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Mohammad Ebrahim Banihabib
University of Tehran, banihabib@ut.ac.ir

Abolfazl Laghabdoost-Arani
University of Tehran

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Mohammad Ebrahim Banihabib[1a] **and Abolfazl Laghabdoost-Arani**[2]

[1a] *Ph.D. of Civil Engineering, Water Resource Engineering, Associate Professor, Irrigation & Drainage Engineering Department, University of Tehran, Tehran, Iran, E-mail: Banihabib@ut.ac.ir*
[2]*MSc. Water resources Engineering, Irrigation & Drainage Engineering Department, University of Tehran*

Abstract: Flood management alternatives are investigated based on sustainable development criteria (SDC) by using a non-compensatory multicriteria decision-making (MCDM) model, ELECTRE-III, to reduce flood damage in a study reach of the Gorganrood River in Golestan Province, north of Iran. The selection of optimal alternative of flood management is a multi-objective issue and thus using MCDM models becomes necessary. Considering the physical, social and economic conditions of the region, a set of structural and non-structural alternatives is proposed for the flood management in the study reach of the Gorganrood River. To model sustainable development, 11 criteria are proposed for decisions regarding flood management considering benefits to future generation. Sensitivity analysis was used to investigate the effect of uncertainty in thresholds and ratings of alternatives. The results show that a non-compensatory MCDM model is appropriate to incorporate social, economic and environmental criteria for the ranking of flood management alternatives. In addition, ranking alternatives is sensitive to changes in the weights of criteria. Nevertheless, in spite of sensitive weights, the best alternative remained unchanged. The optimal decision achieves an integrated alternative of flood warning system and flood insurance based on the sustainable development concept.

Keywords: ELECTRE-III, non-compensatory, MCDM, structural, non-structural, flood management.

1. INTRODUCTION

Flood management consists of a wide range of plans to reduce destructive effects of floods on human society, environment and economy. These activities include various structural alternatives, which use a structure for flood control, and non-structural alternatives, which mitigate damages without controlling a flood. On the other hand, several social, environment and economic criteria should be used to assess each alternative. Thus, the selection of the optimal alternative of flood management is a multiple criteria decision-making issue, and determination of a proper multi-criteria decision making models (MCDM) is essential.

Flood imposes destructive effects on social, ecological and economic environment, and threatens sustainable development of flood-prone areas. Flood management can be an integrated solution if social, environmental and economic instabilities of the region due to the destruction of floods are controlled, and a sustainable foundation for the development of the region is provided.
According to World Commission on Environment and Development (WCED, 1987), sustainable development is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Destructive floods jeopardize settlements in the floodplains and conflict with sustainable development in these areas. As a result, flood management activities can be considered as a part of sustainable development if the flood management would be economically feasible, socially acceptable and environmentally sound. Moreover, future generation resources should not be sacrificed by eliminating the hazard of floods for the present generation. In other words, to assess whether sustainability is considered in flood control projects or not, the four criteria (fairness, reversibility, risk and consensus) proposed by Simonovic should be observed

(Takeuchi, 1998). Therefore, consideration of the sustainable development in flood management projects requires observing fairness, reversibility,` risk and consensus criteria which leads decision making to select an appropriate MCDM.

MCDMs are divided into two groups due to the tradeoff of values between different criteria. In the first group, the low rate of an alternative for satisfying a criterion is compensated by the high value of the criterion of another alternative. This kind of MCDM is called compensatory MCDM. In the second group, trade-off of values between criteria is not possible and it is called non-compensatory MCDM. Although theoretical principles of multiple criteria decision making are raised for more than two decades and they are used in different applications in industrial engineering, a limited number of them are applied in flood risk management (Meyer et al. 2008). They include the application of DEFINTE software for long-term assessment of flood risk management alternatives in Netherland and Iran (Janssen 2003; Yazdandoost and Bozorgy 2008; Bozorgy 2007). This software does multicriteria decision making by two methods of simple weighting and Evamix, which are considered compensatory MCDMs. In some researches, despite using particular economic, social and environmental criteria, several compensatory decision-making models such as MACBETH model (Measuring Attractiveness by a Categorical Based Evaluation Technique), simple weighting method and AHP (Analytical Hierarchy Process) are used (Costa et al. 2004; Brouwer 2004; Kubal 2009; Dang 2010; Willett 1991). In another study, a compensatory method, Utility Additive function (UTA), is used for prioritization of sub basins for structural flood control and only technical indices of flood are used as criteria (Kholghi 2002). Therefore, the applied MCDMs in previous researches are of compensatory type, and due to value trade-off between criteria in these models, decision–making by these MCDMs cannot address integrality of sustainable development criteria (SDC). In this paper, ELETRE-III model is used as a non-compensatory decision-making model to assess flood management alternatives based on the integrality of SDC.

2. MATERIAL AND METHOD

2.1 The study area

In this research, flood management alternatives are examined based on SDC using non-compensatory MCDM, ELECTRE-III, to reduce flood damage in a study reach of the Gorganrood River in Golestan Province, north of Iran. The study reach starts from Golestan Dam I and continues to downstream of Gonbad-e Qabus City (Figure 1).

Figure 1. The location of the study area

2.2 Flood Management Alternatives

Considering the physical, social and economic conditions of the case study area, the following structural and non-structural alternatives are proposed for flood management in the study reach of the Gorganrood River (Bozorgy, 2007):

Alternative (A1): Natural conditions (no project case for comparison),
Alternative (A2): Using the flood control capacity of Golestan dam,
Alternative (A3): Construction of levees along the river,
Alternative (A4): Construction of a diversion channel in the upstream of the study area,
Alternative (A5): Using a flood forecasting and warning system,
Alternative (A6): Applying a flood insurance in the study area,
Alternative (A7): The combination of the sixth and seventh alternatives.

2.3 Sustainable Development Indices

To protect the benefits of future generation, flood management approach applied by the present generation should be resiliency, economically feasible, socially acceptable and environmentally sounds (De Bruijn, 2005; Takeuchi et al., 1998). Criteria 1-3 are designed to examine resiliency of flood management approaches (De Bruijn, 2005). Criterion 4 and 11 are used to inspect techno-economic feasibility, criteria 5-7 are applied to check social acceptance and criteria 8-10 are to examine environmental soundness (Table 1). The criteria should be scored to attain the following circumstances: being feasible technically and economically, being acceptable for the present and future residents and improving the environment to the maximum environmental soundness. Indeed, maximization of each criterion is not leading to the fulfilment of the maximization of other criteria. Under those circumstances, using multi-criteria decision-making is unavoidable, and a non-compensatory MCDM model should be utilized to assure all the 11 criteria are present in the decision-making process.

Table 1. The proposed criteria for assessing flood management alternatives based on sustainable development

Criterion No.	Criterion	Description
Crit1	Expected average number of casualties per year	The expected average number of casualties per year, which is used to asses amplitude of flood (De Bruijn, 2005).
Crit2	Recovery Rate	Recovering rate from the flooding state to the normal state or to a better condition.
Crit3	Graduality	Increasing the system by discharge growth (De Bruijn, 2005).
Crit4	Expected Annual Damage (EAD)	Expected Annual Damage (EAD) is used to evaluate amplitude of flood (De Bruijn, 2005).
Crit5	Feeling safety by people	People’s satisfaction due to the achievement of a flood management alternative, which helps the social sustainability of a region.
Crit6	Employment rate	Increasing the number of employment is one of the most important factors of consensus and social sustainability.
Crit7	Participation	people participation in an alternative is a good index of consensus and social sustainability.
Crit8	Protection and improvement of natural landscape	Protection and improvement of natural landscapes is an index of environmental sustainability.
Crit9	Protection of wild life habitat	Protection of wild life habitat by an alternative is assessed as a part of environmental sustainable development concept.
Crit10	Protection of water quality	Protection of water quality against pollutants and sediment helps the improvement of the water resource and environment.
Crit11	Technical feasibility and construction speed	Financial and technological limitations can affect technical feasibility and execution speed of an alternative in developing communities and make each alternative different from the others in terms of economic feasibility and people consensus.

2.4 Decision Making Model

To address the integrity of SDC in selecting the best alternative for flood management ELECTRE-III, as a non-compensatory MCDM, was utilized for decision making. ELECTRE is originally proposed by Roy (1968, 1991), and it differs from many decision-making models in two fundamental ways. First, it explicitly incorporates the fuzzy (imprecise and uncertain) nature of decision making by using the concept of indifference, preference and veto thresholds (Roy, 1968). Second, decision-making models of ELECTRE are non-compensatory. That is to say, good scores on some criteria cannot necessarily compensate for an alternative scoring very poorly in one particular criterion. Considering these two characteristics, ELECTRE-III model can be used in ranking flood management alternatives. Considering uncertainty or impreciseness in some of social, environmental and economic criteria, and the necessity of keeping the integrity of SDC, ELECTRE-III model (with two above-mentioned characteristics) is a proper model for optimal decision making of flood management projects.

In the ELECTRE-III model, to be assured of ordering bSa assertion, b is minimum as good as a, the following two conditions should be provided:
- A concordance condition: a majority of criteria are concordant with the assertion.
- A non-discordance condition: none of the criteria strongly refuses bSa.

To make the first condition quantify, the overall concordance index is used as followings:

$$C(b,a)=\frac{1}{k}\sum k_j C_j(a,b) \quad (1)$$

where,

$$k=\sum_{j=1}^{r} k_j \quad (2)$$

In (1), $C(b,a)$ is overall concordance index; k_j is the importance coefficient for criterion j; $C_j(a,b)$ is partial concordance index related to *j* criterion and is obtained in the fourth interval of variation of criteria scores of different alternatives (Table 2). If $g_j(a)$ and $g_j(b)$ are scores of a and b alternative to criterion, respectively, and q_j, p_j and υ_j are indifference, preference and veto of criterion j, respectively. There are four intervals for $g_j(b)$ as shown in the second row of Table 2. Assertion bSa in these four intervals is as shown in the third row of Table 2. In the first interval, C_j, partial concordance index, is one. It means that bSa assertion (a at least is as good as b) is supported. In third and fourth interval, 100% of this assertion is refuted by j index. In the second interval, the percentage of bSa value is between zero and 100 and changes linearly between the border of first and third intervals. Indeed, C_j is similar to membership function of a fuzzy parameter in the four above-mentioned intervals. This characteristic provides the possibility to consider uncertainties and approximations of the criteria.

Table 2. Partial concordance index and discordance index

Interval	**First**	**Second**	**Third**	**Fourth**
$g_j(b)$ range	$g_j(a)-q\le g_j(b)\le g_j(a)+q$	$g_j(a)+kg_j(b)\le g_j(a)+p$	$g_j(a)+p\le g_j(b)\le g_j(a)+\upsilon$	$g_j(a)+\upsilon\le g_i(b)\le$
*b***S***a*	*a***I***b* or *b***I***a* *a* is as good as *b* with respect to j criterion and *b* is as good as *a* with respect to j criterion.	*b***Q***a* *b* is weakly preferred to *a* with for criterion j.	*b***p***a* *b* is strictly preferred to *a* with for criterion j.	*b***v***a* *b* veto *a* for criterion j.
$C_j(b,a)$	1	$\frac{p_j+g_j(a)-g_j(b)}{p_j-q_j}$	0	0
$d_j(b,a)$	0	0	$\frac{g_j(b)-g_j(a)-p_j}{\upsilon_j-p_j}$	1

In order to investigate the non-discordance condition, it is necessary to determine the discordance index of both a and b for criterion j, (Table 2). This index is zero in the first and second interval of $g_j(b)$ and in the fourth interval is one. In the third interval, this value is varied linearly from the border of second interval to the border of the fourth interval, between zero and one. In spite of concordance condition that requires the combination of partial concordance index to obtain overall concordance index, there is no need to combine discordance indices of criteria with each other and veto of one criterion is enough alone in the final decision making and determination of credibility degree bSa. The credibility degree of bSa is defined as:

$$S(a,b)=\begin{cases} C(a,b), & if\, d_j(a,b)\le C(a,b) \quad \forall j \quad \text{Where J(a,b) is the set of criteria} \\ C(a,b).\prod_{j\in J(a,b)}\dfrac{1-d_j(a,b)}{1-C(a,b)} & \text{Such that } d_j(a,b)>C(a,b) \end{cases} \tag{3}$$

where, $S(b,a)$ shows credibility degree of bSa. If the overall concordance index is more than discordance index for all criteria, credibility degree will be equal to overall concordance index, $C(b,a)$. If at least one of criteria veto bSa assertion completely, $dj(b,a)$ =1, credibility degree of bSa will be zero. If one or more criteria do veto relatively (third interval of Table 2), the credibility degree will be a fraction of overall concordance.

ELECTRE-III ranks the alternatives using credibility matrix whose members are credibility degree, bSa. Two pre-orders $Z1$ and $Z2$ are produced using a descending and ascending distillation process, respectively, and then combined to construct a partial pre-order, $Z1\cap Z2$. The credibility value is obtained from the following equation:

$$T(b,a) = 1 \quad if \quad S(b,a) > \lambda\text{-}s(\lambda)$$

$$T(b,a) = 0 \quad otherwise \tag{4}$$

The maximum value of λ is the greatest member of the credibility matrix, which in this research is equal to one. $S(\lambda)$ equal to 0.15 is used in this research. The values of credibility matrix show that assertion "b at least is as good as a" is credible for which pairs of alternatives. In this case, the amount of related members will be one. In addition, if this assertion is not valid, the amount will be zero. Thus, first rank of Z_1 is determined as subtraction of the maximum of the sum of each matrix row from the sum of each matrix column is determined. Then, the column and row related to first rank of Z_1 are deleted and second rank alternative is determined similar way until the last rank Z_1 is selected. For ascending ranking, Z_2, instead of the selection of the maximum difference, the minimum difference is the basis for the determination of alternative ranks. Finally, the final ranking is determined from $Z=Z_1\cap Z_2$.

3. RESULTS AND DISCUSSION

SDC are divided into qualitative and quantitative groups. The scores of quantitative criteria are estimated using the method presented by De Bruin (De Bruijn 2005). The score of other criteria is determined and averaged according to a survey from 30 experts, who are familiar with the study area. The performance matrix of alternatives is presented in Table 3 according to the SDCs. In addition, the importance coefficient, indifference, preference and veto thresholds of criteria are determined based on the comments of the experts. The average of these parameters is presented in Table 4. The final ranking is determined from $Z=Z_1\cap Z_2$ and, is shown in Table 5. Consequently, the proposed model ranks the alternatives according to qualitative and quantitative SDCs.

Table 3. Performance matrix of flood management alternatives

Alternatives / Criteria	A1	A2	A3	A4	A5	A6	A7
Crit1	4.4	1.9	3.8	2.2	2	4.4	2
Crit2	5.7	6	5.7	5.7	6.3	6.7	6.7
Crit3	0.83	0.8	0.73	0.94	0.86	0.83	0.83
Crit4	1	0.6	0.9	5.8	0.4	1	0.4
Crit5	1	4	3	3.5	4	2.5	5
Crit6	11792	17767	12574	2865	12083	11792	12083
Crit7	2	3	3	3	3.5	2.5	4
Crit8	3	5	1	2	4	3	4
Crit9	4	2	2	2	4	4	4
Crit10	1	5	2.8	3	2	2	2
Crit11	4	2	3	2.5	4	3.5	3

Table 4. Threshold Values and advantages of criteria

Criteria	q_j	p_j	v_j	k_j
Crit1	0.2	1	2	28
Crit2	1	2	3	25
Crit3	0.05	0.1	0.2	18
Crit4	1000	3000	7000	20
Crit5	0.5	2	3	25
Crit6	0.2	1	2	15
Crit7	0.2	1	2	20
Crit8	1	2	3	15
Crit9	1	2	3	20
Crit10	0.5	1	2	22
Crit11	0.5	1	2	20

Table 5. Final ranking of the alternatives

Alternatives	**Rank**
A7	1
A5	2
A2	3
A4	4
A3,A6	5
A1	6

According to the final ranking of alternatives by ELECTRE-III model, the alternatives A1, A2, (A3, A6), A5, A7 are ranked 1 to 6 respectively. The first rank is dedicated to A7 which is the integrated alternative of flood warning system and flood insurance. This alternative is compatible with environment due small environmental impact. The second rank is attributed to A5, using the flood-warning system. It is obvious that A5 compared to A7, does not present a solution for social damages and compensation from insurance for damages. In addition, A7 covers all positive attributes of A5. Thus, A7 alternative is preferred to A5. The A2, A3, A4, which are structural alternatives, are in the next ranks due to their negative effects on environmental. It shows that ELECTREIII due to non-compensatory involved environmental criteria in ranking beside an economic criterion. Since people of the study area are in unsuitable economic condition and flood insurance imposes costs to poor people, A6 is evaluated in the fifth rank as same as the level of A3, structural alternative (construction of the levees). Finally, the A1, which considers no project condition and keeps natural condition, is evaluated in the final rank. This means that the results of ranking by ELECTRE-III model prefer doing any alternative to keeping natural state. In other words, doing each of the 6 alternatives is preferred to not doing them. However, the model could not distinguish the ranks of alternatives A3 and A6 and rank both in same level. Therefore, the review of ranking by the proposed model shows that the model can incorporate all SDCs using the non-compensatory characteristic of the model, but it needs future improvement to distinguish the rank of all alternatives.

4. CONCLUSION

In this paper, a set of social, economic and environmental criteria are introduced as SDC for the evaluation of flood management alternatives. To avoid replacing the weak value of a criterion in ranking of an alternative with the strong value of another criterion, using a non-compensatory multiple criteria decision-making model, ELECTRE-III, is proposed for ranking of the structural and non-structural alternatives of flood management. Finally, the main conclusion of this research can be summarized as:

- The proposed model is able to grade the flood management alternatives according to qualitative and quantitative SDC to achieve sustainable development goals.
- The result of ranking by the proposed model shows that the model could include all SDCs using the non-compensatory characteristic of the proposed model.

Based on the result of this research, the application of the proposed model and SDC are definitely recommended for the determination of an appropriate flood management plan in harmony with sustainable development concept.

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