Chapter 16
Choosing a Voting Procedure for a Water Resources Management Problem

Abstract The management of water resources involves multiple decision-makers, each with their own perspectives on the way the decision problem should be tackled. This Chapter presents an illustration of the framework for choosing a VP for a water resources management problem. The application is based on the Morais and de Almeida (Omega (Oxford) 40:42–52, 2012) group decision model to support the choice of an alternative to stem and reverse the degradation of the hydrographic basin of the Jaboatão River, Pernambuco-Brazil.

16.1 A Water Resources Management Problem

Many decisions on water resources management in Brazil are made by hydrographic basin committees, which were instituted by the Brazilian National Policy on Water Resources (Ministry of the Environment-MMA 2006). The responsibility of hydrographic basin committees is to make the decision process decentralized and participatory by involving civil society, public sector authorities and users of water resources.

However, it is not a simple task to plan activities in these committees, since their members must make decisions on complex problems that consider multiple conflicting criteria (i.e. economic, technical, social and environmental dimensions). Various models were developed to support water resources management decision making using multicriteria analysis (Raju et al. 2000; Hajkowicz and Collins 2007; Morais and de Almeida 2007; Morais et al. 2010; Silva et al. 2010; Morais and de Almeida 2010; Mutikanga et al. 2011; Roozbahani et al. 2012; Trojan and Morais 2012a, b; Markovic 2012; Coelho et al. 2012; Fontana and Morais 2013, De Almeida-Filho et al. 2017; Gonçalo and Morais 2018).

Another important issue in this kind of problem is that committee members are usually able to spend only a limited amount of their time on water resources management activities, since they are typically also engaged on other priority activities (Silva et al. 2010). Therefore, it is very difficult to schedule meetings to make decisions because the actors involved have other commitments. These meetings should be held once per month but, given that members have other priority commitments,

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there are months when the meeting of the hydrographic basin committee to discuss water resources management problems cannot be held.

When the meetings do occur, the members of this committee use the plurality method to reach a collective preference. Each member indicates a single alternative or abstains, so, the alternative with the highest number of votes is the final decision. Therefore, this decision may not correspond to the interests of the majority, i.e., sometimes, the alternative chosen is the worst option for many members involved in the decision process.

Given the complexity of this decision-making, it is important to have a group decision support method to guarantee transparency, swiftness and, especially, a structured analysis of the problem, which incorporates the points of view of all committee members.

In that perspective, it is presented a group decision-making model for analyzing the alternatives to stem and reverse the degradation of the Jaboatão River in the context of hydrographic basin committee. The hydrographic basin of the Jaboatão River (in the state of Pernambuco, Brazil) extends over parts of the townships of Cabo de Santo Agostinho, Jaboatão dos Guararapes, Moreno, São Lourenço da Mata, Vitória de Santo Antão and parts of the city of Recife and has a drainage area of 426.70 km^2. This basin forms part of the Eastern region of the Brazilian Northeast Atlantic, which is the region in Brazil with the second highest population density (about 80 inhabitants/km^2) and it is this which emphasizes the importance of the hydrographic basin in the region. Besides, the interior of the region experiences periods of drought and/or low rainfall. Therefore, the supply of water becomes very critical due to the intermittent nature of the flow of water in the watercourses.

The main problem of this region is environmental, social and economic degradation resulting from the uncontrolled use of soil and water throughout the hydrographic basin. Table 16.1 shows the sources of degradation of the hydrographic basin of the Jaboatão River, defines their degradation status and the areas in which degradation is at a critical level.

Figure 16.1 illustrates the decision model which considers the effective participation of all members involved of the hydrographic basin committee, thereby obtaining individual rankings of alternatives with the aid of a multicriteria method. Thereafter, the framework for choosing a voting procedure (VP) is applied in order to identify the most appropriate VP to aggregate the individual rankings. The final group decision result is the selection of an alternative, which represents the preference of the committee, and which takes into consideration the points of view and interests of the different sectors/entities involved.

This model can increase the transparency of the decision process, thus reducing the possibilities of conflicts involving the use of the hydrographic basin. The sections that follow present the application of the model that seeks to support the group representing the hydrographic basin of Jaboatão River. The aim is to stem and reverse the degradation of the river.

Table 16.1 Characterization of the hydrographic basin

Source of degradation	Degradation status	Critic areas
Public actions	High levels of thermotolerant coliforms and phosphorous in the Jaboatão River and its tributaries are evidence of domestic sewage entering the hydrographic basin	Urban areas of Jaboatão dos Guararapes
	The following solid residues are found in the hydrographic basin: pieces of fishing line and netting, rope for tying up boats, plastic bags, drink containers, foam packaging for food and drinks, containers of lubricating oil	Urban areas, fishing colonies, and areas where the springs are used for recreational purposes
Agro-industrial	Irrigation using the main liquid residues from sugar-cane	Irrigated areas
Industrial	Untreated industrial emissions	Township of Jaboatão dos Guararapes
Agricultural	About 30 principal activities are involved in farming practices in the region served by the river	Township of Vitória de Santo Antão

Source Morais and de Almeida (2012)

16.2 Structuring the Problem

In order to support the choice of an alternative to mitigate the degradation of the hydrographic basin of the Jaboatão River, Pernambuco-Brazil, first of all, the decision-makers (DMs), the alternatives for this problem and the set of criteria to evaluate the alternatives must be identified. This application is based on Morais and de Almeida (2012).

16.2.1 Identifying the Decision-Makers

According to the National Policy for Water Resources, the DMs are the participants that represent public sector bodies, civil society and users of water resources (industries, agro-industries, water treatment and supply companies). For this problem, only one member from each sector/entity was considered, in order to avoid making the group too large. Table 16.2 shows what the composition of the group was.

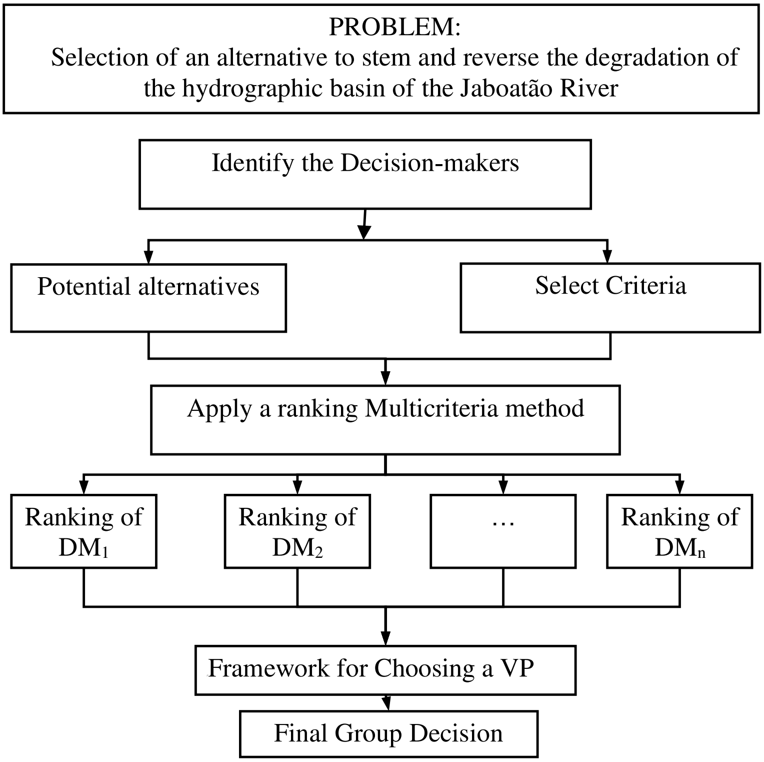

Fig. 16.1 Flowchart of the application in a water resources context (adapted from Morais and de Almeida 2012)

Table 16.2 Decision makers

Representation	Sector/Entity	Quantity
Water resources users	DM1 Industries	01
	DM2 Agro-industries	01
	DM3 Water treatment and supply company	01
Public sector	DM4 Union, State or City	01
Civil society	DM5 Universities or social organizations	01

Source Morais and de Almeida (2012)

16.2.2 Establishing the Set of Potential Alternatives

Based on the information about the status and main sources of degradation of the hydrographic basin presented in Table 16.1, a technical and specific study was conducted in order to formulate a set of alternatives to stem and reverse the degradation identified for the Jaboatão River basin. Some alternatives were also included based on a search for similar alternatives that have already been used in other basins to tackle degradation problems caused by sources of degradation of the same kind.

In order to establish the alternatives to mitigate the main degradation problem, the committee had an open discussion, focused on information about the sources of degradation and their status, to avoid considering alternatives based on specific and particular interests. For each alternative proposed, the DMs gave a technical explanation of how the action will contribute to mitigating the degradation problem detected. If someone disagrees with the arguments, he/she must explain why this is so and must emphasize their negative aspects against the positive ones. This exercise is often very beneficial for the group learning process.

Table 16.3 presents and describes the alternatives that were identified as being able to mitigate the degradation of the Jaboatão River. All DMs agreed that the alternatives identified were possible actions for reducing the degradation in the Jaboatão River Basin.

Table 16.3 Set of alternatives to mitigate degradation in the Jaboatão River Basin

Code	Description
A1	Secondary sewage treatment in Jaboatão dos Guararapes, which requires industrial waste to be pre-treated according to the standards laid down
A2	Educational campaigns in the townships within the hydrographic basin (with the exception of Recife)
A3	A campaign with industry to minimize the quantity of water used in production processes by offering monetary incentives for those industries that show positive results
A4	Maintenance of industrial facilities to prevent the water used for refrigeration from being contaminated by waste from industrial processes
A5	To institute policies for controlling the development of new businesses and/or expansion of current ones to avoid worsening industrial pollution
A6	Development of a plan of sustainable agriculture specific to the rural producers of Vitória de Santo Antão which focuses on soil and water conservation for the hydrographic basin of the Rio Jaboatão
A7	Recovery of native vegetation along the banks of the Jaboatão river
A8	Improving the collection of waste material all along the river, such as providing for the periodic removal of trash
A9	Recovery of the natural aquatic ecosystem
A10	Treatment of the Erosion Points in order to contribute to reducing the silting-up of the rivers and of the rainfall drainage network
A11	Restoring the biodiversity of the fauna in the basin
A12	Development of sustainable tourist activities along the Jaboatão river

Source Morais and de Almeida (2012)

16.2.3 Selecting Criteria for Evaluation

In order to evaluate the alternatives, five criteria were considered with regard to the economic, financial, social and environmental dimensions. These criteria consider the issues addressed by the members of the group during committees' meetings, and include the status of the degradation, its scope (point to the source or covers diffuse sources) and the urgency of implementing actions. Table 16.4 shows the code, name, description and the scale of each criterion.

Table 16.4 Criteria and their respective descriptions

Code	Criteria	Description	Scale
C1	Investment value	This is the monetary value for implementing action	Brazilian currency (Reais) and should be based on estimates of the State company responsible for water supply and sanitation. A smaller value is preferable to a higher value
C2	Maintenance costs	This is the monetary value to maintain the action in annual operation	Brazilian currency (Reais) and should be based on estimates of the State company responsible for water supply and sanitation. A smaller value is preferable to a higher value
C3	Dependence on third-parties	This is the action dependency, which does not consider the involvement and participation of others (society). The involvement of society diminishes the effectiveness of actions	Ordinal scale (very low, low, regular, high, very high). A lower value is preferable to a smaller value
C4	Industrial impacts	Corresponds to the negative impacts that the action will cause on industrial activities from the operational, economic or legal points of view	Ordinal scale (very low, low, regular, high, very high). A lower value is preferable to a smaller value
C5	Agricultural impacts	Corresponds to the negative impacts that the action will cause on agricultural activities	Ordinal scale (very low, low, regular, high, very high). A lower value is preferable to a smaller value

16.3 Individual Results

The group model aims to support DMs in ranking the alternatives while taking any aspects of the criteria into account. A multicriteria method was applied with each DM separately to obtain the individual rankings. It was considered that the DM's preference is directly influenced by the preference of the sector/entity that he or she represents.

The use of a multicriteria method for ranking is helpful due to the difficulty that DMs have in ranking the alternatives while thinking about the economic, environmental and social dimensions without a decision support method and to avoid the problem of manipulating the preference order (a common problem when a voting procedure is used). The choice of the multicriteria method depends on the context and characteristics of the problem analyzed and the DMs' rationality.

For this application, the PROMETHEE II method (Brans and Vincke 1985; Brans et al. 1986), which is appropriate for the ranking problematic, was used to prioritize the individual alternatives. Each DM evaluated the relative importance of the criteria and then attributed corresponding weights to each criterion and the preference functions for each criterion. It is easy to understand the concepts of this method and its inherent parameters, which makes preference modeling simpler and more efficient.

These weights which are defined by the DMs are non-negative numbers, independent of the measurement units of the criteria, whereby the higher value, the more important the criterion. The data should be normalized by dividing each weight by the total of all the weights attributed by a given DM. The sum of the normalized weights is equal to 1.

Since the PROMETHEE method suggests six types of preference functions (Brans et al. 1986), each DM can choose a different preference function per criterion. However, in this application, after discussions, the DMs decided that the preference functions for each criterion were to be chosen globally, that is, the same preference function and the parameters p and q would be the same to represent all DMs.

As criteria C1 and C2 are the measurable ones, the DMs' preference function is the V-shape criterion (or Linear Preference), where the preference for one alternative in relation to other increases linearly with the difference in performance between them, based on a preference threshold (p).

As the other criteria, C3, C4, and C5, are the subjective ones, they are evaluated on a verbal scale. The DMs' preference function is the Usual criterion, which seems to be the most appropriate one when subjective performances are evaluated. This preference function considers that if the performance of one alternative is slightly higher than the performance of another, then the former is entirely preferable.

Table 16.5 shows the normalized criteria weights attributed by each DM and the preference functions chosen per criterion with its respective parameters.

Before applying the multicriteria method, it is important to note that each DM can individually evaluate the alternatives by criteria, in the case of the subjective criteria. In this application, the evaluation was performed in an open discussion among DMs. The idea is to analyze each DM's assessment in order to increase understanding of the criteria, alternatives and scales in order to generate more realistic estimates of performance. So, the consequence matrix was the same for all DMs.

From the information collected (criteria weights per DM, judgments of the alternatives, preference functions and their respective parameters), the PROMETHEE II method was applied to obtain the ranking of the alternatives per DM. Table 16.6 presents these individual rankings.

Table 16.5 Criteria and their respective descriptions

Decision makers	Criteria				
	C1	C2	C3	C4	C5
DM1	0.46	0.36	0.06	0.06	0.06
DM2	0.30	0.30	0.10	0.27	0.03
DM3	0.38	0.28	0.14	0.10	0.10
DM4	0.19	0.22	0.29	0.22	0.08
DM5	0.20	0.10	0.10	0.20	0.40
Preference Functions	V-shape criterion	V-shape criterion	Usual criterion	Usual criterion	Usual criterion
Parameter p	100,000	50,000	–	–	–

Source Morais and de Almeida (2012)

Table 16.6 Individual rankings per decision-maker

Ranking	DM1	DM2	DM3	DM4	DM5
1	A5	A2	A5	A9	A9
2	A2	A5	A4	A6	A4
3	A10	A6	A3	A4	A3
4	A4	A4	A2	A2	A6
5	A6	A9	A10	A3	A12
6	A3	A10	A9	A11	A10
7	A9	A3	A6	A7	A8
8	A7	A7	A7	A8	A2
9	A11	A12	A11	A10	A5
10	A12	A8	A8	A5	A1
11	A8	A11	A12	A12	A7
12	A1	A1	A1	A1	A11

16.4 Applying a Framework for Choosing a VP

In this stage of the model, the framework for choosing a voting procedure (VP) is used, as presented in Chap. 14 of this book, in order to aggregate the individual rankings and select an alternative to mitigate the degradation of the Jaboatão River Basin.

First, it is important to analyze which VPs are appropriate for this problem, which has rankings as input, but only one alternative is needed as an output. Based on this perspective, either a VP that results in rankings or a VP that results in a single alternative can be considered. Therefore, the VPs that were considered for evaluation were: Amendment, Copeland, Dogson, Minmax, Kemeny, Plurarity, Borda, Approval, Black, Pl. runoff, Nanson and Hare.

Voting proprieties, in terms of which the goodness of the procedures is assessed (Nurmi 1983), were considered as criteria to evaluate the VP. In this application we used the same set of proprieties that are presented in Table 7.4. Thus, the consequence matrix of the VPs versus their proprieties is based on a discrete binary outcome (see Table 14.1, Chap. 14). Value function considered is Eq. (14.1) in Chap. 14.

For this problem, there is a concern related to which DM will be given the preferences in order to evaluate the VPs. For this case, all DMs agreed that DM 5 (the representative from Universities and social organizations) should assume the role of making the decision, thus acting as a Supra-Decision-Maker. They argued that DM5 understands the voting proprieties better than they did, and therefore he will be better at evaluating their relative importance.

On the other hand, DM5 had difficulty in expressing his preference regarding relative importance among the criteria. So, he required the support of the "Simos' revised Procedure" by Figueira and Roy (2002). The aim of this procedure is to elicit the weights of the different criteria and it does so by using two sets of cards, thus facilitating the assessment of criteria. As it is a relatively simple technique, it can be learned inductively (Figueira and Roy 2002).

Under this process, the DM is given two sets of cards: in one set, each card has the name and description of a criterion, and the other set consists of blank cards. The DM takes the set of named cards (in effect, the criteria) and orders them in ascending degree of importance. If the DM has an equal preference for two cards, he/she should put them together, in pairs

After the DM has ranked the named cards, the DM should think about the importance of a named card (criterion) relative to its immediate neighbors, and to express the degree of difference in importance between them, he should place one or more blank cards between the pairs of named cards.

Subsequently, an algorithm is set which will be used to calculate non-normalized and normalized weights. The SRF 2.2 (Simon Roy Figueira) software, developed by Lamsade (Paris-Dauphine University, Paris, France), is recommended to support this process (Figueira and Roy 2002). Table 16.7 shows the result of the weights by using SFR.

Using these weights for the VP proprieties, the PROMETHEE method is applied to evaluate the decision matrix [considering as value function Eq. (14.1), Chap. 14], based on the discrete binary outcome (see Table 14.1, Chap. 14). Figure 16.2 shows the result.

Table 16.7 Weight for VP proprieties given by DM5

Criteria	Order (ascending)	White cards	Normalized weights	Weights
h. Independence of irrelevant alternatives	1		3.5	0.035
		0		
a. Condorcert winner	2		5.4	0.054
b. Condorcert loser	2		5.4	0.054
c. Strong Condorcet	2		5.4	0.054
		0		
e. Pareto	3		7.3	0.073
		2		
d. Monotonicity	4		13	0.130
		0		
f. Consistency	5		14.9	0.149
		2		
i. Invulnerability	6		20.6	0.206
		1		
g. Chernoff	7		24.5	0.245

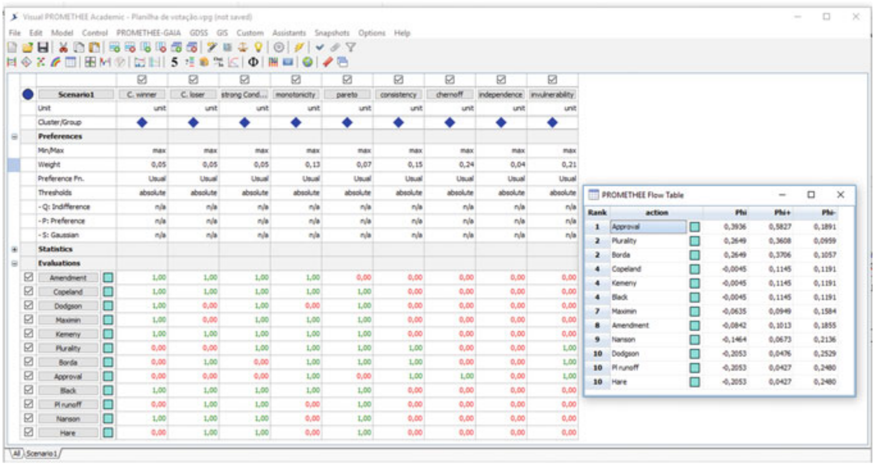

Fig. 16.2 Result of the VP chosen for the problem of water resources management

As can be observed, the Approval voting method was identified as the most appropriate VP for the problem to aggregate the individual results of the DMs involved in the decision about choosing the alternative to mitigate the degradation of the Jaboatão River Basin.

16.5 Global Result

Table 16.8 shows the results after applying the Approval Voting (AV), a voting procedure in which DMs may vote for as many candidates as they wish. The AV rule selects the candidate receiving the maximum number of votes or "approvals".

As can be observed, DM1, DM3 and DM5 decided to approve the first three alternatives in their ranking, while DM2 and DM4 approved the first two alternatives. In accordance with the results, the winner alternative is A5 with three votes in its favor. This alternative is related to instituting policies for controlling the development of new businesses and/or the expansion of current ones to avoid worsening industrial pollution.

Table 16.8 Result of approval voting

Alternatives	DM1	DM2	DM3	DM4	DM5	Total
A1						0
A2	X	X				2
A3			X		X	2
A4			X		X	2
A5	X	X	X			3
A6				X	X	2
A7						0
A8						0
A9				X	X	2
A10	X					1
A11						0
A12						0

16.6 Topics for Further Reflection

The group decision model for water resources management was applied for the specific problem of choosing an alternative to mitigate the degradation in the Jaboatão River Basin. This application serves to illustrate the framework for choosing the VP for a water resources problem. In this case, a Supra-decision-maker was used to evaluate the voting proprieties. This Supra-DM was a member of the group. The other DMs considered that he understood the properties of these consequences better than they did. The "playing cards" method, also known as the Simos' revised Procedure was used in order to obtain the weights of the proprieties of the VP (criteria).

The discrete binary outcome was used in the decision matrix for the VPs, and the multicriteria method that was applied to evaluate the VPs was Promethee. The same method was applied in order to aid the DMs to rank the alternatives.

In this problem, only five DMs took part in the process. However, a larger number of members can do so.

This proposal considers that each DM interprets a given situation differently and can generate different results (based on their individual way of thinking), even although they evaluate the same alternatives.

The use of the framework for choosing the VP was helpful and makes the process more transparent and acceptable. Note, however, that there are other methods for making social choices other than voting procedures and there are different VPs that can be used, which may generate different results.

16.7 Suggestions for Reading

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