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Environmental Risk Analysis by Using Multi-Criteria Decision-Making Method(Case Study: Karoon 3 Dam of Iran)

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Abstract. Karoon 3 dam, with the height of 75m and the crest length of 470m, is located in the east of khoozestan Province. Dam construction activities always impose some risks on the environment. However, most of the studies about dam construction have been already done on safety and security aspects of the dams, but the environmental issues have been less considered. In this paper, the environmental risks of Karoon 3 dam construction were identified, ranked and evaluated using two practical methods of Multi-Criteria Decision-Making (MCDM). The risk factors were first identified by the Delphi Questionnaire, and rated using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Then, the Analytical Hierarchy Process (AHP) was applied to classify the risk factors into four major categories, and the Expert Choice software was used to determine their weights. Based on the obtained results, *"Physicochemical"*, *"Biological"*, *"Economic, Social and Cultural"* and *"Health and Safety"* risks were rated by the weights of 0.123, 0.080, 0.048 and 0.021 respectively. Among the physicochemical risks, *Erosion* and *Sedimentation* were identified as the most serious risks weighting 0.061 and 0.047.

Keywords: Environmental Risk Analysis, Multi-Criteria Decision-Making (MCDM), Analytical Hierarchy Process, TOPSIS, Karoon 3 dam

1. Introduction

Environmental risk assessment is considered as an important tool in the environment management to mitigate project risks and achieve sustainable development, which is now considerably regarded in planning and policy-making in the most countries of the world (Barrow 1999). Dam construction activities always impose some risks on the environment. Severity of these risks depends on the project dimensions and the environmental sensitivities of the region. Environmental risk assessment is a qualitative and quantitative analytical process of potential risks and their occurrence rate in the project, as well as sensitivity and vulnerability of the ambient environment (Muhlbauer 2004). Most of the studies about dam construction in the countries of the world have been already done on safety and security aspects of the dams; but the environmental issues have been less considered (Harrald et al. 2004). Analytical Hierarchy Process (AHP) (Satty 1980, 1990) is one of the most practical methods of Multi-Criteria Decision-Making (MCDM) (Vaidya and Kumar 2006), and many papers have already been published about the application of the AHP method in nvironmental engineering (Tesfamariam and Sadig 2006). The background study about the application of the AHP method in risk assessment shows that this method has been used alone or together with other methods for risk assessment in different cases (Eldin et al 2004).

2. Materials and Methods

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Basic data about the region were collected through the library studies and internet surveys. Field studies and visiting the Karoon 3 dam site were also performed to identify the environmental characteristics of the region, to observe the project situation, and to inspect the dam specifications. In the next step, the qualitative and quantitative samplings (including physical, chemical and biological parameters measurements) of the surface water resources in the region was performed at 10 sampling stations once a month in 2008. For the quality analysis of surface water resources in the region, the following parameters were measured in all the sampling stations: pH, Sodium Absorption Ratio (SAR), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Dissolved Oxygen (DO), Calcium, Magnesium, Sodium, Phosphate, Nitrate, Total Coliforms (TC), Excremental Coliforms (EC) and Parasites Eggs (PE). All of the above parameters were precisely compared with the standards provided by Iran Environmental Protection Organization (1994) and World Health Organization (1992) to obtain a summary result of the samplings.

2.1 The TOPSIS Method

There is generally an m×n decision-making matrix in the TOPSIS method; and here, we had 5 experts who made their decisions for 22 risk alternatives, thus making a 5×22 matrix. The quantitative values obtained from the experts' decisions are shown in Table 1, wherein the experts are shown with $N_1, N_2, \dots, N_5$ symbols, and the risk factors are shown with $A_1, A_2, \dots, A_{22}$ symbols.

Table 1:Decision matrix

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	A_{17}	A_{18}	A_{19}	A_{20}	A_{21}	A_{22}
N_1	7	7	3	9	8	9	6	7	8	4	6	2	2	7	1	7	9	9	4	5	3	1
N_2	6	6	2	9	7	8	4	5	7	3	4	2	1	6	1	4	9	8	3	4	2	1
N_3	6	6	3	7	7	7	5	5	6	4	5	3	3	5	2	5	8	7	4	5	4	2
N_4	5	5	2	8	7	7	4	5	6	3	5	1	1	5	1	5	9	8	3	4	2	1
N_5	8	8	2	9	8	9	7	7	8	6	7	2	1	8	1	7	9	9	5	6	3	1

Then, the decision matrix values were converted to have no scale, using the normalization process, and the normalized decision matrix is presented in Table 2. Each element of the normalized matrix (r_{ij}) was calculated by the following formula:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \qquad i = 1,2,\dots,m \qquad j = 1,2,\dots,n \qquad (1)$$

Table 2:Normalized decision matrix

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	A_{17}	A_{18}	A_{19}	A_{20}	A_{21}	A_{22}
N_1	3.381	3.381	1.643	4.293	3.859	4.500	3.021	3.725	4.056	1.725	2.930	0.853	1.000	3.474	0.354	3.826	4.112	4.399	1.848	2.301	1.389	0.354
N_2	2.484	2.484	0.730	4.293	2.955	3.556	1.343	1.901	3.105	0.970	1.302	0.853	0.250	2.552	0.354	1.249	4.112	3.476	1.039	1.473	0.617	0.354
N_3	2.484	2.484	1.643	2.597	2.955	2.722	2.098	1.901	2.281	1.725	2.034	1.919	2.250	1.772	1.414	1.952	3.249	2.661	1.848	2.301	2.469	1.414
N_4	1.725	1.725	0.730	3.392	2.955	2.722	1.343	1.901	2.281	0.970	2.034	0.213	0.250	1.772	0.354	1.952	4.112	3.476	1.039	1.473	0.617	0.354
N_5	4.416	4.416	0.730	4.293	3.859	4.500	4.112	3.725	4.056	3.882	3.988	0.853	0.250	4.537	0.354	3.826	4.112	4.399	2.887	3.314	1.389	0.354

In the next step, the weight of each alternative (W_i) was determined by the Entropy method, and the resultant weight vector is shown in Table 3.

Table 3: Weight vector for the risk alternatives

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	A_{17}	A_{18}	A_{19}	A_{20}	A_{21}	A_{22}
W	0.007	0.004	0.012	0.003	0.001	0.004	0.015	0.008	0.013	0.055	0.028	0.081	0.179	0.027	0.076	0.021	0.001	0.004	0.070	0.044	0.129	0.218

The multiplication of the normalized decision matrix by the weight vector produced the weighed normalized decision matrix for the risk alternatives, which is presented in Table 4.

Table 4:Positive and negative ideal solutions

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	A_{17}	A_{18}	A_{19}	A_{20}	A_{21}	A_{22}
A^+	0.013	0.007	0.009	0.007	0.004	0.010	0.020	0.016	0.029	0.053	0.036	0.017	0.045	0.048	0.027	0.026	0.003	0.010	0.073	0.065	0.080	0.077
A^-	0.033	0.019	0.020	0.012	0.005	0.017	0.061	0.031	0.052	0.213	0.110	0.156	0.403	0.123	0.107	0.080	0.004	0.017	0.202	0.146	0.319	0.308

To determine the deviation of each alternative from the positive and negative ideal solutions (D^+ and D^-), the Euclidean method was used with the following equations, and the results are presented in Table 5.

$$D_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \qquad i = 1,2,...,m \qquad (2)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \qquad i = 1,2,...,m \qquad (3)$$

Table 5:Relative closeness to the ideal solutions

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}	C_{22}
C	0.543	0.543	0.551	0.387	0.551	0.503	0.577	0.551	0.504	0.623	0.547	0.553	0.633	0.575	0.667	0.495	0.333	0.445	0.580	0.577	0.585	0.667

In order to calculate C_i that states the relative closeness to the ideal solutions, the following equation was used, and the values are shown in Table 6.

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-} \qquad i = 1,2,...,m \qquad (4)$$

C_i is a number between 0 and 1; so that the being closer to 1, means the lower risk for the alternative. Finally, the risk alternatives were rated according to the C_i values, which are given in Table 6 (Olson 2004).

Table 6:Ranking of the risks alternatives

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}	A_{11}	A_{12}	A_{13}	A_{14}	A_{15}	A_{16}	A_{17}	A_{18}	A_{19}	A_{20}	A_{21}	A_{22}
R	7	7	9	2	9	5	13	9	6	16	8	10	17	11	18	4	1	3	14	12	15	18

2.2 The AHP Method

The AHP method has generally 3 phases: modeling, evaluation and ranking. In the first phase, the hierarchical structure is built for presenting the problem. The second phase consists of the judgments that show the priorities of the factors in the analysis process. At the last phase, the priorities of the compared factors are presented (Maria et al. 2005).

3. Results and Discussion

Based on the results from the TOPSIS method (given in Table 8), Polrood dam construction risks were rated by the following ranks: Population Displacement and Resettlement (1), Soil Erosion (2), Sedimentation (3), Effects on the Vegetation Cover (4), Land Use Change (5), Drowning of Buildings, Facilities and Residential Areas (6), Pollutions (7), Earthquake (7), Landslide (8), Effects on the Water Resources (9), Effects on the Habitats (9), Effects on the Wildlife (9), Employment and Income (10), Flood (11), Sudden Explosions (12), Workers Downfall (13), Road Accidents (14), Materials Charging and Discharging Accidents (15), Induced Earthquake (16), Social Acceptance and Security (17), Migration (18) and Tourism (18).

Based on the results obtained by the AHP method (shown in Figure 2), the 22 risk alternatives existing in the region were classified in 4 categories as below:

(1) Physicochemical Risks (8 alternatives)
(2) Biological Risks (3 alternatives)
(3) Economic, Social and Cultural Risks (7 alternatives)

(4) Health and Safety Risks (4 alternatives)

Then, the risk alternatives in each category were compared with regard to their occurrence probability and intensity, which were affected by the Karoon 3 dam construction activities.

4. Physicochemical Risks

Soil Erosion and Sedimentation: The increase of soil erosion and sedimentation in the region is due to the considerable landslides in Karoon River catchment area, the absence of suitable vegetation cover in more than 50% of this area, and the climatic conditions of this region, which will be followed by the continuous rainfalls and floodwaters. Annual sediment loads are rather high at the Karoon hydrometric station, due to the high loads of suspended sediments and riverbed sediments. Results of the calculations concerning the annual sediment loads are presented in Table 7.

Table 7:Annual sediment loads at the hydrometric stations (Iran Ministry of Energy, 2006)

Hydrometric Station Name	Annual River Outflow Volume (MCM/Year)	Annual Sediment Loads (10 Tons/Year)			Net Discharge (Ton/Year/Km^2)
		Suspended Sediments	River Bed Sediments	Total Sediments	
Polrood	482.27	1.9130	0.2870	2.2000	1345.80
Shalmanrood	245.57	0.1650	0.0247	0.1897	484.33
Khoshkehrood	74.77	0.0240	0.0035	0.0275	277.73
Samoosh	66.60	0.0080	0.0012	0.0092	91.09

Water Resources: The measurements of some physical, chemical, biological and microbial parameters of the surface water resources were performed in 10 sampling stations in the region once a month in 2008. The average results of these experiments are summarized in Table 8.

Table 8:Summary results of the physical, chemical, biological and microbial Parameters Measurements of the surface water resources in the region

Parameter	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Station 9	Station 10
pH	7.874	7.791	7.721	7.658	7.688	7.608	7.488	7.753	7.775	7.877
SAR	0.157	0.114	0.191	0.203	0.642	0.629	0.912	0.149	0.090	0.517
TDS (mg/L)	268.771	238.117	175.568	241.360	241.858	417.718	389.089	280.820	153.156	265.989
TSS (mg/L)	90.700	67.025	19.500	32.558	18.108	306.108	62.867	69.575	57.500	245.683
BOD (mg/L)	0.993	1.077	1.610	1.855	1.542	1.537	1.988	1.450	1.342	1.762
COD (mg/L)	3.400	4.750	4.393	6.171	4.008	6.708	8.750	5.288	3.208	4.918
TOC (mg/L)	0.973	1.439	2.441	2.741	4.049	5.661	4.011	1.159	1.637	1.574
DO (mg/L)	9.367	9.125	9.500	9.842	9.150	8.167	7.858	9.658	9.675	9.500
Ca^{2+} (meq/L)	47.843	49.355	40.482	42.892	48.843	65.775	54.598	56.410	35.402	52.703
Mg^{2+} (meq/L)	18.135	12.813	5.662	11.945	10.359	22.064	17.240	14.967	5.630	18.620
Na^{+} (meq/L)	5.087	3.476	4.450	5.794	7.262	25.299	32.614	4.872	2.196	3.605
PO_4^{3-} (mg/L)	0.047	0.044	0.091	0.091	0.105	0.111	0.150	0.038	0.033	0.059
NO_3^{-} (mg/L)	0.292	0.279	0.283	0.293	0.233	0.233	0.298	0.230	0.228	0.241
TC	9133.333	10033.333	12266.667	13333.333	15816.667	17016.667	16933.333	13283.333	9183.333	12916.667
EC	7468.333	9883.333	7876.667	9483.333	10076.667	13666.667	16033.333	8976.667	7035.000	8400.000
PE	-	-	-	-	-	-	-	-	-	-

mg/L: milligrams per liter meq/L: milliequivalents per liter

The results showed that the parameters measured were mostly at the desirable values or the standard levels. However, among the physical factors, only the values obtained for COD showed that this parameter is much lower than the standard value advised for agricultural uses. Besides, the results obtained from the microbial parameters measurements in the sampling stations showed that all the surface waters contain excremental and non-excremental Coliforms more than the standard level, both for drinking and agricultural use. Finally, about 50% of the wells contained EC and TC more than the standard level and there were no PE in the measured samples.

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