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Risk Management and Control of Dams Based on Integrating TOPSIS and RAM-D Techniques (Case Study: Paveh Rood Dam, Iran)

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Abstract
The purpose of this study was to manage the risks of Paveh Rood Dam at constructional phase by integrating TOPSIS and RAM-D techniques. After investigating the environmental conditions of the study area and the technical specifications of the dam, the risks of the dam construction were listed in a questionnaire. After analyzing the given scores by Preliminary Hazard Analysis (PHA), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) was used to prioritize the identified risks of the Paveh Rood Dam. According to the results, among 43 risk factors, erosion, due to the severe erosion in the study basin, and its intensification, due to the loss of top soil and damage to vegetation cover, were two factors given the first and highest priority. Excavation and embankment, due to large-scale dam construction operations to build the dam reservoir, and building roads, tunnels, and camps, were placed second. The results of risk assessment showed that damage to Sorkhabad Protected Area (with a score of 9), due to its proximity to the dam site and placement of a part of irrigation and drainage network within which, intensification of erosion (with a score of 6), due to high erodibility of the study area, work at height in terms of the importance of safety issues and earthquake (with a score of 3), given that the area around the dam site has seismic dynamics, were recognized the most important risks of Paveh Rood Dam at constructional phase.

Keywords: Environmental Risk Management, Dam, Constructional Phase, TOPSIS, RAM-D, Paveh Rood Dam, Iran.

Introduction

Construction of large dams leaves environmental, biological, health, social, and economic effects on their surroundings (Najmaie, 2006). The increasing development of dam construction in the world, especially in Iran, specifies the need for the environmental impact assessments of dam building (Nikbakht and Shahmohammadi Heydary, 2010). Dam risk management is a process by which decisions are made about whether the level of risk induced by dam building is tolerable or whether the identified risks need to be mitigated through some control measures (Matalucci Rudolph, 2002).

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Due to the importance of the issue, there have been conducted several studies about risk management of larges dams. As such, Khosravani in 2011 identified the environmental risks of Roudbar Dam in Iran at constructional phase using Multi Attribute Decision Making (MADM) methods and RAM-D (Khosravani, 2011). He used RAM-D method to identify and classify the environmental risks imposed on the upstream and downstream areas of the dam site. Matalucci in 2002 declared that this method was first developed by Sandia National Laboratories for the Interagency Forum for Infrastructure Protection (IFIP) to address dam missions, unwanted events that prevent dams from being successful, their potential inconsistencies and their features, the outcomes of risk mitigation options, and risk reduction alternatives (Matalucci Rudolph, 2002). Jozi et al. (2014) used Multi Criteria Decision Making (MCDM) methods to identify the environmental and human health risks induced by Balarood Dam in Iran at constructional phase. They gave first to third priority to cut and fill, drilling, and explosion. Rezaian et al. (2016) assessed the potential risk factors of Gavi Dam in western Iran risks in the constructional phase and using MIKE-11 model and TOPSIS. They found that “Habitat fragmentation”, “water pollution”, and “impacts on aquatics” were three top priority risks at the construction phase. Jozi and Malmir in 2014 assessed the environmental risks of Polrood Dam in northern Iran, at the constructional phase by integrating TOPSIS and AHP methods. According to their findings, erosion and sedimentation were the most important physicochemical risks of the dam at construction phase. The purpose of the environmental risk management of dams is to identify, classify and assess the environmental risks posed by them. Accordingly, the present study was conducted to identify the most important risks induced by construction of Paveh Rood Dam in Iran at the constructional phase. The study integrated three techniques of PHA, TOPSIS, and RAM-D to perform the risk control. It is the first time that these techniques are integrated and simultaneously used for risk management studies.

Material and Methods

Case study

The Pavehdord Regulatory Dam in northwest of Iran is situated at the border of Zanjan and Gilan Provinces in the in the geographical coordinates of 36° 47' 30"-37° 5' northern latitudes and 48° 41'-49° 7' eastern longitudes. The Ghezel Ozan is the main river of the dam basin, which originates from the Zagros heights and flows towards the northwest to the southeast direction. The dam, depending on the daily needs of the irrigation network, gradually discharges the stored water for irrigation of the agricultural fields. The crown height of the dam is 19 m and its reservoir has a volume of 15.3 MCM. The area of its lake reaches to 208 ha (Tamavan, 2000). Figure 1 depicts the geographic situation of the Paveh Rood in Iran.

Figure 1. Location of Paveh Rood Dam in Iran

Research procedure

The purpose of this research was to assess the environmental risks of Paveh Rood Dam; identifying, classifying and assessing the environmental risks it poses by combining the Ram-D and TOPSIS methods. In Figure 2, the stages of the research are shown, separately.

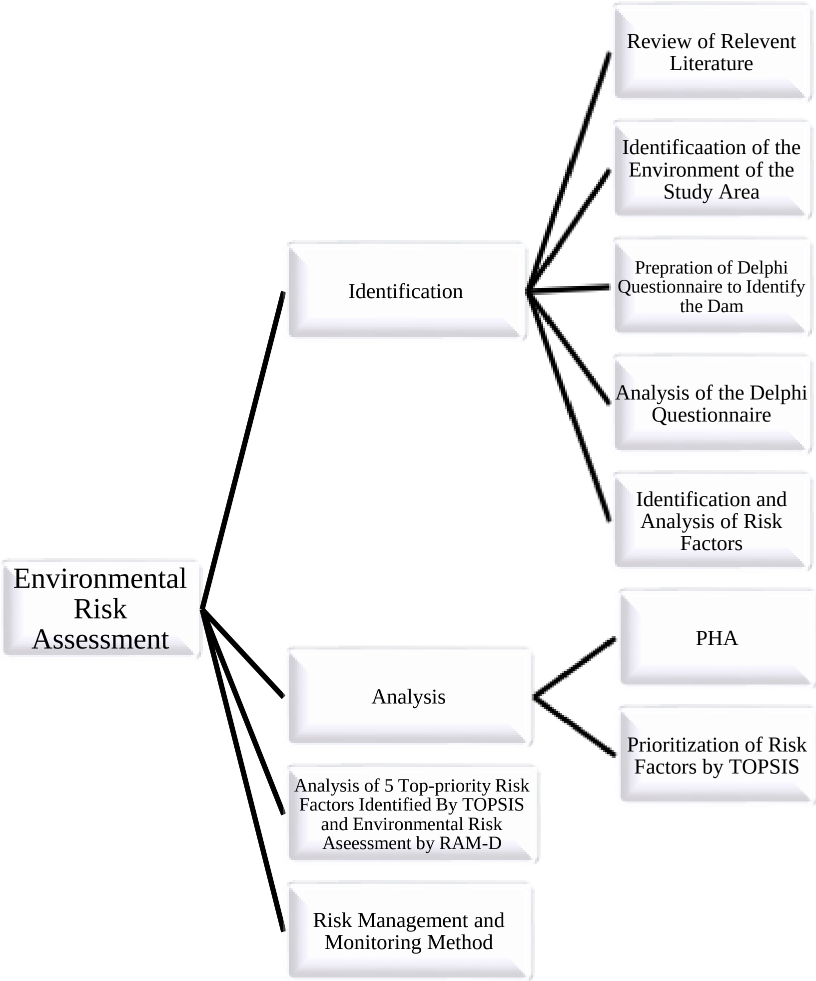

Figure 2. Environmental risk assessment of Paveh Rood Dam

The population size (number of panelists in the Delphi group), in this research, was determined by Cochran's formula as 28 people.

$$n = \frac{\frac{z^2 pq}{d^2}}{1 + \frac{1}{N}\left(\frac{z^2 pq}{d^2} - 1\right)} \tag{1}$$

Where;
N= size of the statistical society, n= sample size, Z = standard normal distribution, which equals to 1.96 at the confidence level of 95%, P = a value to show the proportion of sample elements that have a particular attribute. If it is not available, it can be considered as 0.5. In this case, the variance reaches its maximum value.
q = percentage of people who do not have that attribute in society (q = 1-p)
d = absolute allowable error (Sarmad et al. 2013).

After reviewing the research background, identifying, collecting, and studying the relevant information about either the environmental conditions of the study area or the technical conditions of the dam construction, a list of potential risk factors was prepared in the form of a questionnaire and placed at the disposal of a Delphi group to verify it (Padash et al. 2016). The Delphi group consisted of elites and professors in the fields of environment and dam engineering. The panelists were asked to score the risk factors listed in the questionnaire using the Likert scale, ranging from 1 as very low importance to 9 as very important (1, 3, 5, 7, and 9). Preliminary Hazard Analysis (PHA) was used to achieve an initial and overview of the hazards in the study area induced by dam construction. Considering the features of the dam and the affected environment, the identified risk factors were prioritized by TOPSIS. Finally, the risk assessment of the dam was performed by RAM-D method.

Achieving an overview of the potential risks by PHA

PHA is a systematic safety analysis that is used to identify critical areas of safety in order to assess the most important hazards and identify the requirements for the safety design of the system (Mohammad Fam, 2001). Tables 1-3 show the phases of PHA.

Table 1. Hazard severity in PHA (Halvani, 1998)

Class	Rank	Comment
Catastrophic	1	Mortality or severe impact on the ecosystems of the region
Critical	2	Damage to the ecosystems and human communities in the region
Major	3	Indirect effects on the ecosystems and human communities in the region
Minor	4	Minor effect on the ecosystems and human communities in the region

Table 2. Hazard probability in PHA (Halvani, 1998)

Class	Rank	Comment
Frequent	A	It occurs frequently
Probable	B	It occurs several times over the life time of a system (process)
Occasional	C	It occurs sometimes over the life time of a system (process)
Remote	D	Its likelihood of occurrence is very low throughout the life of the system
Very unlikely	E	It is very unlikely to occur

Table 3. Risk assessment matrix in PHA (Halvani, 1998)

Impact severity / Occurrence probability	Catastrophic(1)	Critical(2)	Major(3)	Minor(4)
Frequent(A)	1A	2A	3A	4A
Probable(B)	1B	2B	3B	4B
Occasional(C)	1C	2C	3C	4C
Remote(D)	1D	2D	3D	4D
Very unlikely(E)	1E	2E	3E	4E

Risk index	Unacceptable	Undesirable	Acceptable with manager's revision	Acceptable without revision

Prioritization of risk factors by TOPSIS

In this method, a total number of m alternatives are evaluated by n criteria. The basis of this technique is that the selected alternative should have the least distance from the ideal positive solution (the best possible condition) and at the same time, have the greatest distance from the ideal negative solution (the worst possible condition) (Padash, 2017; Momeni, 1998).

Risk assessment by RAM-D

This methodology is an assessment process developed for safety analysis of risks of dams. It also provides information to support effective risk reduction decisions taken by managers. The main RAM-D core is a process completed by a systematic risk assessment (Matalucci Rudolph, 2002). The RAM-D method employs Fault tree analysis (FTA) method and provides the necessary information from experts, resources, and internet sites, on which the primary design of the dams heavily depends. RAM-D is a dynamic process that needs to be reviewed and changed by changing the threat environment (Jozi, 2001). In Figure 3, the steps to implement the risk assessment by RAM-D are shown.

Table 4 shows the value of probability factors and severity in RAM-D method and Table 5 shows how to evaluate the risk outcomes. The outcomes address the effects of unwanted risks that result in the project failure to achieve the goals. The mean by efficiency is the effectiveness of facilities and the safety system in protecting against the identified risks (Padash et al. 2015). After filling out the worksheets, according to the experts' opinion, environmental conditions, and technical specifications of the project, the scores assigned to each risk factor are included in the equation below (Jozi, 2001):

$$Risk= (system\ efficiency - 1)\times(outcomes)\times(threat\ probability) \quad (2)$$

Table 4. Value of probability factors and severity in RAM-D method(Matalucci Rudolph, 2002)

Score	Value	Group
4	VH	Very high, catastrophic, fatal, severe environmental damage
3	H	High probability, critical, resulting in injury, major environmental damage
2	M	Moderate probability, leading to injury, minor disease, minor damage to the environment
1	L	Low probability, negligible, less than minor injury, low environmental damage

Table 5. Valuating the risk outcomes (Matalucci Rudolph, 2002)

Score	Value	Group
3	H (high)	Critical, leading to injury, major environmental damage
2	M (medium)	Leading to injury, minor illness, minor damage to the environment
1	L (low)	Negligible, less than minor injury, low environmental damage

Taking the conditions into consideration, a statistical sample of 17 experts was gathered. Following the administered arrangements, the questionnaires were distributed in the specified deadline. The factors used to choose the experts are as below:

1. Having at least 10 years of activity in related system. 2. Having at least relevant undergraduate degree. 3. Being an expert in administrative, supervisory or scientific matters in the region. (Padash et al. 2016)

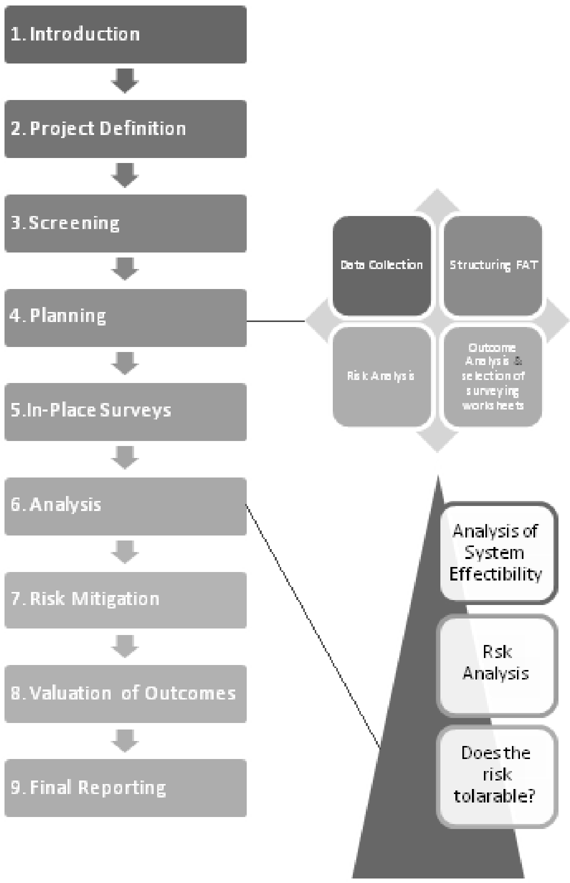

Figure 3. Risk assessment process of dams based on RAM-D method (Jozi, 2001)

Results and Discussion

Figure 4 illustrates the results of PHA method. According to the environmental conditions of the study area and technical specifications of the project, occurrence probability and severity of risks were evaluated.

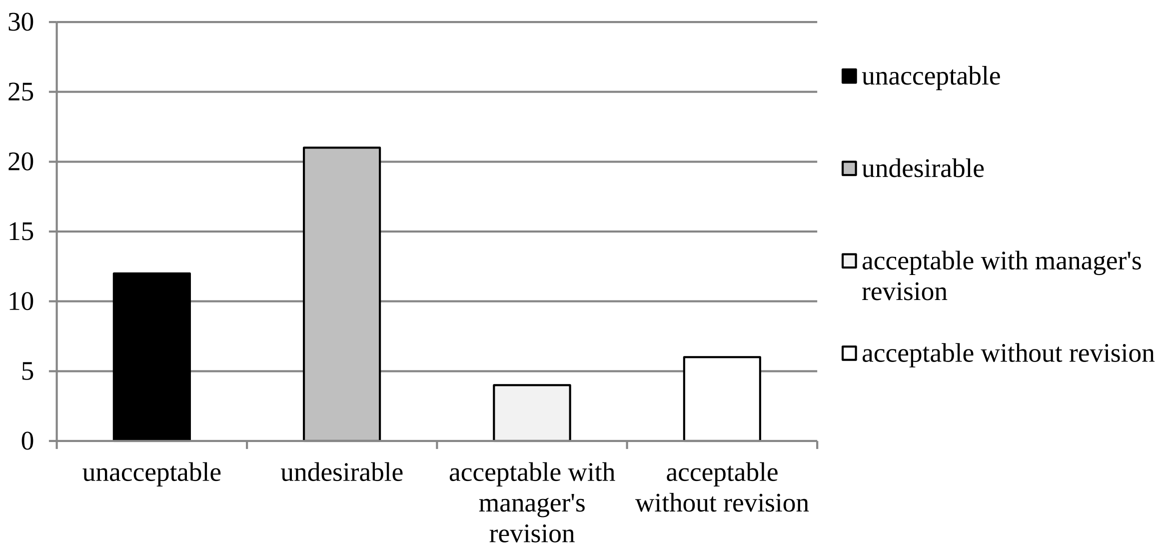

Figure 4. Results of PHA method

The results are given in Table 6. After collecting the filled-out questionnaires, based on the results of the PHA method, TOPSIS was used to prioritize the identified risks of the Paveh Rood Dam. The prioritization results are presented in Table 7.

Table 6. PHA of Paveh Rood Dam

		Risk	Assessment			
			Occurrence probability	Impact severity	RPN	Risk level
1.	Technical risks	Excavation and embankment	B	2	2B	
2.		Explosion	C	2	2C	
3.		Drilling	B	3	3B	
4.		Tunneling	B	2	2B	
5.		Temporary access road construction	C	2	2C	
6.		Construction of permanent access roads	B	2	2B	
7.		Construction of workshop and residential camps	C	4	4C	
8.		Construction of temporary parking lots	C	4	4C	
9.		Equipment and machinery activities	B	3	3B	
10.		Storage of petroleum products	C	2	2C	
11.		Disposal of solid waste and wastewater	B	2	2B	
12.		Transportation	B	3	3B	
13.		concrete works	B	3	3B	
14.		Revetment	C	4	4C	

High risk	Medium risk	Low risk

According to the Table 9 and the results of TOPSIS, among the identified risk factors, erosion, due to the severe erosion rate in the study basin, and its intensification, due to the loss of top soil and damage to vegetation cover was given the first priority. Excavation and embankment, due to the large-scale dam construction operations to build the dam reservoir, and building roads, tunnels, and camps, were placed second. The least priority was assigned to the change in microclimate, due to its minor and negligible affectability. After prioritizing the risks of Paveh Rood Dam by TOPSIS, risk assessment was performed using RAM-D method. This was done by filling out the worksheets designed based on occurrence probability of risks, the outcomes, and the system efficiency. The proposed scores for quantification of efficiency factor is presented in Table 8.

Since the output of TOPSIS was the basis for the judgments in the RAM-D method, therefore, out of the 41 risk factors analyzed in the TOPSIS method, only the five top-priority factors were selected to be analyzed in the RAM-D method. The environmental risk assessment results of Paveh Rood Dam are presented in Table 9.

Table 7. Prioritization of the risks of Paveh Rood Dam using TOPSIS

Rank	Risk	Code
1	Erosion	A23
2	Excavation and embankment	A1
3	Water quality	A25
4	Sedimentation	A24
5	Effect on SORKHABAD Protected Area	A37
6	Drilling	A3
7	Disposal of solid waste and wastewater	A11
8	Tunneling	A4
9	Equipment and machinery activities	A9
10	Work at height	A20
11	Explosion	A2
12	Concrete works	A13
13	Impact on wildlife	A36
14	Storage of petroleum products	A10
15	Effect on aquatics	A33
16	Flooding	A39
17	Seismicity	A38
18	Poisoning from toxic gases in tunnels	A19
19	Effect on fauna	A35
20	Construction of permanent roads	A6
21	Reduce downstream water volume	A26
22	Construction of temporary access roads	A5
23	Land leveling	A31
24	Soil quality	A29
25	Barking by snake, scorpion, etc.	A22
26	Human activities at workshops	A18
27	Change in downstream river bed	A27
28	Migration	A41
29	Transportation	A12
30	Air quality	A30
30	Accidents caused by transportation	A21
31	Establishment of residential and workshop camps	A7
32	Landslide	A40
33	construction of temporary parking lot	A8
34	Disturbance in providing sand for beaches	A28
35	Borrow materials	A16
36	Entry of new aquatic species to the reservoir	A34
37	Effect on landscape and tourism	A43
38	Land use change	A42
39	Revetment	A14
39	Construction of upstream and downstream cofferdams	A15
40	Transmission of energy and water to the site	A17
41	Change in microclimate	A32

Table 8. Proposed scores for quantification of system efficiency by RAM-D method

Score	System efficiency
1	Very high efficiency
0.75	high efficiency
0.5	Medium efficiency
0.25	Low efficiency

Table 9. Environmental risk assessment results of Paveh Rood Dam by RAM-D method

Factors RAM-D / Risk	Probability	Outcome	System efficiency	1- System efficiency	Risk value
Excavation and embankment	3	1	0.75	0.25	0.75
Work at height	3	4	0.75	0.25	3
Poisoning from toxic gases	3	2	0.75	0.25	2.25
Earthquake	3	2	0.5	0.5	3
Erosion	4	3	0.5	0.5	6
Effect on SORKHABAD Protected Area	4	3	0.25	0.75	9

After prioritization of the risk factors by TOPSIS, risk assessment was performed using RAM-D method. The results showed that damage to SORKHABADProtected Area (with a score of 9), due to its proximity to the dam site and placement of a part of irrigation and drainage network within which, intensification of erosion (with a score of 6), due to high erodibility of the study area, work at height in terms of the importance of safety issues and earthquake (with a score of 3), given that the area around the dam site has seismic dynamics, were recognized the most important risks of Paveh Rood Dam at constructional phase.

Conclusion

Dam building projects are more risky than other projects, because they require spending high costs and involve complicated spatial conditions. Therefore, identification of risk and uncertainty sources in construction of Paveh Rood Dam and identification and assessment of its risks to determine the most important and effective risks of constructional phase.

Risk response planning is the process of selecting and defining the necessary measures to increase opportunities and reduce potential threats to achieve project goals. In this process, due to adequate risk identification, the way individual and collective action, individual or group action to respond to Identified risks are determined. Risk such as damage to SORKHABAD Protected Area, erosion and work at height are included.

This project are not limited to identified risk; tracking and controlling risk, continuous process and taking the assigned risks, controlling remaining risks, identifying new risks during the life cycle of the project, in order to ensure complete implementation of risk programs, as well as assessing the effectiveness of implementing these programs in reducing project risk.

Khosravani just used RAM-D method to identify and classify the environmental risks of upstream and downstream basins of Roudbar Dam in Lorestan Province, Iran. However, in this research, the identified risk factors were initially prioritized by TOPSIS and then, the risk assessment of the top priority risk factors was performed by RAM-D. In other words, this research used three consecutive steps, i.e. preliminary risk assessment by PRA to identify risk factors, prioritization of the identified risk factors by TOPSIS, and risk assessment of top priority risks by RAM-D method, in order to accurately identify and quantify the most important risk factors. It is worth noting that the combination of these three methods for assessing the risk of dam at the construction stage has not been used so far and this article is the first experience.

Given the fact that PHA is a semi-quantitative method (Mohammad Fam, 2001), so the prioritization of risks in this method is also qualitative. In prioritizing the technical risks of the construction phase, excavation and embankment, tunnel construction, permanent road construction, and solid waste and wastewater disposal, due to the extent of their effectiveness, were given a high level of risk. In prioritization of the physicochemical risks, erosion and changes in downstream riverbed were assigned a high risk level. After analyzing the scores given to the risk factors by TOPSIS approach and using the findings of the PHA method, those risk factors with high and medium priority levels were selected for risk assessment of Pavehdar Dam by RAM-D.

The Ram-D method predicts quantitatively the risk of dams and provides a comprehensive analysis of vulnerability of dams (Jozi, 2001). As the results showed, first to fourth priorities were respectively given to erosion, excavation and embankment, water quality, and sedimentation.

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