Water Resources Management (2021) 35:4085–4110
https://doi.org/10.1007/s11269-021-02932-1

# Multi-criteria Decision-making Approach for Environmental Impact Assessment to Reduce the Adverse Effects Of Dams

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Received: 15 March 2021 / Accepted: 11 August 2021 / Published online: 19 August 2021



## Abstract

Environmental Impact Assessments (EIAs) of development projects are necessary to minimize negative impacts and maximize benefits. The objective of this paper is to determine the best strategy to mitigate the adverse effects of dam construction with Multi-Criteria Decision-Making (MCDM) method based on results of EIAs. For this purpose, a group of experts in various pertinent fields was formed, and according to field observations, the main criteria set for evaluating dam construction effects and improvement strategies were proposed by experts group. The main evaluation criteria are defined in terms of impacts on (1) natural resources, (2) ecosystems, (3) socio-cultural institutions, and (4) economics and their sub-criteria. The improvement alternatives are: (1) relocation of city waste disposal, (2) forestry and watershed management, (3) construction of a sewage collection network and treatment plant, and (4) controlling the use of pesticide and fertilizer in agricultural lands and optimizing their type and method of use. Each of sub-criteria were weighted with Integrated Determination of Objective Criteria Weights (IDOCRIW) and the improvement strategies are ranked using the Combined Compromise Solution (COCOSO) method. This paper's methodology is evaluated with the Nohob Earth Dam in Qazvin province, Iran. Results show that socio-cultural criterion has the largest weight. Results of COCOSO demonstrate the alternative of relocation of city waste disposal ranks as the first priority.


**Keywords** The combined compromise solution method · The integrated determination of objective criteria weights · The EIA study for hydrosystems · Improvement alternatives

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## 1 Introduction

Dam construction has been one of preferred alternatives to store and manage water to supply water to growing populations and support economic development. Although, dam construction has had many positive impacts, their adverse effects must not be neglected. Dams inflict irreversible damage on environment and humans, which are compounded by climate change, seismic activity, and landslides (Ismail 2014), vegetation and biodiversity reduction by flooding of land (Appiah et al. 2017), increasing spread of illness (e.g., malaria), triggering migration (Mudzengi and Chazireni 2017), and submersion of cultural and archeologic treasures. Therefore, comprehensive pre-construction studies that assess positive and negative effects of each dam/reservoir project, and monitoring during construction and operation are necessary.

Numerous studies have been reported on various methods to evaluate effects and consequences of dam's construction, such as using ecological risk assessment method to evaluate ecohydrological impacts of dam (Giers et al. 1998), EIA for two dams in Iran (Heydari et al. 2013), International Commission on Large Dams (ICOLD) matrix method (Pazoki et al. 2015), Rapid Impact Assessment Method (RIAM) for (Karami et al. 2016), Leopold matrix method for Shahriar Dam irrigation project using physical, environmental, and socio-economic-cultural criteria (Ashofteh et al. 2017), EIA based on long-term and short-term impacts on ecosystems of Getvand Dam construction/operation (Iran) considering geophysical, socio-economic and cultural factors (Haddad et al. 2017), shallow water approximation to investigate thermal pollution from operation of a power plant (Issakhov and Zhandaulet 2019), and machine learning models (Alizadeh et al. 2018).

A review of previous research indicates importance of conducting EIAs for civil projects, and in particular hydrosystems, which evaluate their environmental, economic, and social impacts. Complexity and conflict, sometimes even contrast of criteria and alternatives, are key features of any EIA study for dam construction projects.

Combining MCDM methods by considering several dimensions of effectiveness associated with criteria and sub-criteria set, and investigting various alternatives to achieve the best alternative is a useful procedure to achieve a sound EIA. MCDMs have a regular structure that measure positive and negative aspects of a project in a coherent framework through interactions between experts. Purpose of using MCDMs in this study is to select the best alternative among several alternatives with purpose of minimizing adverse effects of dam construction and maximizing efficiency of water supply system for all users and beneficiaries.

Remarkable features of MCDMs have led to their wide application in various studies related to water resources management including: using an acronym (in Portuguese) for interactive and multiple attribute decision making (TODIM) method to prioritize inter-basin water transfer alternatives (Ashofteh et al. 2020), Analytical Hierarchy process (AHP) method to assess environmental and social effects of dam breaking (Guanjie et al. 2020), risk assessment of resource development projects with fuzzy concept (Abedzadeh et al. 2020), optimal allocation of water reuse by TODIM with goal programming (GP) Called TODIM-GP (Dehghani and Khoshfetrat 2020), Prioritizing allocation alternatives to adapt to climate change with AHP methods and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Golfam et al. 2019a, selecting best strategy in agricultural sector to supply water with VlseKriterijumska Optimizacija I KompromisnoResenje (VIKOR) and Fuzzy Order Weighted Average (FOWA) methods (Golfam et al. 2019b), evaluation human risk resulting from dam construction with TOPSIS and Weighted Aggregated Sum Product Assessment (WASPAS) methods (Bid and Siddique 2019).

This work's novelty is applying MCDMs to prioritize strategies that reduce adverse effects of dam construction. Integrating MCDMs with multiple project alternatives constitutes a novel approach in completing EIAs of dam construction to achieve sound project designs. This paper's objective is to minimize adverse environmental impacts of dams while meeting water resources functions. This paper's methodology is illustrated with Nohob Dam (In Qazvin Province), Iran. Novel decision-making approach presented in this study is of general applicability to dam construction projects.

Recognizing elements that influence determination of criteria and sub-criteria for decision-making is first step of this paper's method. IDOCRIW that combines Shannon's entropy and Criterion Impact Loss (CILOS) is applied for assigning weights of criteria and sub-criteria. Combination of latter two methods prevents undesirable and unrealistic weight assignment to any criterion. COCOSO is applied to prioritize that improvement actions intended to minimize negative effects of dam construction.

This work applies IDOCRIW to determine weights of criteria and sub-criteria, and COCOSO ranks proposed alternatives to reduce adverse effects of dam construction.

IDOCRIW integrates results of two entropy and CILOS methods that are complementary to each other.

Entropy is an objective method for calculating weights of criteria and sub-criteria. Objective weighting methods rely on mathematical formulas to calculate weights of criteria. Weights obtained from entropy reveal structure of data and their degree of heterogeneity.

A disadvantage of entropy is that it describes only one dimension of data array associated with dominance of one alternative over others considering the same criterion values. This means respective criterion weight obtained using CILOS would be small. This challenge is herein overcome by combining weights calculated with CILOS and entropy methods, which leads to realistic and representative weights.

Main features of COCOSO compared to other MCDM are:

1. Using concepts of combination and compromise

Concept of combination implies integration of weighted sum model (WSM) and weighted product model (WPM) for calculating normalized decision-making matrix. In other words, elements of normalized decision-making matrix are weighted with WSM and with WPM. Concept of compromise means balancing scores obtained with WSM and WPM.

2. Calculation of three types of scores for each alternative

Three types of scores are calculated for each alternative based on (i) arithmetic mean of sums of WSM and WPM scores, (ii) sum of relative score compared to the best, and (iii) balanced compromise of WSM and WPM scores. Lastly, sum of geometric and arithmetic means is used to calculate final weight of each alternative.

Therefore, using WSM and WPM, and applying compromise and combination in proposed method leads to more accurate results than those obtained with other methods. It is notworthy that this paper's method can be used with ordinary fuzzy environments, distance values, and intuitive fuzzy sets.

## 2 Materials and Methods

This paper's objective is to present a methodology to prioritize and determine best alternative for reducing adverse effects of dam construction. To this end, various impacts of dam construction are first assessed by EIA. In next step, main decision-making criteria are determined. IDOCRIW is implemented to determine weight of decision-making criteria and sub-criteria. IDOCRIW determines type of criterion, i.e. benefit (positive) and cost (negative). In final step, COCOSO is appled to prioritize alternatives and select best alternative that reduces negative effects of dam construction. Flowchart of this paper's methodologyis displayed in Fig. 1.

### 2.1 Criteria, Sub-Criteria, and Alternatives for Dam Construction Projects

Criteria, sub-criteria, and alternatives that are proposed in this research are based on field observations. Interviews with local stakeholders and consequences of dam operation were adapted from expert's reports of Zima Kaspian Omran consultancy. Alternatives for Nohob dam consider various effects of its operation, which are expressed in form of main criteria and sub-criteria sets.

Field observations, results of interviews with local stakeholders, reports, and library studies on effects of dam construction in Iran (See Ashofteh et al. 2017; Haddad et al. 2017) were used in determining set of criteria, sub-criteria, and project alternatives.

Main criteria are: impacts on natural resources, effects on ecosystems, socio-cultural impacts, and economic impacts on habitant's economic condition. These criteria have related sub-criteria with which improvement alternatives for dam construction projects are evaluated to selects the most suitable one. Detailed reasons for selecting criteria and sub-criteria are provided below.

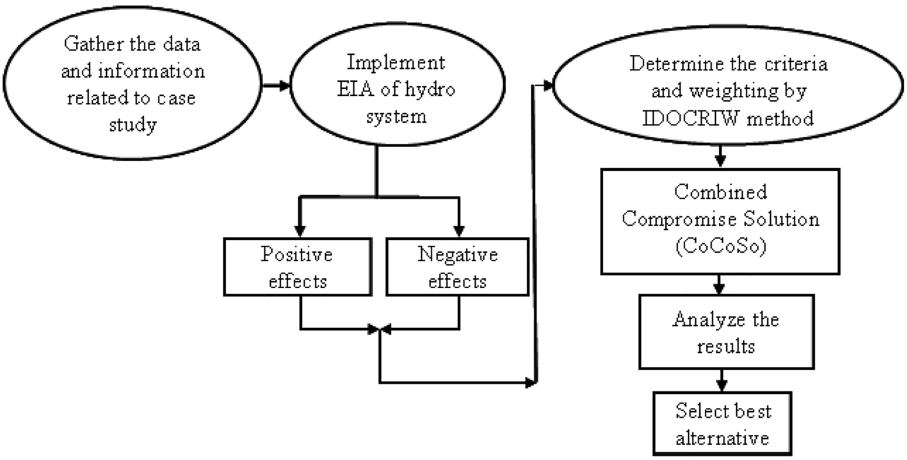


**Fig. 1** Flowchart of this paper's methodology

#### 2.1.1 Natural Resources Criterion

Sub-criteria of natural resources are: (I) soil quality, (II) surface water quality, (III) groundwater quality, and (IV) air quality. These sub-criteria are of a cost nature in IDOCRIW. Cost criteria have negative impacts on system, and their impacts must be minimized.

**Soil Quality** At the time of dam construction land changes are made that modify its morphology and river geomorphology. In addition to mechanical and physical changes in soil, there is reduction of natural soil moisture, disruption of vegetation, degradation of natural properties and drainage, and intensification of runoff and erosion. These are consequences of changes in soils. Therefore, criterion of soil quality was selected as main physical criterion.

**Surface Water Quality** Local studies revealed that surface water quality declines with declining river water velocity and with longer retention time which leads to sedimentation of suspended particles. Quality of water retained by dam decreases during construction. Therefore, surface water quality was selected as a sub-criterion of effects on natural resources criteria.

**Groundwater Quality** Excavation operations for construction of dam impacts water infiltration in sub-soil near construction site of dam. These changes lead to reduced groundwater quality. Therefore, it was selected as a sub-criterion of effects on natural resources criteria.

**Air Quality** Construction of dam and accumulation of water behind dam have caused climate change and reduced range of temperature changes and increased relative humidity. Air quality was also considered as a sub-criterion of natural resources due to importance of air quality for human and animal life.

#### 2.1.2 Ecosystem Criterion

Sub-criteria of ecosystem criterion are: (I) density and diversity of vegetation, (II) species diversity, (III) animal species balance, and (IV) quality of dry and aquatic habitats. All sub-criteria except density and diversity of vegetation are of benefit type.

**Density and Diversity of Vegetation** A part of lands along Kharrood had species such as *Salix sp* and *Populus sp*, which had great ecological importance but they were destroyed during construction of dam, and restoring them is necessary. Therefore, vegetation density and diversity were considered as a sub-criterion of ecosystem criteria.

**Species Diversity** Animal wildlife in any geographical area is part of a region's native genetic resources. Activities during dam construction, including drying of riverbed, diversion of river from main route, changes in water quality and high noise pollution from construction work caused many important animal species, such as rams and seasonal migratory birds, to leave area due to insecurity ecologic disturbances. Therefore, animal diversity was considered as a sub-criteria of ecology criteria.

**Animal Species Balance** Small mammals and migratory birds increased uncontrollably during construction of dam. Excessive increase of these species caused negative effects on crops and livestock, and in some cases cause transmission of disease to cows and damaged beehives. Therefore, maintaining balance of animal species was considered as an ecology criterion.

**Quality of Dry and Aquatic Habitats** Construction of new roads, increasing area under cultivation, and permanent presence of ranchers have caused damage to natural habitats. Invasive and thorny species have affected most habitats and caused extinction of important animal species such as deer and blackfish. Therefore, quality of terrestrial and aquatic habitats was considered as a sub-criterion.

### 2.1.3 Socio-cultural Criterion

Sub-criteria of socio-cultural criterion are: (I) social acceptance and public participation, (II) archaeological landmarks, (III) customs and traditions, (IV) tourism and leisure. Some of these sub-criteria are of cost type and others are benefits. Benefit criteria have positive impacts on system, and those impacts must be maximized. Among socio-agricultural sub-criteria archaeological landmark is a cost sub-criterion and three others are benefit sub-criteria.

**Social Acceptance and Public Participation** Studies have shown that construction of Nohob Dam forced relocation of 329 households which resided in lands that were submerged by dam. These people lost their lands and sources of income and migrate to other places. Displaced people receive compensation. Social acceptance and public participation were considered as a sub-criterion of impacts on socio-cultural criterion.

**Archaeological Landmarks** The most important antiquities in Kharrood Basin are:

1. Towers of Kharqan, located 20 km from city of Abgarm and near village of Hesar
2. Shah Abbasi Bridge located at Nohob Dam downstream

Protection of antiquities was considered as a sub-criterion of socio-cultural criteria due to importance of preserving and maintaining historical monuments during dam construction/operation.

**Customs and Traditions** There are holy places in region that must be protected, preservation of mother language, and observance of rural environmental health standards are key concerns for residents. Residents worry that their traditions may be disruptedby forced relocation of local peoples, presence of non-indigenous labor, and by tourists. Therefore customs and traditions were considered as a sub-criterion of socio-cultural criterion.

**Tourism and Leisure** Nohob Reservoir creates a pleasant landscape that will bring in tourism to enjoy recreation resources. Recreation and tourism centers in upstream areas such as mineral springs in Abgarm city can develop tourism industry of region and have positive effects.

#### 2.1.4 Economic Criteria

Sub-critera of economic criteria are: (I) immigration, (II) income, (III) employment, and (IV) quality and land use. Income and employment sub-criteria are of benefit type, and immigration and land use sub-criteria are of cost type.

**Immigration** Most inhabitants in region were dedicated to raising livestock and to agriculture before construction of Nohob. Lack of infrastructure facilities for agricultural development have caused most residents to migrate to Qazvin and Takestan cities. Need to use native labor during construction and operation of dam and its facilities and equipment will prevent uncontrolled migration to cities.

**Income** Economic prosperity and improving livelihood of residents are among main goals of construction of Nohob. It was predicted that economic prosperity would be achieved through agricultural development, improving welfare of region, and increasing number of tourists. Hence, income was considered as a sub-criterion of economic criteria.

**Employment** During construction and operation of dam required labor was estimated at about 700 people. Number of indirect jobs is estimated to be five times number of employees per project. Therefore in addition to 700 direct jobs, a large number of in-directed jobs will be created.

**Quality and Land Use** According to socio-economic and cultural characteristics of region agricultural land is main wealth of most households. With operation of Nohob and conversion of rainfed to irrigated lands value and price of agricultural lands will increase significantly. This improves economic condition of residents and creates more incentives for agricultural activities, which is reason why it is considered as an economic sub-criterion.

#### 2.1.5 Alternatives

Many dam-construction projects are of a wide-ranging nature, and have adverse effects. Project alternatives must be formulated to minimize or avoid negative impacts and maximize positive impacts of dam-construction projects. Suggested alternatives are

1. Forestry and watershed management
2. Relocation of Abgarm city waste disposal
3. Construction of a sewage collection network and treatment plant for Abgarm city
4. Controlling use of pesticides and fertilizer in agricultural lands, and optimizing their type and methods of use

Proposed alternatives are based on field observation, interviews with local residents, and on consequences of dam operation assuggested by expert's reports of Zima Kaspian Omran consultancy.

#### 2.1.6 Forestry and Watershed Management

First alternative i.e., forestry and watershed management, was proposed in order to reduce effects of clearing to build dam. Results of experts' study showed that clearing during construction of dam caused loss of a large number of trees and vegetation cover. This has led to a reduction in water quality, destruction of habitats, and changes in soil density and to soil erosion in area, and immediate measures must be taken to improve situation. This action is responsibility of Natural Resources Department of Qazvin province

#### 2.1.7 Relocation of Abgarm City Waste Disposal

Current situation of landfilling and solid waste in villages adjacent to Reservoir is such that most of solid waste from residential areas is dumped in Kharrood River. Currently, solid waste disposal site of Abgarm city and surrounding villages is located Kharrood River upstream. Therefore solid waste management in rural areas and in Abgarm City calls for relocation of Abgarm's city waste disposal. This action is responsibility of Abgarm City municipality.

#### 2.1.8 Construction of a Sewage Collection Network and Treatment Plant for Abgarm City

Currently, Abgarm city does not have a comprehensive sewage plan, and effluent of Abgarm city, especially during rainy seasons, would lead to pollute lake's water. Therefore, wastewater management in rural areas and in Abgarm City calls for a comprehensive hygienic waste disposal program in dam upstream. This action is responsibility of Water and Sewerage Company of Abgarm city.

#### 2.1.9 Controlling Use of Pesticides and Fertilizer in Agricultural Lands, and Optimizing their Type and Application Method

Development of agricultural lands, and excessive use of chemical fertilizers have polluted soil and water resources in region.

Pollution of natural resources has contaminated reservoir, and, therefore it is necessary to control amount and type of fertilizers used in agriculture. This action is responsibility of Agriculture Department of Qazvin province.

### 2.2 IDOCRIW Method

This work applies IDOCRIW to determine weights assigned to criteria and sub-criteria in MCDM. IDOCRIW was proposed by Zavadskas and Podvezko (2016). IDOCRIW is a combination of Shannon entropy and CILOS methods.

### 2.2.1 Entropy Method

This method was proposed by Shannon (1948). Entropy measures uncertainty in a continuous probability distribution. Shannon's entropy establishes that the more scattered values of a criterion, the more important that criterion is. Steps of entropy are as follows:

- **Formation of Decision Matrix**
  In this step decision matrix is formed considering $m$ criteria and $n$ project alternatives (Eq. (1)):

$$R = \| r_{ij} \| \tag{1}$$

where $R$ = initial decision matrix; and $r_{ij}$ = elements of decision matrix, which are determined based on opinions of experts.

- **Normalization of Decision Matrix**
  Elements of initial decision matrix are normalized with Eq. (2):

$$\tilde{r}_i = \frac{r_{ij}}{\sum_{i=1}^{n} r_{ij}} \tag{2}$$

where, $\tilde{r}_{ij}$ = normalized decision matrix elements.

- **Calculation of Degree of Entropy**
  For each criterion $j$ degree of entropy is calculated with Eq. (3):

$$E_j = -\frac{1}{lnn} \sum_{j=1}^{n} \tilde{r}_{ij} \, . \, ln\tilde{r}_{ij}(j = 1, \; 2, \; ...., \; m; 0 \leq E_j \leq 1 \tag{3}$$

where $E_j$ = degree of entropy of any criterion.

- **Calculation of Deviation of Degrees**
  Deviation of degrees is calculated according to Eq. (4):

$$d_j = 1 - E_j \tag{4}$$

where $d_j$ = deviation of degrees.

- **Calculation of Entropy Weight of Each Criterion**
  Weighting of each criterion is calculated based on Shannon entropy with Eq. (5).

$$W_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{5}$$

where $W_j$ = weight of each criteria based on entropy.

### 2.2.2 CILOS Method

From this point on steps of CILOS proposed by Mirkin (1974) are applied. This method adjusts scattering obtained from a criterion that is unrealistically assigned a large weight by entropy event though criterion might have a relatively small impact.

- **Converting Cost Criteria Into Benefits**
  Cost criteria in normalized decision matrix are transformed into benefit criteria with Eq. (6):

$$\tilde{r}_{ij} = \frac{min_i r_{ij}}{r_{ij}} \tag{6}$$

where $\tilde{r}_{ij}$ = values of cost criteria converted to benefit metrics.

After converting cost criteria into benefits normal decision matrix is reconstructed and maximum value of each criterion in each column is calculated with Eq. (7):

$$x_j = max_i x_{ij} = x_{k_i j} \tag{7}$$

where $k_i$ = row number containing the largest value of column $j$.

- **Calculation of Square Matrix Values**
  A square matrix is formed. For this purpose, the largest value of each criterion corresponding to each alternative is called original diameter. Row $i$ of matrix $A$ contains $x_{kj}$ from matrix $X$. Some rows in matrix $A$ may be similar to those of matrix $X$ (Eq. (8)):

$$A = \|a_{ij}\| \; a_{ii} = x_i \; a_{ij} = x_{k_i j} \tag{8}$$

where $A$ = square matrix.

- **Formation of Relative Loss Matrix**
  Criterion Impact LOS matrix is computed with Eq. (9):

$$p_{ij} = \frac{x_j - a_{ij}}{x_j} = \frac{a_{ii} - a_{ij}}{a_{ii}}, \; p_{ii} = 0 \; : \; i,j = 1, 2, ...m \tag{9}$$

where $p_{ii}$ = value located in original diameter (that it is equal to zero), and other elements $p_{ii}$ are calculated as difference of maximum value with each matrix element, divided by maximum value.

- **Weight System Matrix Formation**
  Weight system matrix is formed according to Eq. (10):

$$F = \begin{bmatrix} -\sum_{i=1}^{m} p_{i1} & p_{12\ldots} & p_{1m} \\ p_{21} & -\sum_{i=1}^{m} p_{i2} & p_{2m} \\ & \ldots & \\ p_{m1} & p_{m2}\cdots & -\sum_{i=1}^{m} p_{im} \end{bmatrix} \tag{10}$$

where $F$ = weight system matrix, and $-\sum_{i=1}^{m} p_{ii}$= negative of sum of elements of each column of relative loss matrix. Other elements are the same as those of matrix given by Eq. (9).

- **Calculation of Weight of Each Criterion**
  Criteria weights are calculated by solving following equation (Mirkin 1974):

$$F_q^T = 0 \tag{11}$$

where vector $q$ has elements $q_1$ = natural resources criterion weight, $q_2$ = ecosystem criterion weight, $q_3$ = socio-cultural criterion weight, and $q_4$ = economic criterion weight.

- **Calculation of Final Criteria Weights**
  Final criteria weights are calculated with Eq. (12):

$$\omega_j = \frac{q_j W_j}{\sum_{j=1}^{m} q_j w_j} \tag{12}$$

where $\omega_j$ = final weight of criterion $j$, $q_j$ = weight of $j$ criterion obtained with CILOS.

### 2.2.3 Combined Compromise Solution by MCDM

COCOSO proposed by Yazdani et al. (2019) is based on use of combined-compromise decision-making. COCOSO extends decision-making beyond intuitive and personal experience-based approaches, and creates compromise and convergence among problem factors, thus enhancing accuracy of decision-making process. Following are steps of COCOSO:

### 2.2.4 Formation of Initial Decision Matrix

Decision matrix is based on results of questionnaires' responses by experts (Eq. (13)):

$$x_{ij} = \begin{bmatrix} x_{11} & x_{12} & a & x_{1n} \\ x_{21} & x_{22} & a & x_{2n} \\ a & a & a & a \\ x_{m1} & x_{m2} & a & x_{mn} \end{bmatrix} \tag{13}$$

where $x_{ij}$ = initial decision matrix.

### 2.2.5 Normalization of Criteria Values

Benefit and cost criteria are normalized based on Eqs. (14)–(15), respectively.

$$r_{ij} = \frac{x_{ij} - minx_{ij}}{maxx_{ij} - minx_{ij}} \tag{14}$$

$$r_{ij} = \frac{maxx_{ij} - x_i j}{maxx_{ij} - minx_{ij}} \tag{15}$$

where $r_{ij}$ = normalized element of initial decision matrix.

### 2.2.6 Comparative Weight for Each Alternative

Each alternative is assigned a weighted comparability sequence and a power weighted comparability sequence according to Eqs. (16)–(17), respectively:

$$S_i = \sum_{j=1}^{n} w_j r_{ij} \tag{16}$$

$$P_i = \sum_{j=1}^{n} \left(r_{ij}\right)^{w_{ij}} \tag{17}$$

where $S_i$ = weighted comparability sequence obtained by gray relation production approach; $P_i$ = power weighted comperability sequence obtained by weighted product of WASPAS.

### 2.2.7 Determination of Relative Weight of Alternatives

Relative weights of alternatives are calculated with aggregation strategy as Eq. (18):

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)} k_{ib} = \frac{S_i}{min\}S_i} + \frac{P_i}{minP_i} k_{ic} = \frac{\lambda(S_i) + (1-\lambda)(P_i)}{(\lambda)maxS_i + (1-\lambda)maxP_i} 0 \leq \lambda \leq 1 \tag{18}$$

where $k_{ia}$, $k_{ib}$, $k_{ic}$ = arithmetic means of sums of Weighted Sum Model (WSM) and Weighted Product Model (WPM) scores, sum of relative scores of WSM and WPM scores compared to the best alternative, and balanced compromise of WSM and WPM scores, respectively, and $\lambda$ = a coefficient (that is determined by decision makers involved in a dam-construction project).

### 2.2.8 Final Ranking of Alternatives

In final step, weight of each alternative is calculated based on Eq. (19).

$$K_i = \left(k_{ia} k_{ib} k_{ic}\right)^{\frac{1}{3}} + \frac{1}{3}\left(k_{ia} + k_{ib} + k_{ic}\right) \tag{19}$$

where $K_i$ = final weight of each alternative. The greater value of $K_i$, the better alternative.

## 3 Case Study

Nohob Dam, Iran, is being constructed on Kharrood River (Fig. 2) with an average discharge of 148.8 × $10^6$ $m^3$ per year whose volume of sediment yield is estimated at 100 × $10^6$ $m^3$. Kharrood River is one of major tributaries of Shor River in Qazvin Province. Total volume of reservoir and its dead volume are estimated at 250 × $10^6$ $m^3$ and 100 × $10^6$ $m^3$, respectively. Type of dam is a clay core soil with a height of 59 m above foundation, length of dam crest is about 1800 m, and spillway system is of Calvert type. Dam is one of main sources of water supply for region agricultural lands. Climate is

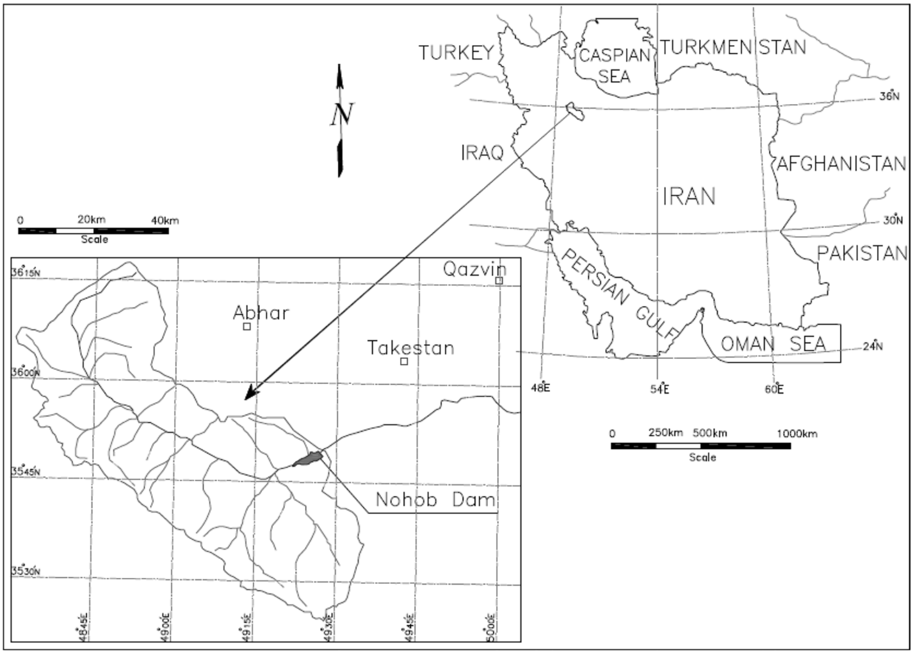


**Fig. 2** Location of region

arid and semi-arid with average annual rainfall equal to 303.1 mm. Average frost days are estimated to be 95 days per year and mean evaporation equals 2197 mm annually.

Main objectives of Nohob Dam were to store and regulate water flow for drinking, agriculture, and pisciculture, flood control, artificial recharge downstream of dam to reduce drop in groundwater level. Also, fostering economic growth in region, by providing better conditions for agricultural production and increasing efficiency due to development of irrigation system, were other goals of dam.

# 4 Results

## 4.1 Results of IDOCRIW

Fifteen-expert from diverse scientific and technical backgrounds were invited to determine criteria, sub-criteria, and options of alternatives for dam management. A questionnaire was prepared, and it was answered by 15-expert, who evaluated and weighted effects associated with Nohob Dam construction. There were 3, 4, 4, and 4 experts in fields of economics, water resources management, ecology, and socio-cultural issues, respectively, who determined criteria, options or alternatives for dam management, and evaluated options based on each criterion.

There are 4 main criteria and 16 sub-criteria in project. Details of calculations of weights for main criteria are herein presented. Only final results for sub-criteria are reported given similarity of weight-calculation procedure.

#### 4.1.1 Results of Entropy Method

First step in IDOCRIW is to calculate entropy weights. According to Table 1 decision matrix for main criteria was developed based on experts' opinions (Eq. (1)). Next, normal decision matrix was formed once decision matrix had been calculated (Eq. (2)). Normal decision matrix is shown in Table 2. Degree of entropy was calculated for each criterion in third step (Eq. (3)). Results are presented in Table 3. Deviations of criteria were calculated (Eq. (4)) and results are listed in Table 4. Criteria weights were calculated in last step (Eq. (5)) and are listed in Table 5.

#### 4.1.2 Calculation of Criteria Weights by Criterion Impact LOS Method

First step on CILOS is forming square matrix (Eqs. (6), (7) and (8)), as shown in Table 6. Then matrix of relative loss was formulated (Eq. (9)) as shown in Table 7. Weight system matrix was created (Eq. (10)) according to Table 8. Criteria weights were calculated by solving Eq. (20), and were subsequently normalized. Results of CILOS (Eq. (12)) are presented in Table 9.

$$Fq^T = 0 = \begin{cases} -0.5375q_1+0.200q_3+0.384q_4 = 0 \\ -0.213q_2+0.200q_3+0.384q_4 = 0 \\ 0.187q_1+0.181q_2-0.886q_3+0.274q_4 = 0 \\ 0.35q_1+0.031q_2+0.484q_3-1.043q_4 = 0 \end{cases} \tag{20}$$

Final weight of each criterion was obtained by combining entropy and CILOS according to Table 10. It is seen in Table 10 that socio-cultural criterion received the largest weight equal to 0.8316. Second largest weight was assigned to economic criterion, with a weight equal to 0.1053. Ecologic and natural natural resources criteria were third and fourth ranked criteria, respectively. Figure 3 shows final weight of main criteria. Results reveal maximum entropy and minimum degree of deviation belong to ecologic criterion, which also received smallest weight, while socio-cultural

**Table 1** Decision Matrix

| Alternatives | Main criteria | | | |
|---|---|---|---|---|
| | C1<br>Natural resources | C2<br>Ecological | C3<br>Socio-cultural | C4<br>Economic |
| A1 | 80 | 73.3 | 70.3 | 56 |
| A2 | 57.3 | 72 | 50.3 | 89.6 |
| A3 | 65 | 60 | 88 | 66 |
| A4 | 52 | 71 | 45.3 | 91 |
| Sum | **254.3** | **276.3** | **254** | **302.6** |

*A1* Forestry and watershed management, *A2* relocation of city waste disposal, *A3* construction of a sewage collection network and treatment plant, *A4* Optimizing the use of pesticide and fertilizer in agricultural lands

**Table 2** Normal Decision Matrix

| Alternatives | Main criteria | | | |
|---|---|---|---|---|
| | C1 Natural resources | C2 Ecological | C3 Socio-cultural | C4 Economic |
| A1 | 0.31 | 0.26 | 0.28 | 0.18 |
| A2 | 0.23 | 0.26 | 0.20 | 0.29 |
| A3 | 0.26 | 0.22 | 0.35 | 0.21 |
| A4 | 0.20 | 0.26 | 0.17 | 0.30 |
| Sum | **1** | **1** | **1** | **1** |
| Min | **0.20** | **0.22** | **0.17** | **0.18** |
| Max | **0.31** | **0.26** | **0.35** | **0.30** |

criterion received largest weight. Final weight values indicate importance of criteria in final decision-making and ranking process of strategies. A summary of results is presented for sub-criteria of main criteria follows. Decision matrix was developed for all sub-criteria based on experts' evaluations and then normalized. Degree of entropy was calculated next for all sub-criteria and results are reported in Table 11. Degrees of deviation of sub-criteria were calculated according to Table 11. For ease of discussion sub-criteria of natural resource, ecosystems, socio-cultural, and economic criteria were named $C_{1-1}$-$C_{1-4}$, $C_{2-1}$-$C_{2-4}$, $C_{3-1}$-$C_{3-4}$, and $C_{4-1}$-$C_{4-4}$, respectively. Weights of sub-criteria based on entropy are listed in Table 12. After calculating weight by Shannon entropy all steps of CILOS were repeated for sub-criteria, whose weights are presented in Table 12 by solving equations systems (Eqs. (21)–(24)) based on CILOS.

Sub-criteria related to natural resource's criterion (Eq. (21)):

$$Fq^T = 0 = \begin{cases} -0.9130q_1+0.1691q_2+0.4816q_3+0.2465q_4 = 0 \\ 0.3184q_1-0.2918q_2+0.4508q_3+0.1704q_4 = 0 \\ 0.2972q_1+0.0613q_2-0.9324q_3 = 0 \\ 0.2972q_1+0.0613q_2-0.4170q_4 = 0 \end{cases} \quad (21)$$

Sub-criteria related to ecosystem's criterion (Eq. (22)):

$$Fq^T = 0 = \begin{cases} -1.2459q_1+0.2638q_2+0.4311q_3+0.2019q_4 = 0 \\ 0.4153q_1-0.2638q_2 = 0 \\ 0.4153q_1-0.4319q_3 = 0 \\ 0.4153q_1-0.2019q_4 = 0 \end{cases} \quad (22)$$

Sub-criteria related to socio-cultural criterion (Eq. (23)):

**Table 3** Calculation of degree of entropy of main criteria

| The degree of entropy (E) | | | |
|---|---|---|---|
| Main criteria | | | |
| Natural resources (E1) | Ecological (E2) | Socio-cultural (E3) | Economic (E4) |
| 0.99031 | 0.998 | 0.975 | 0.985 |

**Table 4** Calculation of deviation of main criteria

| Deviation of the Main criteria | | | |
|---|---|---|---|
| Natural resources (d1) | Ecological (d2) | Socio-cultural (d3) | Economic (d4) |
| 0.00969 | 0.002 | 0.025 | 0.015 |

$$Fq^T = 0 = \begin{cases} -0.0103q_1+0.5221q_2 = 0 \\ 0.1030q_1-1.5664q_2+0.1197q_3+0.1808q_4 = 0 \\ 0.5221q_2-0.1197q_3 = 0 \\ 0.5221q_2-0.1801q_4 = 0 \end{cases} \tag{23}$$

Sub-criteria of economic criterion (Eq. (24)):

$$Fq^T = 0 = \begin{cases} -1.0781q_1+0.3924q_2+0.3978q_3+0.23q_4 = 0 \\ 0.3535q_1-0.7258q_2+0.3390q_4 = 0 \\ 0.3535q_1-0.8509q_3+0.3390q_3 = 0 \\ 0.3709q_1+0.3333q_2+0.4531q_3-0.9081q_4 = 0 \end{cases} \tag{24}$$

Recall each criterion has four sub-criteria. After calculating weight of each sub-criterion its final weight was multiplied by weight of related main criterion. Final weights of sub-criteria by IDOCRIW are listed in Table 13. Table 13 show that sub-criterion of social acceptance and public participation ($C_{3\text{-}1}$) has the largest value among 16 sub-criteria, while sub-criterion of quality of dry and aquatic habitats ($C_{2\text{-}4}$) has the smallest weight. Figure 4 is a graph of weights received by all sub-criteria, which provides a comparison among them. According to Fig. 4 changes of criteria weights are not significant except for sub-criterion of social acceptance and public participation. Results show that experts consider sub-criterion of social acceptance and public participation as the most important factor in Dam construction. This is so because it would be impossible to achieve objectives of dam construction without integrating local inhabitants who are main stakeholders of project.

### 4.2 COCOSO Method

This section describes results of COCOSO. Decision matrix was first formulated according to Table 14. Normal decision matrix was created based on revenue and cost criteria (Eqs. (14)–(15)), as shown in Table 15. The $S_i$ values were calculated (Eq. (16)) for all sub-criteria according to Table 16. According to Table 16 the largest *Si*

**Table 5** Calculation of main criteria weights

| Weighting | Main criteria | | | | Sum |
|---|---|---|---|---|---|
| | Natural resources (w1) | Ecological (w2) | Socio-cultural (w3) | Economic (w4) | |
| Weight of each criterion (w) | 0.187 | 0.042 | 0.489 | 0.282 | 0.223 |
| Normalized weight of each criterion | 0.139 | 0.078 | 0.578 | 0.206 | 1 |

**Table 6** Calculation of square matrix

| Alternatives | Main criteria | | | |
|---|---|---|---|---|
| | C1<br>Natural resources | C2<br>Ecological | C3<br>Socio-cultural | C4<br>Economic |
| A1 | 0.315 | 0.265 | 0.277 | 0.185 |
| A2 | 0.315 | 0.265 | 0.277 | 0.185 |
| A3 | 0.256 | 0.217 | 0.346 | 0.218 |
| A4 | 0.204 | 0.257 | 0.178 | 0.301 |
| Max | 0.315 | 0.265 | 0.346 | 0.301 |

value was assigned to forestry and watershed, and the smallest value to fourth alternative which optimizes fertilizer use in agriculture. Next, relative weights of sub-criteria were calculated with Eq. (17), which are listed in Table 17. According to Table 17 the largest $P_i$ was assigned to second alternative of relocating city waste disposal with a value equal to 14.7367, and the smallest value was assigned to third alternative of constructing sewage collection and treatment plant. In last step of COCOSO experts decided that value of $\lambda$ was 0.5. The $k_a$, $k_b$, $k_c$ (Eq. (18)), and $K_i$ (Eq. (19)) were calculated, and values are presented in Table 18. It is seen in Table 18 that alternative of relocating city waste disposal was assigned the largest value of $K_i$ equal to 5.863, for highest ranking. The other $K_i$ values ordered decreasing magnitude were 5.744, 3.019, and 1.693 which were asssigned to forestry and watershed management, construction of a sewage collection and treatment plant, and optimizing use of pesticides and fertilizers in agriculture, respectively.

### 4.3 Management Implications for Region

Access to clean and healthy water resources are essential for human life and environmental well being. Analysis of impacts of dam construction and operation must comprehensive as they cover a wide range of economic, environmental and socio-cultural issues. EIA of development projects, especially dams, is necessary to maximize benefits of their implementation.

This section describes practical and management results for region. First alternative is essential because of lack of a suitable place for waste disposal in dam upstream, which has caused accumulation of wastes and their migration to Nohob. Sources of pollution in Dam

**Table 7** Calculation of relative loss matrix

| Alternatives | Main criteria | | | |
|---|---|---|---|---|
| | C1<br>Natural resources | C2<br>Ecological | C3<br>Socio-cultural | C4<br>Economic |
| A1 | 0 | 0 | 0.201 | 0.385 |
| A2 | 0 | 3 | 0.201 | 0.385 |
| A3 | 0.188 | 0.182 | 0 | 0.275 |
| A4 | 0.35 | 0.032 | 0.485 | 0 |

**Table 8** Calculation of weights matrix

| Alternatives | Main criteria | | | |
|---|---|---|---|---|
| | C1<br>Natural resources | C2<br>Ecological | C3<br>Socio-cultural | C4<br>Economic |
| A1 | -0.538 | 0 | 0.201 | 0.385 |
| A2 | 0 | -0.214 | 0.201 | 0.385 |
| A3 | 0.188 | 0.182 | -0.886 | 0.275 |
| A4 | 0.35 | 0.032 | 0.485 | -1.044 |

upstream include agricultural activities, urban and rural pollutants, and livestock which is estimated to product 800 kg per capita.

Garbage in villages near Dam (four villages of Badamak, Hesar, Sagznab, and Shears) is released into environment, and pollutes Kharrood River. Farms neighboring villages are located in Kharrood banks, whose discharges drain into river. Main agricultural pollutants are pesticides, phosphorus and nitrogen due to use of chemical fertilizers that are released into Kharrood River during rainy season. One of most important economic activities is animal husbandry, and animal waste is an important source of pollution. Large amounts of livestock excrement are spread on land and enter river due to rainfall and surface water runoff. Therefore, the most urgent action is changing location of waste disposal.

Second alternative highlights need for implementing watershed management programs. Watershed management programs, such as conservation and vegetation management, monitoring rural development programs, respecting carrying capacity of grassland to support livestock balance between number of livestock and grassland capacity must be well implemented.

Restoration of vegetation, agricultural and irrigation sector management, livestock control, compliance with principles of rangeland management and creation and proper use of farmland are necessary to control and reduce severity of catchment erosion.

The most important consequences of not implementing forestry and watershed management programs are:

1. Reduction of crop and rangeland production per unit area
2. Increasing runoff volume, reducing base-runoff, increasing volume of floods
3. Accumulation of sediment in reservoir, reducing its storage volume
4. Reducing per capita income of farmers and ranchers in region

**Table 9** Calculation of main criteria weights

| Weight | Main criteria | | | | |
|---|---|---|---|---|---|
| | C1<br>Natural resources | C2<br>Ecological | C3<br>Socio-cultural | C4<br>Economic | Sum |
| Weight of criteria obtained by CILOS (q) | 0.056 | 0.138 | 0.089 | 0.055 | 0.338 |
| Final weight of each criterion resulting from normalization | 0.166 | 0.408 | 0.263 | 0.163 | 1 |

**Table 10** Calculation of main criteria final weights

| Main criteria | C1 Natural resources | C2 Ecological | C3 Socio-cultural | C4 Economic | Sum |
|---|---|---|---|---|---|
| Final weight of each criterion | 0.0480 | 0.0149 | 0.8316 | 0.1053 | 1 |

Currently, farmlands of Badamak, Hesar, Sagznab, Shears villages are located in Kharrood banks, whose discharges enther river. Main agricultural pollutants are pesticides, phosphorus, and nitrogen due to use of chemical fertilizers that are discharged into Kharrood River during rainy season, and pollute water in dam upstream. Therefore, construction of a sewage network and treatment plant in Abgarm, which is the closest to and the largest city upstream of Dam, was ranked third.

Construction of dam allowed cultivation of agricultural lands, which has led to increasing use of fertilizers and pesticides. These substances contaminate water. Therefore, fertilizer use must be limited, especially soluble and toxic phosphorus fertilizers. Biological and integrated pest control methods can also be implemented in region. Therefore, controlling and optimizing fertilizer consumption and its type received the lowest ranking.

Results of obtained rankings show that first alternative, i.e. relocating municipal waste disposal in dam upstream with aim of providing adequate, clean and healthy water that is directly related to health of human environment, is the first priority.

Subsequently, forestry and watershed management operations, which, on the one hand restore natural resources, and, on the other hand, increase efficiency and useful life of dam, and creates safe and secure habitats for a variety of animal and plant species is ranked in second place.

Construction of sewage collection network and treatment plant, in order to prevent groundwater resources contamination and inflow river pollution, which is expected to increase with increasing population and industrialization of region, was the third priority.

The fourth alternative is to control amount and type of fertilizer used in agricultural lands which would increase yield of agricultural products, and, as a result, this would provide compensation for losses inflicted.

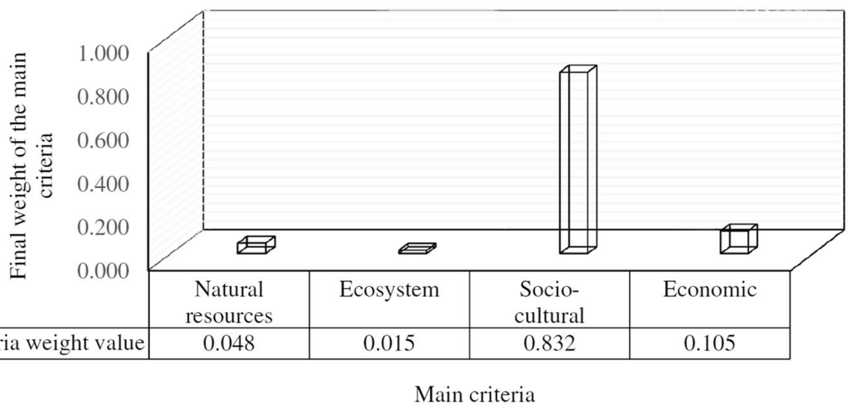


**Fig. 3** Diagram of final weights of main criteria

**Table 11** Degree of entropy and deviations of sub-criteria

| C1 Sub-criteria | (E) | (d) | C2 Sub-criteria | (E) | (d) | C3 Sub-criteria | (E) | (d) | C4 Sub-criteria | (E) | (d) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $C_{1\text{-}1}$ | 0.989 | 0.011 | $C_{2\text{-}1}$ | 0.981 | 0.019 | $C_{3\text{-}1}$ | 0.988 | 0.012 | $C_{4\text{-}1}$ | 0.989 | 0.011 |
| $C_{1\text{-}2}$ | 0.998 | 0.002 | $C_{2\text{-}2}$ | 0.994 | 0.006 | $C_{3\text{-}2}$ | 0.992 | 0.008 | $C_{4\text{-}2}$ | 0.986 | 0.014 |
| $C_{1\text{-}3}$ | 0.952 | 0.048 | $C_{2\text{-}3}$ | 0.984 | 0.016 | $C_{3\text{-}3}$ | 0.979 | 0.021 | $C_{4\text{-}3}$ | 0.987 | 0.013 |
| $C_{1\text{-}4}$ | 0.994 | 0.006 | $C_{2\text{-}4}$ | 0.997 | 0.003 | $C_{3\text{-}4}$ | 0.951 | 0.049 | $C_{4\text{-}4}$ | 0.992 | 0.008 |

**Table 12** Weight of sub-criteria based on Entropy and CILOS

| Entropy Weight (w) | | | | | | | |
|---|---|---|---|---|---|---|---|
| $C_{1-1}$ | 0.164 | $C_{2-1}$ | 0.429 | $C_{3-1}$ | 0.131 | $C_{4-1}$ | 0.237 |
| $C_{1-2}$ | 0.024 | $C_{2-2}$ | 0.128 | $C_{3-2}$ | 0.091 | $C_{4-2}$ | 0.306 |
| $C_{1-3}$ | 0.718 | $C_{2-3}$ | 0.369 | $C_{3-3}$ | 0.232 | $C_{4-3}$ | 0.291 |
| $C_{1-4}$ | 0.093 | $C_{2-4}$ | 0.074 | $C_{3-4}$ | 0.545 | $C_{4-4}$ | 0.166 |
| CILOS Weight (w) | | | | | | | |
| $C_{1-1}$ | 0.199 | $C_{2-1}$ | 0.176 | $C_{3-1}$ | 0.878 | $C_{4-1}$ | 0.234 |
| $C_{1-2}$ | 0.490 | $C_{2-2}$ | 0.282 | $C_{3-2}$ | 0.007 | $C_{4-2}$ | 0.254 |
| $C_{1-3}$ | 0.097 | $C_{2-3}$ | 0.175 | $C_{3-3}$ | 0.068 | $C_{4-3}$ | 0.217 |
| $C_{1-4}$ | 0.214 | $C_{2-4}$ | 0.367 | $C_{3-4}$ | 0.046 | $C_{4-4}$ | 0.295 |

**Table 13** Calculation of sub-criteria final weights

| C1 Sub-criteria | | C2 Sub-criteria | | C3 Sub-criteria | | C4 Sub-criteria | |
|---|---|---|---|---|---|---|---|
| $C_{1-1}$ | 0.012 | $C_{2-1}$ | 0.006 | $C_{3-1}$ | 0.611 | $C_{4-1}$ | 0.024 |
| $C_{1-2}$ | 0.004 | $C_{2-2}$ | 0.003 | $C_{3-2}$ | 0.004 | $C_{4-2}$ | 0.033 |
| $C_{1-3}$ | 0.025 | $C_{2-3}$ | 0.005 | $C_{3-3}$ | 0.084 | $C_{4-3}$ | 0.027 |
| $C_{1-4}$ | 0.007 | $C_{2-4}$ | 0.002 | $C_{3-4}$ | 0.133 | $C_{4-4}$ | 0.021 |

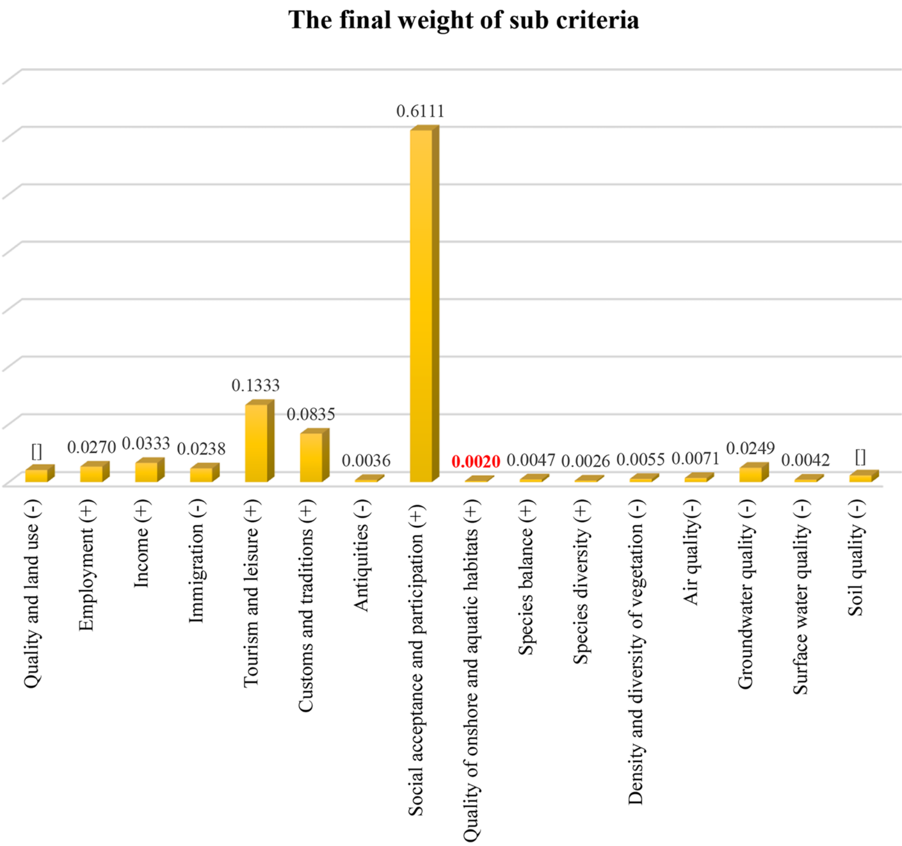


**Fig. 4** Diagram of final weights of sub-criteria

**Table 14** Initial matrix of sub-criteria in COCOSO

| Sub-criteria | Type of sub-criterion | Final weight | Alternatives | | | |
|---|---|---|---|---|---|---|
| | | | A1 | A2 | A3 | A4 |
| $C_{1-1}$ | -1 | 0.012 | 85.3 | 76.3 | 52 | 74 |
| $C_{1-2}$ | -1 | 0.004 | 73.7 | 67.3 | 81 | 71.7 |
| $C_{1-3}$ | -1 | 0.025 | 71.3 | 43.7 | 46.3 | 24 |
| $C_{1-4}$ | -1 | 0.007 | 79 | 66.3 | 73 | 55 |
| $C_{2-1}$ | -1 | 0.006 | 82.6 | 49 | 48.33 | 66.66 |
| $C_{2-2}$ | +1 | 0.003 | 72 | 54.66 | 53 | 57.66 |
| $C_{2-3}$ | +1 | 0.005 | 72.66 | 49.66 | 41.33 | 51 |
| $C_{2-4}$ | +1 | 0.002 | 67.66 | 54.16 | 54 | 56.83 |
| $C_{3-1}$ | +1 | 0.611 | 64.66 | 64 | 49 | 41.66 |
| $C_{3-2}$ | -1 | 0.004 | 40 | 42 | 33.66 | 28.33 |
| $C_{3-3}$ | +1 | 0.084 | 47.33 | 41.66 | 33.33 | 24.33 |
| $C_{3-4}$ | +1 | 0.133 | 990.33 | 74 | 57 | 30 |
| $C_{4-1}$ | -1 | 0.024 | 60.33 | 57.33 | 62 | 39 |
| $C_{4-2}$ | +1 | 0.033 | 62 | 43.66 | 41.33 | 37.66 |
| $C_{4-3}$ | +1 | 0.027 | 62 | 45.33 | 42.66 | 37.33 |
| $C_{4-4}$ | -1 | 0.021 | 77.66 | 63.66 | 51.33 | 66.66 |

*The column type of sub-criterion: number (+1) represents a benefit criterion and number (-1) represents a cost criterion

**Table 15** Normal matrix of sub-criteria in COCOSO

| Sub-criteria | Type of sub-criterion | Final weight | Alternatives | | | |
|---|---|---|---|---|---|---|
| | | | A1 | A2 | A3 | A4 |
| $C_{1-1}$ | -1 | 0.0120 | 0 | 0.270 | 1 | 0.3390 |
| $C_{1-2}$ | -1 | 0.0040 | 0.2703 | 1 | 0 | 0.679 |
| $C_{1-3}$ | -1 | 0.0250 | 0 | 0.584 | 0.529 | 1 |
| $C_{1-4}$ | -1 | 0.0070 | 0 | 0.5290 | 0.2500 | 1 |
| $C_{2-1}$ | -1 | 0.0060 | 0 | 0.9810 | 1 | 0.4660 |
| $C_{2-2}$ | +1 | 0.0030 | 1 | 0.0880 | 0 | 0.2460 |
| $C_{2-3}$ | +1 | 0.0050 | 1 | 0.2660 | 0 | 0.3090 |
| $C_{2-4}$ | +1 | 0.0020 | 1 | 0.0120 | 0 | 0.2070 |
| $C_{3-1}$ | +1 | 0.6110 | 1 | 0.9710 | 0.3190 | 0 |
| $C_{3-2}$ | -1 | 0.0036 | 0.1460 | 0 | 0.6100 | 1 |
| $C_{3-3}$ | +1 | 0.0835 | 1 | 0.7360 | 0.3910 | 0 |
| $C_{3-4}$ | +1 | 0.1333 | 1 | 0.7290 | 0.4480 | 0 |
| $C_{4-1}$ | -1 | 0.0238 | 0.0730 | 0.2030 | 0 | 1 |
| $C_{4-2}$ | +1 | 0.0333 | 1 | 0.2470 | 0.1510 | 0 |
| $C_{4-3}$ | +1 | 0.0270 | 1 | 0.3240 | 0.2160 | 0 |
| $C_{4-4}$ | -1 | 0.0210 | 0 | 0.0050 | 1 | 0.4180 |

*The column type of sub-criterion: the number (+1) represents a benefit criterion and the number (-1) represents a cost criterion

**Table 16** Comparison of comparative weighting of sub-criteria in COCOSO

| Sub-Criteria | Alternative | | | |
|---|---|---|---|---|
| | A1 | A2 | A3 | A4 |
| $C_{1-1}$ | 0 | 0.003 | 0.012 | 0.004 |
| $C_{1-2}$ | 0.002 | 0.004 | 0 | 0.003 |
| $C_{1-3}$ | 0 | 0.015 | 0.013 | 0.025 |
| $C_{1-4}$ | 0 | 0.004 | 0.002 | 0.007 |
| $C_{2-1}$ | 0 | 0.005 | 0.006 | 0.003 |
| $C_{2-2}$ | 0.003 | 0.0002 | 0 | 0.001 |
| $C_{2-3}$ | 0.005 | 0.001 | 0 | 0.002 |
| $C_{2-4}$ | 0.002 | 0 | 0 | 0.0004 |
| $C_{3-1}$ | 0.611 | 0.593 | 0 | 0.195 |
| $C_{3-2}$ | 0.001 | 0 | 0.002 | 0.004 |
| $C_{3-3}$ | 0.084 | 0.063 | 0.032 | 24.330 |
| $C_{3-4}$ | 0.133 | 0.097 | 0.060 | 0 |
| $C_{4-1}$ | 0.002 | 0.005 | 0 | 0.024 |
| $C_{4-2}$ | 0.033 | 0.008 | 0.005 | 0 |
| $C_{4-3}$ | 0.027 | 0.009 | 0.006 | 0 |
| $C_{4-4}$ | 0 | 0.011 | 0.021 | 0.009 |
| Si | **0.902** | **0.189** | **0.354** | **0.080** |

**Table 17** Calculation of sub-criteria relative weights in CoCoSo

| Sub-Criteria | Alternative | | | |
|---|---|---|---|---|
| | A1 | A2 | A3 | A4 |
| $C_{1-1}$ | 0 | 0.985 | 1 | 0.987 |
| $C_{1-2}$ | 0.997 | 1 | 0 | 0.998 |
| $C_{1-3}$ | 0 | 0.987 | 0.984 | 1 |
| $C_{1-4}$ | 0 | 0.996 | 0.990 | 1 |
| $C_{2-1}$ | 0 | 0.999 | 1 | 0.996 |
| $C_{2-2}$ | 1 | 0.994 | 0 | 0.996 |
| $C_{2-3}$ | 1 | 0.994 | 0 | 0.994 |
| $C_{2-4}$ | 1 | 0.991 | 0 | 0.997 |
| $C_{3-1}$ | 1 | 0.982 | 0.497 | 0 |
| $C_{3-2}$ | 0.993 | 0 | 0.998 | 1 |
| $C_{3-3}$ | 1 | 0.977 | 0.925 | 0 |
| $C_{3-4}$ | 1 | 0.959 | 0.898 | 0 |
| $C_{4-1}$ | 0.939 | 0.963 | 0 | 1 |
| $C_{4-2}$ | 1 | 0.954 | 0.939 | 0 |
| $C_{4-3}$ | 1 | 0.970 | 0.959 | 0 |
| $C_{4-4}$ | 0 | 0.987 | 1 | 0.982 |
| $P_i$ | 10.930 | 14.737 | 10.191 | 10.951 |

**Table 18** Final ranking of alternatives

| Alternatives | $k_a$ | Ranking | $k_b$ | Ranking | $k_c$ | Ranking | $K_i$ | Final ranking |
|---|---|---|---|---|---|---|---|---|
| **λ=0.5** | | | | | | | | |
| A1 | 0.242 | 2 | 12.303 | 1 | 0.757 | 2 | 5.744 | 2 |
| A2 | 0.318 | 1 | 11.6436 | 2 | 0.995 | 1 | 5.863 | 1 |
| A3 | 0.215 | 4 | 5.400 | 3 | 0.674 | 4 | 3.019 | 3 |
| A4 | 0.225 | 3 | 2.075 | 4 | 0.705 | 3 | 1.693 | 4 |

## 5 Concluding Remarks

This work investigated impacts of Nohob Dam to minimize its adverse effects. Field visits, interview with local residents were conducted to identify effects on environment, followed by formulation of alternatives to mitigate adverse impacts. Impacts resulting from dam construction were diverse, such as economic effects on life of habitants, adverse effects on water quality, animals and plants; therefore, there is a need to apply a method that could be aggregate all dimensions and impacts of dam's construction.

MCDM is a powerfull tool to select the best alternative. First step in MCDM is to select efficient criteria to capture multiple aspects of problem being solved. This study considered four main criteria and for each of four main criteria sub-criteria were selected and weighted with IDOCRIW. Subsequently, COCOSO was applied to obtain final weight of each alternative and ranking of alternatives from best to worst.

Main differences of COCOSO with respect to other MCDM are: (1) it applies a special scheme for constructing normalized weighted decision-making matrix, (2) integrates several approaches to extract final ranking of alternatives. Therefore, results of COCOSO are more reliable relative to other MCDM.

Results of weighting of main criteria showed that socio-cultural criteria had the largest weight, and economic, natural resources, and ecological criteria received next ranks, respectively. Among sub-criteria weight for social acceptance was the largest. Results of COCOSO established that relocation of city waste disposal was first priority, and forestry and watershed management was second priority.

## 6 Future Developments

Following is recommended to reduce undesired aspects of Nohob reservoir/dam's operation:

- Releasing at least 10 % of river discharge, or $15\times10^6$ $m^3$ from Nohob dam annually, to prevent damages to aquatic ecosystem downstream of dam
- Implementation of watershed management programs upstream of Nohob dam to prevent sediment accumulation in reservoir
- Release water from dam during rainy seasons to favor spawning of fishes
- Establishment of an environmental management system linked to reservoir operation, monitoring reservoir water quality, making optimized releases of reservoir

water, monitoring economic and social impacts of reservoir operation, development of a safety plan to prevent dam failure and effect flood control.

**Acknowledgements** Authors thank Iranian Civil Roads Development Company, and Zima Kaspin Omran consultancy, who is project contractor for construction of Nohob reservoir project.

**Authors Contributions** Vahideh Eslami developed theory and performed computations. Parvin Golfam verified analytical methods. Parisa-Sadat Ashofteh and Parvin Golfam encouraged Vahideh Eslami to investigate a specific aspect. Parisa-Sadat Ashofteh supervised findings of this work, and Parvin Golfam, and H. Loáiciga helped supervise project. All authors discussed results and contributed to final manuscript. Vahideh Eslami wrote manuscript with support from Parisa-Sadat Ashofteh, Parvin Golfam, and especially H. Loáiciga. Parisa-Sadat Ashofteh and Parvin Golfam conceived original idea.

**Availability of Data and Materials** Authors have restrictions on sharing data.

## Declarations

**Conflict of Interest** None.

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