

## ORIGINAL RESEARCH PAPER

# Environmental risk assessment of a dam during construction phase

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**ABSTRACT:** The present study was conducted to assess the possible risks induced by construction of Gavi Dam in Ilam Province; western part of Iran, using MIKE-11 model and technique for order of preference by similarity to ideal solution. For this purpose, vulnerable zone of the dam site against the flooding risk of Gavi River was calculated for different return periods. The flooding zones were stimulated by MIKE-11 model. In order to check whether or not the dam construction could affect the quality of the Gavi River, the physicochemical quality of the river water was also tested. Afterwards, a questionnaire was prepared containing an inventory of possible risks supposed to be induced by construction of Gavi Dam. The questionnaires were placed at disposal of experts to score the items based on their importance. The questionnaires were then analyzed using SPSS Software, version 16. According to which, a total number of 12 risk factors were identified. The dam construction risks were qualitatively assessed by preliminary hazard analysis. Based on the results, 3 of 12 identified risks were recognized unacceptable. The shortlisted risks were prioritized at final step using technique for order of preference by similarity to ideal solution. "Habitat fragmentation" with a weight of 0.3002, "water pollution" with a weight of 0.295, and "impacts on aquatics" with a weight of 0.293 were identified as three top priority flooding risks. Among the most important corrective measures for mitigation of the risks at construction phase can be pointed to "restoration of the land cover", "conservation of areas surrounding the dam as a new wildlife habitat", "prevention of water contamination", and "conservation of fish spawning sites".

**KEYWORDS:** Construction phase; Gavi Dam; MIKE-11; Preliminary hazard analysis (PHA); Risk; Technique for order of preference by similarity to ideal solution (TOPSIS)

## INTRODUCTION

Nowadays, particular methods, techniques, and tools have been presented in order to control, eliminate, or minimize hazards to human health and the surrounding environment. Modern human, instead of dealing with risks in an emergency situation, takes action to identify, measure, prioritize and control their occurrence because he believes that prevention is better

than cure. Thus, risk assessment and management is of the great issues of importance in human life. Large projects such as dam building can impose a variety of potential risks to the receiving environment either in construction or operational phases (Samaras *et al.*, 2014; Zhang *et al.*, 2009; Jozi *et al.*, 2015; Jozi and Seyfosadat, 2014). It can cause catastrophic flooding and immense damage at downstream areas (Hooshyaripor and Tahershamsi, 2015, Andrew Charles, 2012, Jozi and Malmir, 2014) and impose external costs

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to local people (Monavari et al., 2014, Tajziehchi et al., 2012, Tajziehchi et al., 2014, Tajziehchi et al., 2013). Therefore, it is necessary to take steps for preparing against these risks, prior to deal with them (Marche and Robert, 2002; Wolfe et al., 2015). Environmental risk assessment is a step beyond the risk assessment, by which in addition to the study of various aspects of risk, the fragility and particular values of the receiving environment should also be regarded (Heller, 2006; Morales-Torres et al., 2016).

Bocchiola and Rosso in 2014 used generalized extreme value (GEV) distribution to study the return period of large dams in Italy. Xin et al. (2011), by using tailing dam failure probability analysis assessed consequences of dam failing. Goodarzi et al. (2014) investigated the application of risk and uncertainty analysis to assess the overtopping risk of Doroudzan Reservoir in southern Iran. They concluded that both increasing water level and wind speed have a significant impact on the risk of overflowing. Chen et al. (2010) predicted possible ecological risks induced from dam building. They could be able to show how an affected river ecosystem reacts to the artificial perturbation on a whole-ecosystem scale. Danso-Amoako et al. (2012) developed a rapid screening tool to study sustainable flood retention basins for the prediction of corresponding dam failure risks. They concluded that failure risks of dams located near cities are higher than those situated in rural locations. Tosun et al. (2007) discussed the seismic risks of a total number of 32 large dams in Euphrates basin. They revealed that fifteen large dams in the basin should be categorized in the class of high-risk. Haoyao et al. (2012) used Entropy theory and fuzzy matter-element method to establish a comprehensive risk assessment model for earth-rock dams under drought condition. Lee and You (2013) developed a framework for the management of reservoir risks. They found that the capacity of flood control has an influential effect on the induced risk.

The present study was conducted within one year period from 2011 to 2012 to assess the flooding risk of Gavi Dam in Ilam Province western Iran using MIKE-

11 Model and TOPSIS. It also identified and prioritized the most important risks induced by construction of the dam.

## MATERIAL AND METHODS

### Study area

The Gavi Dam is located in Mehran County in Ilam province in the western part of Iran, near the common borderline with Iraq. As a part of Gavi Basin, the study area is situated within the longitudes of 46° 23' - 46° 22'E and the latitudes of 33° 10' - 33° 27'N. Table 1 presents the technical specifications of the Gavi Dam.

The Gavi Dam was constructed to supply drinking water to the Mehran County, control and store untimely floods, and to distribute appropriately irrigating water to 4 million ha of the farmlands. Major resources of surface water in the study area include Gavi River, Konjanham River, and Changoule River, with a total annual yield of 390 mcm. The average annual rainfall in the basin is 529 mm. The maximum and minimum temperatures in the dam basin are 52 °C and -27.5 °C. The study area provides habitats for Gavi Dam, small and large mammals, porcupine, birds of prey, saxicolous birds, plain birds, and aquatics. There are situated two villages of Amirabad and Konjanham in the study area (Puyab Consulting Engineers, 2005). Fig. 1 illustrates situation of the study area.

### Research methodology

The study area was investigated by field visits to identify the fragile components of the environment in the basin. At first, in order to identify project risks, physicochemical quality of the river water for drinking and agricultural consumptions, as two main sources of water use in the study area, was checked. To evaluate the chemical quality of the river water, microbiological tests were conducted from February 2012 to December 2013 at the two selected stations of Tangbajak and dam site, using titration, reflux, gravimetric, photometry, and atomic absorption of various pollutants. The parameters of total suspended solids (TSS), total dissolved solids (TDS), chemical oxygen demand

Table 1: Technical specifications of Gavi Dam (Puyab Consulting Engineers, 2005)

Dam type	Earth dam with a vertical clay core
Height from foundation (m)	101.5
Crown length(m)	732.7
Crown width(m)	12
Total volume of the reservoir (mcm*)	47.7

\* Million cubic meters

(COD), biochemical oxygen demand (BOD), electrical conductivity (EC), salinity, some selected trace metals, total coliform, and fecal coliform were tested within the years 2012 and 2013. One of the most annoying agents in construction works was noise generation. This, in outdoor areas, such as Gavi Basin, can adversely affect wildlife habitats by scattering animal communities. The annoying sound can also leave a negatively influence generally on the ecological adverse and specifically on the process of egg-laying of birds and reproductive activities of other animals. All of the construction activities may generate annoying noise upper than the standard limits. These operations are “excavation and embankment”, “clear-cutting”, “harvesting borrow materials”, “drilling and foundation”, “transpiration”, “camp construction”, “tunnel construction”, “construction of coffer and ostour dams”, “operation of crusher machine”, “detonation of explosives”, “equipment and machinery operation” and “operation of fuel tanks”. In order to assess noise level at the dam site, the equivalent sound level meter was measured towards 8 main directions, including north, east, south, west, northwest, northeast, southwest, and southeast. The measurements were done based on the standard method of 1979, 651IEC at a distance of 40m from the equipment by Cell 440 sound level meter, made in UK. According to the instructions presented by Iran

Department of the Environment (DOE, 2007), the equivalent sound level meter was measured at “A weighting network” for 30 min (). Besides, the flooding zone was determined by MIKE-11. Other risk factors were identified using the PHA (Preliminary hazard analysis) questionnaires. The filled out questionnaires were analyzed by SPSS16. The identified risks were then prioritized by TOPSIS as a widely used multi attribute decision making (MADM) method. Fig. 2 presents the research procedure.

*MIKE-11 model and risk identification*

Dimensions of hydraulic structures of dams are a function of flood discharge. Design flood is the expected discharge with a particular return period used for the design of a structure. For calculation of flooding extent, statistics on the maximum flow of hydrometric stations were required. According to which, the flooding of Gavi River was calculated for different return periods. The flooding zone of Gavi River was specified using MIKE 11 Model. The advanced MIKE-11 software developed by the Danish Hydraulic Institute (DHI) which helps users solving hydraulic issues. The software has been written in Pascal language. Investigation of the issues of flood control, assessment of permanent and non-permanent flows and flood routing are of capabilities of this software. Flood zoning

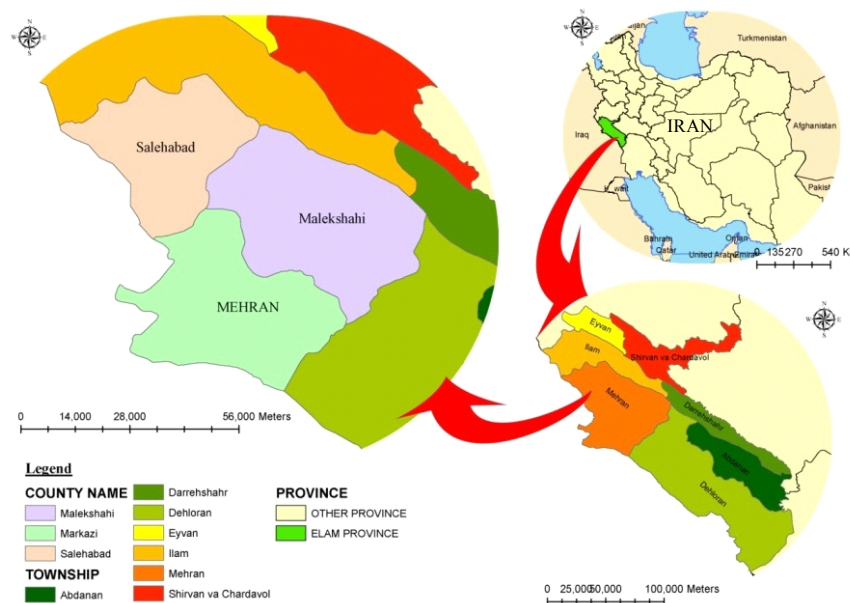


Fig. 1: Situation of the study area

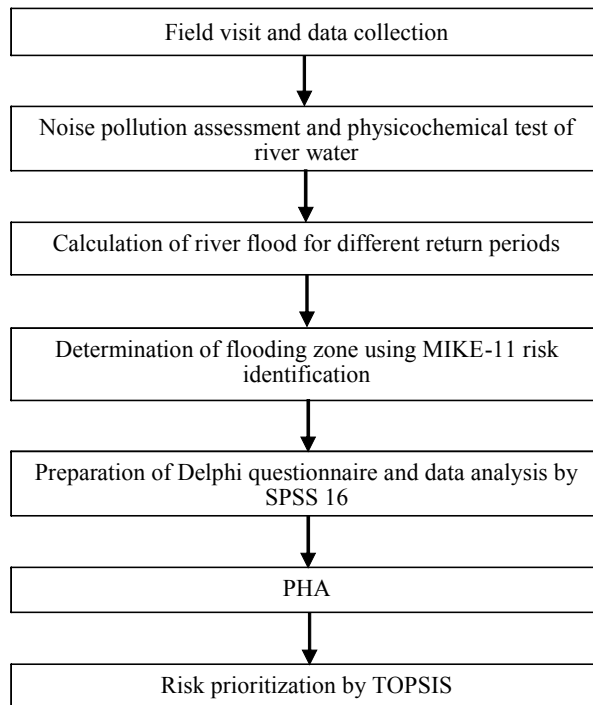


Fig. 2: Procedure of risk assessment of Gavi Dam

Table 2: Methods used to monitor water quality

No.	Parameters	Measurement unit	Measurement method
1	Chemical oxygen demand	Mg/L	Dichromate reflex method
2	Biochemical oxygen demand	Mg/L	Winkler azide method
3	Total coliform	MPN/100ml	Multiple tube method

Table 3: Designing flood of Gavi River for various return periods (m<sup>3</sup>/s)

Stations	2	5	10	20	25	50	100	1000	10000
Return period (year)									
Tangebajak station	76.7	138.8	189.2	244.3	263.2	325.8	394.8	676	1052.5
Dam site station	75	148	211	282	307	392	489	904	1499

by the MIKE-11 is a complex process. Firstly, the river network and the cross sections should be prepared. The river cross section can be taken from the digital elevation model (DEM) of the river. Then, the river flooding zones is prepared by entering the time series of flow data of the stations within the different return periods (Table 2). Fig. 3 is the output of the flood modeling by MIKE-11. After specifying the flooding zone, the risks of Gavi Dam at constructional phase were listed in the form of a questionnaire and placed at the disposal of experts. The experts were asked to score them based on Likert Scale as: (1, 3, 5, 7, and 9) (Table 3).

The filled out questionnaires were analyzed by SPSS16 to calculate the mean, mode, and standard deviation of each risk factor.

#### PHA

The preliminary hazard analysis (PHA) is a systematic safety analysis used to assess the critical and safe areas. The main purpose of this analysis is to achieve significant risk assessment data to help prioritization of risks, allocation of resources and assessment of the compliance the risks. Coding is a common tool in risk assessment studies that is assigned



Table 4: Risk severity in PHA (Leggett 2012, Rooney et al., 1998)

Comment	Rank	Risk level
Death or severe impact on local ecosystems	1	Catastrophic
Damage to local ecosystems and human communities	2	Critical
Indirect effects on local ecosystems and human communities	3	Intermediate
Negligible effects on local ecosystems and human communities	4	Negligible

Table 5: Occurrence probability of risks in PHA (Wells et al., 1993; Rooney et al., 1998)

Comment	Rank	Frequency
Frequently occurs	A	Frequent
Occurs several times during the lifetime of a system (process)	B	Probable
Occasionally occurs during the lifetime of the system (process)	C	Casual
Occurrence probability is very low during the lifetime of the system (process)	D	Very low
Occurrence probability during the lifetime of the system(process) is so low that it can be assumed zero	E	Improbable

Table 6: Risk assessment by PHA (Rooney et al., 1998)

Occurrence probability \ Impact intensity	Impact intensity			
	Catastrophic (1)	Critical (2)	Intermediate (3)	Negligible (4)
Frequent A	1A	2A	3A	4A
Probable B	1B	2B	3B	4B
Casual C	1C	2C	3C	4C
Very low D	1D	2D	3D	4D
Improbable E	1E	2E	3E	4E
Risk index	Unacceptable	Desirable	Accepted with revision of management	Accepted without revision

Table 7: Chemical quality test results of Gavi River

Parameters	Stations	Summer 2011	Winter 2011	Spring 2012	Autumn 2012	National standard limit for potable water use (NSI, 1992)	National standard for agricultural use (DOE, 2014)	Unit
BOD	Dam site	99	105	85	87	50	100	Mg/L
	Tangbajak	88	98	55	63			
COD	Dam site	78	210	65	108	100	200	Mg/L
	Tangbajak	70	155	60	98			
Coliform	Dam site	-	-	-	1500	400	400	NO./ml
	Tangbajak	-	-	-	1000			

$$\bar{a}_i^- = \left\{ \sum_1^n (V_i - V_i^-)^2 \right\}^{1/2}, \quad (i=1,2, \dots, m) \quad (6)$$

Step 6: calculation of  $C_i$  indicating the closeness to the positive ideal and distance from the negative ideal (Eq. 7):

$$C_i = \frac{\bar{a}_i^-}{(\bar{a}_i^- + \bar{a}_i^+)}, \quad (i=1,2, \dots, n) \quad (7)$$

Ultimately, the alternatives are ranked based on descending order of  $C_i$ . The available alternatives can be ranked based on the highest importance (Jozi et al., 2014; Heller, 2006).

## RESULT AND DISCUSSION

Results of water quality analysis revealed that all water quality parameters are within the standard limits, except for microbial and biological parameters in the station of the dam site. As such, electrical conductivity (EC) of the river was 851.1  $\mu\text{s}/\text{cm}$ , at the station of dam site, and 522.8  $\mu\text{s}/\text{cm}$ , at Tangbajak Station, which is suitable for agricultural purposes (Ebadati and Houshmandzade, 2014). Table 7 shows the measurements were performed in four seasons of the year; summer (first turn), autumn (second turn), winter



(third turn), and spring (fourth turn). Due to the large volume of the chemical quality test results, a few of which are here mentioned. Also, due to limited access to laboratory facilities, coliform was only measured on the final turn in spring. Table 7 indicates the chemical quality test results of Gavi River. Noise pollution at dam site was assessed towards 8 main directions and the obtained results were compared with noise pollution standard limits for industrial-residential areas. According to the results, noise level exceeded the standard limits of 70 dB at the two stations. Table 8 shows the results of noise pollution assessment. The risk identification was done by experts. At this step, a total number of 24 risk factors were identified as presented in Table 9.

*Qualitative flood zoning by MIKE-11*

Qualitative flood zoning of Gavi River was obtained by MIKE-11. After specifying the flooding zone, the impacts of flooding on the surrounding villages were also investigated (Fig. 4). As Fig. 4 suggests, two villages, namely Amirabad and Konjan Cham, will be flooded by dam construction. Studies showed that

these two villages are non-resident; thereby the flooding hazard will not be a threat to human life.

After determining the flooding zone, the major flooding risks were identified by questionnaires. The questionnaire data were analyzed using SPSS software, version 16. Those risk factors with an average score of 3 or higher were screened. Table 10 presents descriptive statistics of the identified risks induced by construction of Gavi Dam.

*Risk analysis by PHA*

After risk identification, the PHA was used to determine the risk level of each risk factor. According to which, three risks of “harvesting of borrow materials”, “excavation and embankment”, and “harmful effects on aquatics” were recognized as unaccepted risks. Furthermore, a total number of 5 risks including “drilling and foundation”, “tunnel construction”, “operation of crusher machine”, “detonation of explosives”, and “sedimentation” were evaluated as undesirable risks. Table 11 gives the results of the PHA.

Table 8: Noise assessment at the site of Gavi Dam

No.	Stations	Sampling duration (min)	Measured value (dB)	Standard limit (dB)
1	Extreme north side of the dam at the distance of 40 m	30	60.8	70
2	Extreme south side of the dam at the distance of 40 m	30	62.9	70
3	Extreme east side of the dam at the distance of 40 m	30	68.2	70
4	Extreme west side of the dam at the distance of 40 m	30	63.5	70
5	Extreme northwest side of the dam at the distance of 40 m	30	67.3	70
6	Extreme northeast side of the dam at the distance of 40 m	30	61.7	70
7	Extreme southwest side of the dam- at the distance of 40 m	30	66.1	70
8	Extreme southeast side of the dam- at the distance of 40 m	30	69.3	70

Table 9: Identified risks at constructional phase of Gavi Dam

No.	Risk	No.	Risk
1	Operation of fuel tanks	13	Excavation and embankment
2	Flood	14	Clear-cutting
3	Induced earthquake	15	Harvesting of borrow materials
4	Earthquake	16	Drilling and foundation
5	Internal erosion of the dam and foundation	17	Transportation
6	Landscaping	18	Camp construction
7	Drought	19	Tunnel construction
8	Incidents while loading and unloading of materials	20	Construction of cofferdams and oostour dams
9	Migration	21	Operation of crusher machine
10	Concreting	22	Detonation of explosives
11	Sedimentation	23	Equipment and machinery operation
12	Harmful effects on aquatics	24	Generator operation

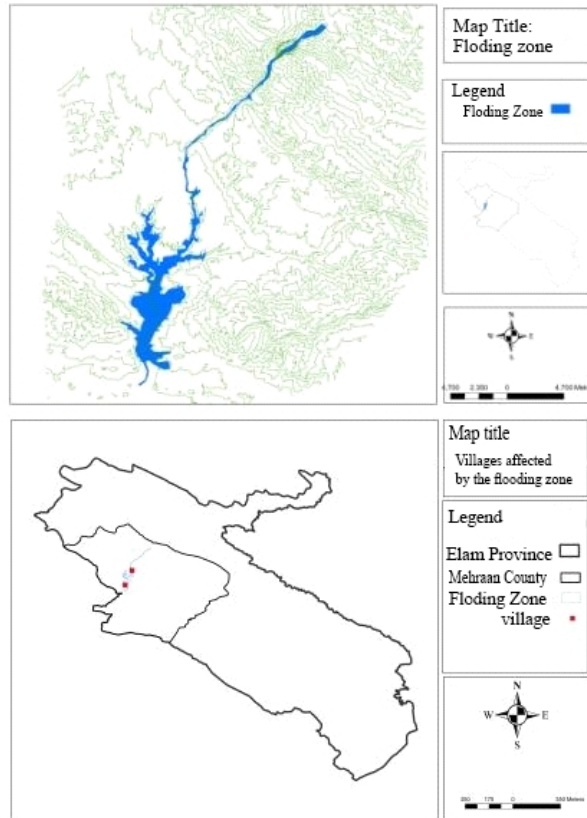


Fig. 4: Villages at risk of flooding

Table 10: Risks of Gavi Dam at constructional phase

Operation	Mean	Mode	SD*
Excavation and embankment	3.6	0	1.560
Clear-cutting	2.5	0	2.167
Harvesting borrow materials	4	5	1.264
Drilling and foundation	3	4	1.549
Transpiration	2.5	0	2.073
Camp construction	3.2	0	1.651
Tunnel construction	3.3	4	1.751
Construction of cofferdams and ostour dams	3.5	3	0.547
Operation of crusher machine	3.3	4	1.751
detonation of explosives	4.8	5	1.834
equipment and machinery operation	4.1	4	0.408
Operation of fuel tanks	2.1	4	1.636
Flood	4.3	5	1.816
Induced earthquake	2.6	2	1.211
Earthquake	2.5	3	1.643
Internal erosion of the dam and foundation	0.8	0	1.329
Landscaping	1.8	3	1.471
Drought	2.1	0	1.834
Incidents of loading and unloading materials	1.1	0	1.329
Migration	1.6	0	1.861
Concreting	2	0	1.673
Sedimentation	3.1	3	0.408
Generator operation	2.6	3	1.722
Harmful effects on aquatics	4.3	5	0.816



Table 11: Ranking of risks by PHA

Risk factor	Environmental risks	Probability	Intensity	Occurrence probability	Risk level
Harvesting borrow materials	Habitat fragmentation	B	1	1B	High
	Habitat pollution				
	Changes in aquatic ecosystems				
	Loss of biodiversity				
	Habitat deterioration				
	Loss of land cover				
Excavation and embankment	Destruction of natural landscape	B	2	2B	High
	Habitat deterioration				
	Loss of land cover				
Drilling and foundation	Habitat fragmentation	B	3	3B	Medium
	Habitat pollution				
	Changes in aquatic ecosystems				
	Loss of biodiversity				
	Habitat deterioration				
	Loss of land cover				
Tunnel construction	Lack of security for wildlife	C	2	2C	Medium
	Habitat pollution				
	Wildlife migration				
	Loss of land cover				
Construction of cofferdams and ostour dams	Habitat fragmentation	B	4	4B	Medium
	Habitat pollution				
	Loss of biodiversity				
	Habitat deterioration				
Operation of crusher machine	Noise pollution	C	2	2C	Medium
	Wastewater				
	Wildlife migration				
Detonation of explosives	Noise pollution	C	2	2C	Medium
	Wildlife migration				
Flood	Loss of biodiversity	B	4	4B	Medium
	Habitat deterioration				
	Wildlife migration				
	Going underwater villages near the dam				
	Destruction of natural landscape				
Construction of workshop and residential camps	Habitat pollution	D	4	4D	Low
	Wildlife migration				
Operation of equipment and machineries	Habitat pollution	B	4	4B	Medium
	Habitat deterioration				
Sedimentation	Habitat pollution	B	3	3B	Medium
	Wildlife migration				
Harmful effects on aquatics	Decline in the quality of ecosystem	A	1	1A	Low
	Bioaccumulation of heavy metals				
	Wildlife migration				

### *Prioritization of risks by TOPSIS*

The identified risk factors were prioritized by TOPSIS. Out of the 24 risk factors, 9 risks were selected as top priority risks of the dam construction. Among which, “habitat fragmentation” with a score of 0.3002, “water pollution” with a score of 0.295, and “harmful effects on aquatics” with a score of 0.293 were given the first to third priorities, respectively. Moreover, the fourth to sixth priorities were assigned respectively to the “loss of biodiversity” with a score of 0.273, “noise pollution” with a score of 0.245, and “air pollution” with a score of 0.239.

### **CONCLUSION**

After identifying the risks of Gavi Dam at construction phase using MIKE-11 and questionnaires, the identified risks were prioritized by TOPSIS. Based on the results, ‘habitat fragmentation’, ‘water pollution’, and ‘harmful effects on aquatics’ were recognized as three top priority risks of Gavi Dam at construction phase. There are 8 habitats in the construction site of the dam. Large volume of earth works and blasting of explosives could affect the wildlife and cause habitat fragmentation. Borrow materials are harvested from the riverbed and the margins at a distance of 4 km downstream of the dam site. Harvesting is usually done mosaically, and sometimes creates holes in the riverbed. These holes in warm places such as Mehran County can cause blooming of *cyanophyta algae* and consequently increasing water turbidity and death of aquatics at downstream that threaten aquatic biodiversity. According to the results, the flooding risk of the Gavi Dam is not critical. There are several methods for risk management, one of which is risk mitigation. Risk mitigation reduces the probability of risk occurrence or the intensity of the corresponding consequences. As mentioned earlier, habitat fragmentation is one of the major risks of Gavi Dam that would be mitigated by restoration of land cover, and conservation of areas surrounding the dam lake as a new wildlife habitat. The risks can be reduced somewhat by preventing the discharge of construction materials and debris into the river, siting suitable waste disposal places, and conservation of fish spawning sites. In this regard, it is highly recommended to establish wastewater

treatment systems (preferably septic tanks) near the workshop camps and offices. Some construction operations such as explosion must be done in proper seasons in order to avoid coinciding with the sensitive periods for wildlife. Development of green spaces in the surrounding areas of the dam construction site, particularly around the workshop camps and offices, would be another important mitigation measure.

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### **CONFLICT OF INTEREST**

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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