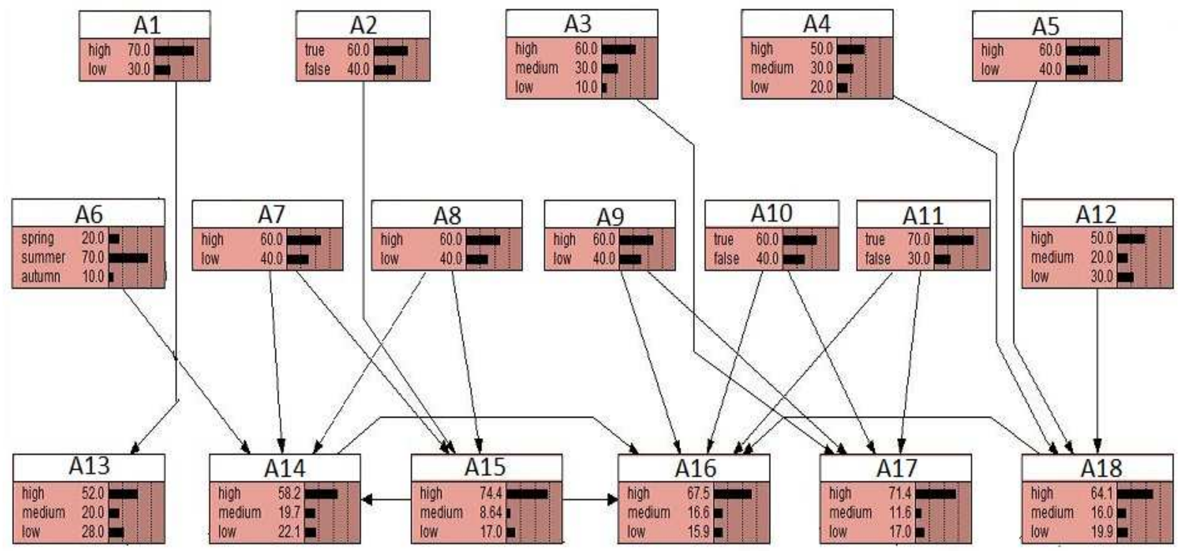

Figure 4. Graphical diagram of environmental risk assessment of Zarivar wetland

4. DISCUSSION

Figure 4 shows the result of the Bayesian network model. The initial (unconditional) probability values have been shown on the parent nodes (risk factors). The amount of risk for each of the child nodes (risks) was calculated in three states (High, Medium, and Low). As can be seen from the diagram, risk of overexploitation of wetland resources (A13) in state H is 52% and for M and L is 20% and 28%, respectively. Risks of other nodes for different states have been shown on the diagram.

To prioritize risks of the wetland, a coefficient was allocated to each state as a degree of importance. If the degree of importance for state H be 1, state M be 0/5 and state L be 0, by multiplying the amount of risk of each state in allocated degree of importance to that state and then adding them for each node, the risk of nodes can be calculated. The amount is higher, the risk is higher.

Risk of each node = (1* H + 0/5 * M + 0 * L)

Risk of overexploitation of wetland resources (A13): (1 * 52 + 0/5 * 20) = 62

Risk of Occurrence of Eutrophication (A14): (1 * 58/2 + 0/5 * 19/7) = 68/05

Risk of Increase pollution of wetland (A15): (1 * 74/4 + 0/5 * 8/64) = 78/72

Risk of Decrease of biodiversity (A16): (1 * 67/5 + 0/5 * 16/6) = 75/8

Risk of Increase of sedimentation (A17): (1 * 71/4 + 0/5 * 11/6) = 77/2

Risk of Increase in level of land use changes (A18): (1 * 64/1 + 0/5 * 16) = 72/1

According to the calculated values, the risk of pollution of the wetland (A15) is the highest. Risks of increase of sedimentation (A17), loss of biodiversity (A16), an increase in the level of land use changes (A18), and occurrence of eutrophication (A14) are in lower degrees, respectively. The risk of overexploitation of wetland resources is the lowest to the wetland.

Determining and prioritizing risks of the wetland helps to provide proper management strategies to control and reduce these threats and then to preserve the wetland. According to risk factors and the amount of these risks, some control measures to reduce the effects of risk factors of Zarivar wetland have been presented in table 4.

Table 4. Control measures to reduce effects of risk factors of Zarivar wetland

Risk factor	Management strategies
Overexploitation of water	- Preventing of drilling wells in the basin of the wetlands - Proper management of transmission, distribution, and consumption of water in households, agriculture, and industry - Filling the wells that have been dug illegally
Unmanaged tourism development	- Designating an ecological border for the wetland and preventing destructive activities at this area - Preventing of constructing leisure facilities in the sensitive ecological area of the wetland - Monitoring private sector tourism development - Training local residents and tourists in the area of the wetland
Destruction of vegetation	- Restoration of rangeland and forest around the wetland - Creating balance between livestock and livestock grazing - Soil conservation and control runoff
Increase in agricultural land use changes	- Conservation of land and vegetation around of the wetland and prevention of changing them into farmland and residential area

	- Proper management of agriculture - Using of modern irrigation systems - Evaluating ecological capability to achieve proper plans based on the capacity of the wetland ecosystem
Increase in residential construction	- Preventing and dealing with illegal land-grabbing and encroachment on the wetland - Preventing sprawl of residential areas around the wetland
Changes of water temperature	- preventing the entrance of human consumption warm waters into the wetland - Removing or disabling nutrients which along with increase in temperature leads to eutrophication in the wetland
Discharge of domestic sewage into the wetland	- Wastewater treatment before discharge into the wetland - discharging purified wastewater into the downstream part of the wetland - removing solid wastes and pollutants, and purifying discharged pollutions
Entrance of agricultural sewage into the wetland	- Reducing and eliminating the use of fertilizers especially Nitrate and phosphate - Reducing the use of pesticides - Removing animal waste near the pond
Wildfire in the wetland	- Avoiding the plan and unplanned fires - Using biological methods to prevent the spread of marshlands
Zarivar Dam	- Constructing culverts on the dam to communicate both sides of the wetland - Dredging and preventing excessive accumulation of sediments behind the dam
Ghezelcheso channel	- Preventing of entrance of transported sediments by Ghezelcheso channel into the wetland - transferring of Ghezelcheso water to the downstream side of the wetland - Water treatment of Ghezelcheso before entering to the wetland
Increase in the level of road-making	- Preventing of road-making in ecological border of the wetland - Establishing communication corridors in sections of the roads that have disrupted ecological connections

5. Conclusion

Environmental risk assessment can be used to understanding the actual ecological situation and potential risks in wetlands and other natural systems. Wetlands are complex systems with complex relationships and functions among their components. Due to these complex relationships, a change in any part of the wetland leads to change in the other related components. Determining these changes and managing them are very important to the preservation of wetlands, but this is difficult and the outcome is uncertain. With regard to this conditions, Bayesian network method was used for Zarivar wetland risk assessment. So, wetland features and components in terms of ecological, physical and chemical condition were studied, and threats and factors that lead to disturbance in the ecological condition and integrity of the wetland were identified and assessed. The most important Zarivar wetland risks include an increase in pollution of the wetland, increase in sedimentation into the wetland, loss of biodiversity, an increase of land use changes, occurrence eutrophication in wetland and excessive exploitation of water resources. These risks have occurred as a result of a number of factors known as risk factors. Netica software was used to draw Bayesian networks diagram and determine the probability distributions of risks. The results of analyzing this model show that the risk of pollution has the greatest risk and after that increasing in sedimentation of wetland, a decrease of biodiversity, increasing in land use changes, the occurrence of eutrophication and excessive exploitation of water resources have the greatest level risk to Zarivar wetland, respectively. The results show that the wetland is in a vulnerable condition and proper management strategies should be provided and applied to control and reduce these threats.

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