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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 46º 23´- 46º 22´E and the latitudes of 33º 10´ - 33º 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, Konjancham 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 ºC and -27.5 ºC. 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 Konjancham 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 connectivity (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

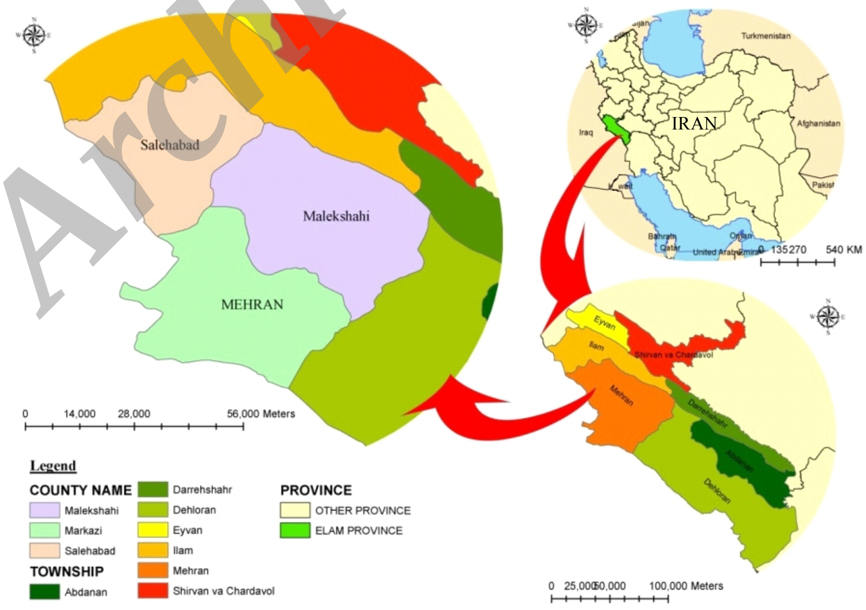

Fig. 1: Situation of the study area

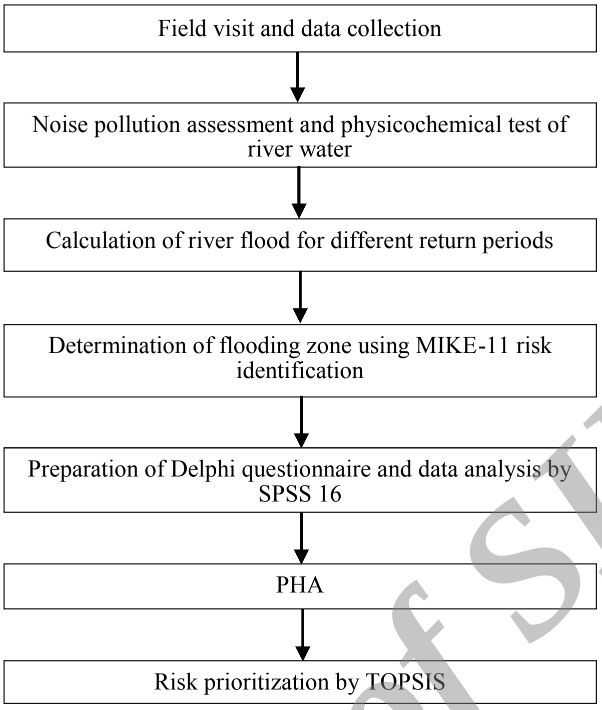

Fig. 2: Procedure of risk assessment of Gavi Dam

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^3/s)

Stations Return period (year)	2	5	10	20	25	50	100	1000	10000
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 to the intensity and occurrence probability of risks. The intensity and occurrence probability of risks are presented in Tables 4 and 5, respectively. Table 6 also provides the PHA matrix.

TOPSIS

Technique for order of preference by similarity to ideal solution (TOPSIS) is one of the best and widely used MADM models. In this method, a total number of “m” alternatives are evaluated by “n” attributes. The technique is based on the concept that the selected alternative should have the shortest distance from the positive ideal solution (the best possible state) and the maximum distance from the negative ideal solution (the worst possible state). This method includes 6 steps as described in Eqs. 1 to 6:

Step 1: formation of decision matrix: TOPSIS evaluates those decision matrices with “m” alternatives and “n” attributes.

Step 2: normalization of the decision matrix (Eq. 1)

$$n_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \qquad (1)$$

The normalized matrix is called N_D.

Step 3: calculation of weighted N_D (Eq. 2)

$$V = N_D \times N_{n\times n} \qquad (2)$$

Where, V is the weighted N_D and, W is a diagonal matrix of the weighted attributes.

Step 4: Calculation of the positive ideal and negative ideal alternatives (Eqs. 3 and 4)

Positive ideal alternative =

$$A^+ = \{(\max_{i} V_{i} \mid j \in J_1).(\min V_{i} \mid j \in J_2) \mid i = 1.2.\cdots.n\} \qquad (3)$$

Negative ideal alternative =

$$A^+ = \{(\min_{i} V_{i} \mid j \in J_1).(\max_{i} V_{i} \mid j \in J_2) \mid i = 1.2.\cdots.m\} \qquad (4)$$

Step 5: Deviation from the ideal positive and negative alternatives (EqS. 5 and 6):

$$a_i^+ = \{\sum_{1}^{m} (V_i - V_i^+)^2\}^{1/2}, \quad (i=1.2.\cdots.m) \qquad (5)$$

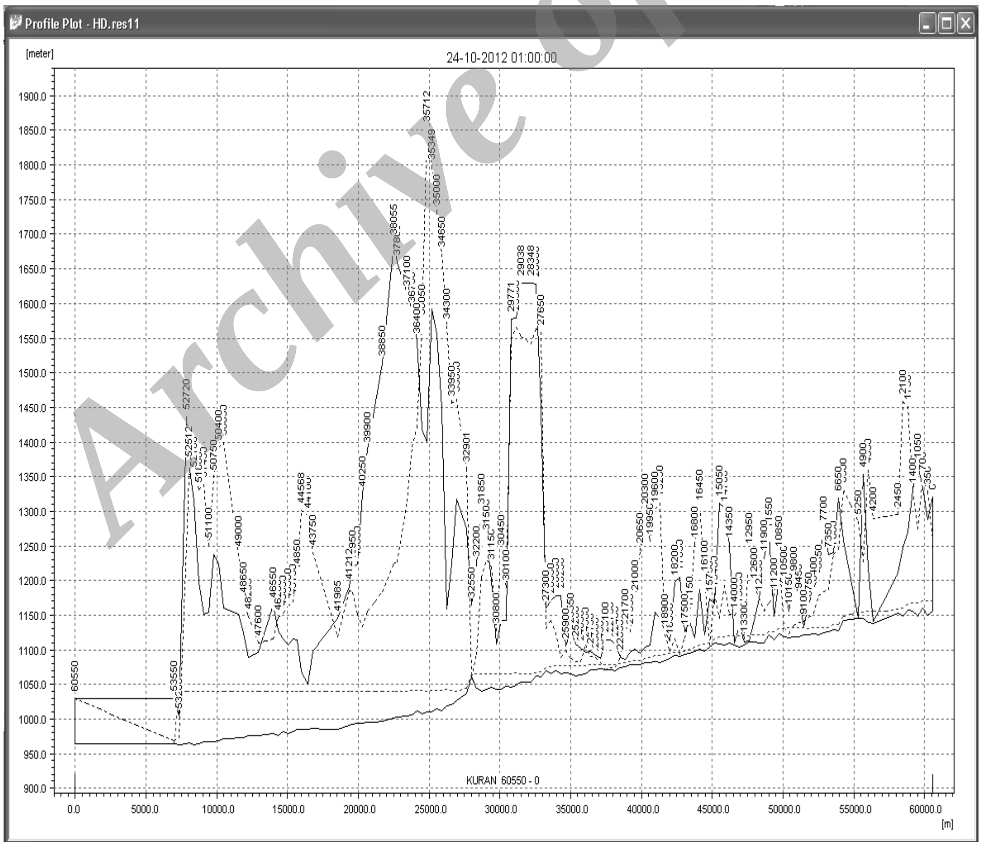

Fig. 3: Output of the MIKE-11 Model for flood zoning of Gavi Dam

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)

Impact intensity Occurrence probability	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			

$$a_i^- = \{\sum_1^n (V_i - V_i^-)^2\}^{1/2}, \quad (i=1.2. \cdots .m) \tag{6}$$

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

$$C_i = \frac{a_i^-}{(a_i^- + a_i^+)}, \qquad (i=1.2. \cdots .n) \tag{7}$$

Ultimately, the alternatives are ranked based on descending order of Ci. 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 connectivity (EC) of the river was 851.1 µs/cm, at the station of dam site, and 522.8 µs/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 Konjancham, 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 induce 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 crasher 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 ostour 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

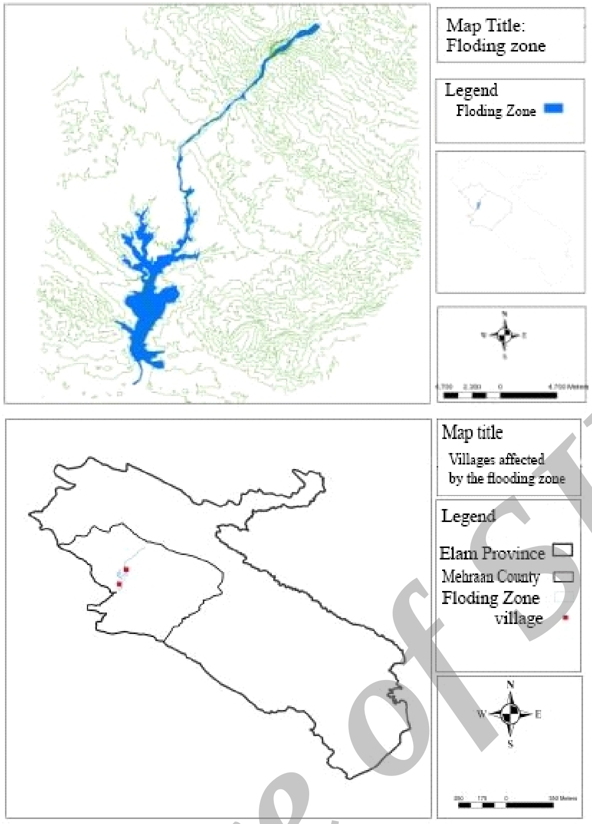

Fig. 4: Villages at risk of flooding

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 Habitat pollution Changes in aquatic ecosystems Loss of biodiversity Habitat deterioration Loss of land cover Destruction of natural landscape	B	1	1B	▓
Excavation and embankment	Loss of land cover Destruction of natural landscape Habitat deterioration	B	2	2B	▓
Drilling and foundation	Habitat fragmentation Habitat pollution Changes in aquatic ecosystems Loss of biodiversity Habitat deterioration Loss of land cover Destruction of natural landscape	B	3	3B	▒
Tunnel construction	Lack of security for wildlife Habitat pollution Wildlife migration Loss of land cover	C	2	2C	▒
Construction of cofferdams and ostour dams	Habitat fragmentation Habitat pollution Loss of biodiversity Habitat deterioration	B	4	4B	░
Operation of crusher machine	Noise pollution Wastewater Wildlife migration	C	2	2C	▒
Detonation of explosives	Noise pollution Wildlife migration	C	2	2C	▒
Flood	Loss of biodiversity Habitat deterioration Wildlife migration Going underwater villages near the dam Destruction of natural landscape	B	4	4B	░
Construction of workshop and residential camps	Habitat pollution Wildlife migration	D	4	4D	□
Operation of equipment and machineries	Habitat pollution Habitat deterioration	B	4	4B	░
Sedimentation	Habitat pollution Wildlife migration	B	3	3B	▒
Harmful effects on aquatics	Decline in the quality of ecosystem Bioaccumulation of heavy metals Wildlife migration	A	1	1A	▓

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 forth 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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