

A Multiple Criteria Decision Analysis Model Based on ELECTRE TRI-C for Erosion Risk Assessment in Agricultural Areas

F. Macary · J. Almeida Dias · J. R. Figueira · B. Roy

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Abstract This paper deals with a real-world decision-aiding problem for zoning the risk of erosion, total suspended solids emissions, and ecological consequences of their transfers towards the streams. One of these consequences is the decrease of fishes into the streams in agricultural watersheds, because of the clogging of spawning areas. Given the multiple criteria nature of the problem, the originality of our research is to adapt a new decision-aiding sorting method, ELECTRE TRI-C, for identifying risk zones in rural areas, where measures must be taken. The developed model was applied in a small watershed (Low Normandy, France) where the objective was to assess the most appropriate intervention for protecting the reproduction habitat of the salmonid fishes. Agricultural parcels were evaluated on multiple criteria for grouping them into four risk

categories, which are related to risk levels as well as priorities on the improvement works. The decision-aiding sorting model is co-constructed, within a constructive approach, through an interaction process between decision-aiding analysts, environmental experts, and local actors for improving transparency and communication on the results. This model is linked with a geographical information system (GIS) for assessing a set of criteria and the visualization of the farming parcels along with their type of intervention they should be submitted to best practices. The assignment results were validated by the environmental experts. These results have a strong impact on the agricultural practices of the farmers into the watersheds. The model proposed in this paper can be considered as a useful decision aid tool in any regions for implementing public agricultural and environmental policies for protecting the ecological areas.

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1 Introduction

The intensification of cropping practices and major changes in rural landscapes have led to many physicochemical and ecological disturbances in aquatic environments [1, 2]. These phenomena are mainly the result of the increasing particle transfer to groundwater as total suspended solids (TSS) or to the substrate of the river beds, which depends on hydrological conditions. An excess turbidity in streams has consequences on the functioning of the aquatic ecosystems [3], and especially for fishes. In particular, clogging the substrate disrupts salmonid embryonic development [4], which takes place in winter under the gravel. As a result, the

population of these fishes suffered a decreasing trend over a period of several years [5].

There is a broad range of studies dealing with environmental problems in agriculture, as for example, cropping systems and their impact on groundwater quality [6], assessing pollution risks to water supply [7], land use suitability assessment [8], classifying agricultural data for environmental problems [9], assessment of erosion hot spots in the Peruvian Andes Watershed [10], water management and catchment modeling [11], watershed model under uncertainty situations [12], and scenario analysis tool for sustainable river basin management [13].

In agri-environmental issues, the definition of risk results from the crossing of a random phenomenon with the vulnerability of an element considered, when facing a challenge. In this study, we estimate a potential of contamination of surface waters by agricultural inputs. When we consider a challenge, like the preservation of the water quality, the potential of contamination becomes a risk for surface waters.

Assessment of environmental risk in rural areas, especially due to water erosion, in relation with intensive farming, is becoming a problem of utmost importance around the world, with strong impacts on the ecological areas and quality of life of populations [14–17]. In France, many researches over the last three decades were done on the territory [18–20]. Moreover, the region of Normandy in the northwest is famous for the different impacts on the ground [21–23].

A large majority of these problems have a multidimensional nature. To model such decision problems, multiple criteria decision aiding (MCDA) tools gained, over the last three decades, an enormous popularity and practical success [24, 25]. Among the sorting methods (the ones that are adequate to assess the risk of farming parcels) in the literature of the domain [26–31], the decision-aiding analysts in interaction with the *environmental experts* were opted by using ELECTRE TRI-C [30]. This choice was mainly because of some important features that should be modeled, as for example, the use of a tool that allows to characterize each category by a characteristic reference parcel, instead of other norms; the possibility to deal with ordinal scales; the conceptual framework of the tool allows to model the imperfect knowledge of the data; and the possibility to produce robust conclusions to be used for deriving the recommendations (“agronomical advices” on the interventions to be done).

In Europe, and especially in some regions like Low Normandy (France), there is a crucial need for assessing the risk of each farming parcel with the objective of applying the most adequate intervention for protecting the habitat of the salmonid fishes. Our study deals with this concrete problem at the scale of a small watershed of Violettes in this region. Let us notice that the environmental experts are

composed of a team of agronomists, agricultural advisors, and environmental managers. The main actors were farmers, local territorial authorities, technicians of the agriculture chamber, and technicians in charge to stream upkeep.

The objective of the study was to identify the farming parcels in a small watershed, where there is a risk of TSS emissions and transfers towards the streams. We took into account the main points of view of the problem operationalized as a set of criteria considering their natural features (such as sloping surface) and anthropic features (such as land use and agricultural practices).

The MCDA model is linked with a geographical information system (GIS) in a complementary way. This allowed to model in a more appropriate way the coherent set of criteria, the evaluation of the farming parcels, and the spatial visualization of the assignment results. In particular, the aim is to assign the farming parcels to a set of risk categories, which was associated with the priorities of the arrangements. The arrangements are improvement works, which are required to restore environmental protection of the streams and embankment strengthening regarding the down part of the farming parcels. Moreover, the main scientific interest of our research was to build a new MCDA model based on the ELECTRE TRI-C method, in interaction with a GIS for an agro-environmental issue.

The paper is organized as follows: Section 2 is devoted to the materials and methods (such as the set of criteria, the set of risk categories, the imperfect knowledge of the data, and the role of the criteria). Section 3 presents the results and discussion (the assignment results, the spatial visualization of these results, and the discussion on the validation of the model). Section 4 consists of the major conclusions of this study and lines for future research. Three appendices are also provided in this paper; they are related to the chosen decision-aiding sorting method, the performances of the farming parcels, and the detailed assignment results.

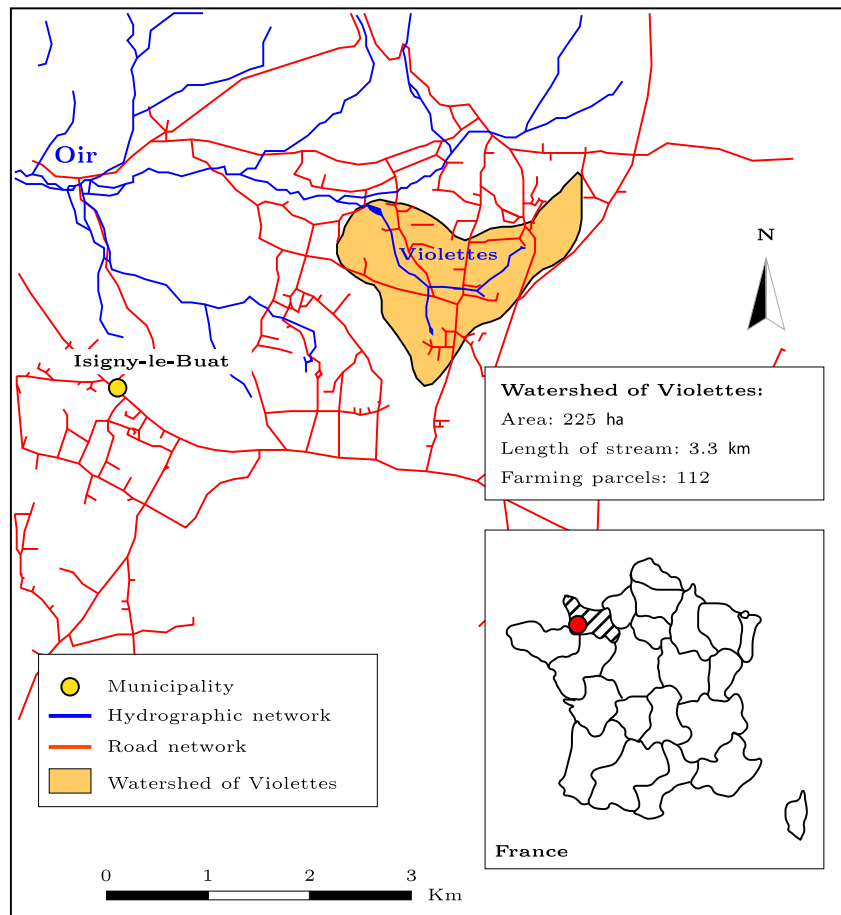
2 Materials and Methods

This section presents the context of our environmental risk application, the chosen sorting method, the modeling framework of the decision-aiding sorting model, and the relationship between this model and an implemented GIS.

2.1 Identifying the Agricultural Risk of Erosion

This environmental study was carried out on the southern part of Low Normandy (France), about 30 km far from Mont Saint-Michel, in the watershed area of Oir, a tributary of the Sélune River. It is an area of intensive dairy farming, which produces considerable modifications on the rural space. A watershed was selected: Violettes (see Fig. 1).

Fig. 1 Localization of the watershed of Violettes



Source: Irstea, UR ADBX

The size of the selected watershed for the study was deliberately kept small, in which a very detailed analysis could be carried out at a farming parcel scale. The hydrographic watershed has a geological substrate of schist. The soils are dominated by silt, which facilitates the transfer of TSS with runoff surfaces and erosion.

The fairly rugged relief around the steep-sided streams is a factor that favors runoff and erosion phenomena. The anthropic activities associated with rural space management in the two selected watersheds were assessed by means of exhaustive field surveys of all the local actors concerned.

Rural landscapes consist essentially of pastures alongside streams, which play a protective role with respect to particle transfer, in contrast to maize forage crop production, where surface areas have increased considerably in the last few decades, replacing pasture and, till recently, providing no protection for soils during the winter. Despite the regression of permanent (perennial) and temporary (4–5 years) pasture, embankments and pastures, basic elements in the hedged farmland, still hold a considerable place: about 50 % of the used agricultural area across the watershed in 2001, but only 35 % in 2008 [32].

The agricultural use of crop rotation in this watershed is essentially based on annual green maize crops (silage), soft wheat, and pasture. At the same time, since the 1970s, the changes that have taken place in the rural space have led to the slow destruction of this hedged farmland network, and hedge maintenance has been abandoned. Nowadays, this network is less compact and the embankments (if they exist) no longer provide a necessary support for the hedges. On the contrary, the tree alignments along the edges of the farming parcels are mainly the remnants of former hedge/embankment complexes. For more details about the risk of erosion in the context of this environmental risk application, see [33].

2.2 An Overview of ELECTRE TRI-C

ELECTRE TRI-C [30] was designed to be used within the framework of a constructive approach. This decision-aiding sorting method must be applied in the contexts where the categories are completely ordered (from the worst to the best, for instance). Each category must be defined a priori for assigning objects a (here, a represents farming parcels), which will be or might be processed in the same way.

Each farming parcel, as an object of a decision, must be evaluated on multiple criteria, denoted g_j , $j = 1, \dots, n$ (here, $n = 5$; see Section 2.4). Thus, the so-called *performance of farming parcel a*, denoted $g_j(a)$, represents the manner in which this parcel a is assessed according to the criterion g_j , $j = 1, \dots, 5$. The aim is to assign the farming parcels to a set of categories. This set is composed of four risk categories (see Section 2.5), denoted C_1 (very high risk), C_2 (high risk), C_3 (intermediate risk), and C_4 (low or no risk). The definition of each one of the four categories is based on a unique characteristic reference parcel, which is the most representative on the set of criteria, taking into account next processing operations.

Let b_h , $h = 1, \dots, 4$, denote the four *characteristic reference parcels* introduced to characterize the categories C_h , $h = 1, \dots, 4$, respectively. Let $B = \{b_0, \dots, b_5\}$ denote the set of characteristic reference parcels, where b_0 and b_5 denote two particular characteristic reference parcels defined as follows: $g_j(b_0)$ is the worst possible performance on the criterion g_j and $g_j(b_5)$ is the best possible performance on the same g_j , $j = 1, \dots, 5$.

The ELECTRE TRI-C method makes use of the so-called *outranking credibility index* (see Appendix 1) based on an absolute pairwise comparison framework. Each farming parcel a is not compared to the remaining ones, but it is compared to the characteristic reference parcel b_h , $h = 0, \dots, 5$. This index gives a *synthesis* of the risk level, taking into account the set of five retained criteria.

ELECTRE TRI-C assignment procedure is composed of two joint rules for providing a possible assignment of farming parcel a . These rules are defined as follows:

Definition 1 (Descending rule) Choose a credibility level, λ ($\frac{1}{2} \leq \lambda \leq 1$). Decrease h from 5 until the first value, t , such that $\sigma(a, b_t) \geq \lambda$:

1. For $t = 5$, select C_4 as a possible category to assign farming parcel a .
2. For $0 < t < 5$, if $\min\{\sigma(a, b_t); \sigma(b_t, a)\} > \min\{\sigma(a, b_{t+1}); \sigma(b_{t+1}, a)\}$, then select C_t as a possible category to assign a ; otherwise, select C_{t+1} .
3. For $t = 0$, select C_1 as a possible category to assign a .

Definition 2 (Ascending rule) Choose a credibility level, λ ($\frac{1}{2} \leq \lambda \leq 1$). Increase h from zero until the first value, k , such that $\sigma(b_k, a) \geq \lambda$:

1. For $k = 1$, select C_1 as a possible category to assign farming parcel a .
2. For $1 < k < 5$, if $\min\{\sigma(a, b_k); \sigma(b_k, a)\} > \min\{\sigma(a, b_{k-1}); \sigma(b_{k-1}, a)\}$, then select C_k as a possible category to assign a ; otherwise, select C_{k-1} .

3. For $k = 5$, select C_4 as a possible category to assign a .

ELECTRE TRI-C assignment procedure leads to select the lowest and the highest possible categories to which a farming parcel a can be assigned to by using the descending rule (Definition 1) and the ascending rule (Definition 2) conjointly (and not separately). Therefore, the assignment results can lead to one category, when the two selected categories are the same; two categories, when the two selected categories are consecutive; or a range of more than two consecutive categories, delimited by the two selected categories.

2.3 Decision Aiding Analysts, Environmental Experts, and Actors

An MCDA analysis was performed through an interaction process with decision-aiding analysts, the environmental experts, and the actors (i.e., the farmers who cultivate farming parcels into the Violettes Watershed, and their advisers).

The group of environmental experts was composed of two agronomist advisers from an agricultural professional organization, two agricultural managers from the regional service of the agricultural ministry, two environmental specialists from the water policy local service, and different colleagues from the research teams that study the growth and development of salmonid fishes at an agronomic high school and the University of Rennes, France.

Three meetings, with all participants, have been organized at the village of Isigny-le-Buat. The first meeting took place before starting the project, with the objective of introducing the necessary background and the aim of the project. The second meeting was done as an intermediate step to validate the methodology. The third meeting, in the end of the project, was done for showing the results (in particular, the zoning maps) and to share some conclusions to the participants. In addition, during the realization of this project, we have met twice the experts and some farmers for getting their contribution in modeling the set of criteria, the set of categories, and other relevant inputs. Unfortunately, the remoteness of the watersheds, located 700 km away from our headquarters, led to strong constraints of a more frequent interaction with experts and farmers.

The experts had a particular and important role in the construction of a coherent set of criteria, in the assessment of their weights, in the explanation of the different risk categories and parameters, and in the validation of the scores used to establish a performance for each farming parcel according to each criterion. At the end of the sorting process of the farming parcels, the farmers could indicate if the results correspond or not with their knowledge of the field.

2.4 Modeling the Set of Criteria

Each *farming parcel* a must be analyzed with respect to the risk associated with agricultural practices and breeding of the farmers belonging to the studied watersheds. Indeed, the farming parcels are the part of the space where farmers decide what they really want to do, including the *improvement works*. These practices are directly connected with risk of erosion due to TSS emissions and transfers.

Knowing that the farming parcels, which represent the highest environmental risk, can help the managers to develop some measures to decrease such a risk, the aim is, thus, to evaluate each farming parcel according to the following points of view of TSS:

- The overall sloping surface of each farming parcel,
- The quality of the connectivity between each farming parcel and the stream,
- The type of embankment in the lower part of each farming parcel,
- The nature of the crop on the soil of each farming parcel,
- The bank alteration by the cows, when they drink water directly into the stream.

We have chosen the five above points of view to take into account the qualitative nature of the physical factors, which are important for explaining the TSS transfers from farming parcels to the stream, at the scale level of a small watershed. Other factors, as precipitation and soil, also play an important role in the erosion process, but we did not take them into account in our study since our aim was to assess the impact of each farming parcel to the risk of erosion, and not to assess the impact of TSS flows. Our study deals with a qualitative rather than a quantitative assessment of risk by sorting the farming parcels into predefined and ordered categories. The major challenge we have been faced with was to select the appropriate criteria for discriminating all the farming parcels in small watersheds. At this geographical level, precipitation is more or less the same on the whole watershed. Some previous analysis of soils also showed that the physical properties are very similar. Thus, these two factors cannot be used for discriminating the farming parcels: this explains why we did not consider the two essential criteria usually used to explain the process of the physical erosion of soils.

The above points of view were modeled as a *coherent set of criteria* [34] for evaluating the farming parcels, denoted $F = \{g_1, g_2, \dots, g_j, \dots, g_5\}$. For each criterion, the different possibilities of evaluating the farming parcels are levels of a preference scale, which is completely ordered. In general, the performance $g_j(a)$, $j = 1, \dots, 5$, of each farming parcel must be provided by the environmental experts. The chosen set of criteria is defined as follows:

Criterion g_1 —sloping surface This criterion evaluates the overall sloping surface of a farming parcel using the digital elevation model (DEM) interpolated to 10 m, whose performance is computed as follows: $\sum_{u=1}^{k_i} \rho_u s_u$, $i = 1, 2, \dots$, where k_i is the number of polygons of the farming parcel a_i ; ρ_u is the slope of the polygon u , $u = 1, 2, \dots, k_i$; and s_u is the surface area of the polygon u (hectares), $u = 1, 2, \dots, k_i$. Taking into account the DEM output, for avoiding the high values, the obtained sloping surface is then divided by 1,000. In such conditions, the higher the overall sloping surface value, the higher is the environmental risk.

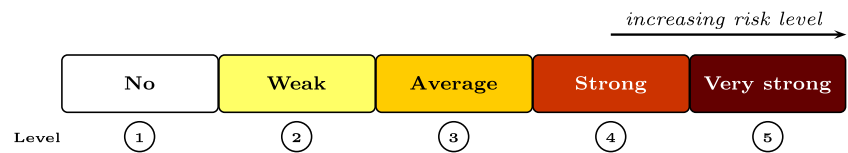
Criterion g_2 —connectivity This criterion evaluates the quality of the connections between the farming parcels and the stream. This evaluation is made by the environmental experts based on the road and ways network. Each farming parcel is associated with one and only one of the five qualitative statements defined in Fig. 2. Level 1 means that the farming parcel is very distant from the stream. Level 2 means that there is no direct connections with the stream and moderately distant from the stream. Level 3 means that the farming parcel is quite distant and connected by short ways. Level 4 means that the farming parcel is very close to the stream, but not crossed by it. Level 5 means that the farming parcel is intersected by the hydrographic network.

Criterion g_3 —embankment This criterion evaluates the type of embankment on the boundary of each farming parcel, especially on the downstream. This evaluation is made by the environmental experts based on land registry of the studied area. Each farming parcel is associated with one and only one of the four qualitative statements defined in Fig. 3. Level 1 means that there is a closed embankment with a hydraulic isolation. Level 2 means that there is an open passage for the agricultural machines. Level 3 means that a part of the embankment disappeared, where the passage is bigger than from level 2. Level 4 means that there is no embankment for protection from runoff.

Criterion g_4 —crop This criterion evaluates land use of each farming parcel, where the annual crop area must be identified. This evaluation is made by the environmental experts based on inquiries to the farmers. Each farming parcel is associated with one and only one of the four qualitative statements defined in Fig. 4. Level 1 includes grassland and orchards. Level 2 includes barley, wheat, and colza. Level 3 includes maize with temporary crop (t.c.). Level 4 includes maize without t.c.

Criterion g_5 —bank alteration This criterion evaluates the damage level of the bank alteration due to cows and other animals, which drink water on or feed at the hedge of the stream. This evaluation is made by the environmental

Fig. 2 Qualitative statements on g_2



experts, where each farming parcel is associated with one and only one of the four qualitative statements defined in Fig. 5. Level 1 means that the bank is vegetated and fenced off. Level 2 means that there are some natural or provoked collapses and sensitive cleared channels. Level 3 means that there exists a presence of a drinking place, where the banks became vulnerable. Level 4 means that there are, for instance, uncontrolled drinking areas.

Thus, according to the above set of criteria, the highest risk of TSS emissions and transfers of a farming parcel is associated to a high sloping surface value (g_1), a connectivity that intersecting the hydrographic network (g_2), no embankments in the lower part (g_3), a land use cover with maize without temporary crop during the winter (g_4), and a strong bank alteration on the stream (g_5).

2.5 Modeling the Set of Categories

The objective of the decision-aiding sorting model is to give “agronomical advice” to the environmental managers about the policies for protecting the hydrographic network as well as to the farmers for choosing wise agricultural practices in order to preserve the habitat of the salmonid fishes. The aim is to provide a *risk level* as well as a *priority on the improvement works* for each farming parcel as the objects of decision, taking into account its evaluation on the set of criteria.

We propose to design a priori some ordinal classes or risk categories with a clear meaning in such a decision-aiding context. Each category has been conceived to receive farming parcels, which must be processed in the same way regarding the risk level. Four categories were retained by the environmental experts according to the next processing operations of the farming parcels as detailed as possible, taking into account the nature of the data as well as the arbitrariness that affects the definition of the set of criteria (see Table 1). This set of categories is completely ordered from the most risky (C_1) to the least risky (C_4).

According to this set of categories, ELECTRE TRI-C must be assigned to C_1 or C_2 , the farming parcels which are more

sensible to have very high or high risk, where it is essential to take an immediate improvement work. On the contrary, the farming parcels associated with low or no risk will be assigned to the category C_4 , where no action is required.

According to ELECTRE TRI-C, each one of the categories (see Table 1) is characterized by a typical reference parcel, denoted b_h , $h = 1, \dots, 4$. These reference actions were conceived, in interaction between the decision-aiding analysts and the environmental experts, to be representative of the level of risk associated with the related categories. Indeed, the characteristic reference parcels were straightforward connected to the risk levels and the priority of the arrangements, after some spatial visualization of the preliminary assignment results, based on the knowledge of the environmental experts about the studied watersheds. The final set of characteristic reference parcels is presented in Table 2.

Table 2 shows that the ELECTRE TRI-C method is an appropriate tool for dealing with the environmental decision problem introduced in Section 1. This problem could be analyzed by making use of another method from the ELECTRE family of decision-aiding methods. More precisely, the ELECTRE TRI-B method [35, 36]. However, ELECTRE TRI-B requires to characterize each category by boundary reference actions to delimit the frontier between two consecutive categories, which would be very ambiguous in such a decision-aiding context. Because of this ambiguity, the decision-aiding analysts in interaction with the environmental experts prefer to make use of ELECTRE TRI-C instead of ELECTRE TRI-B.

Let us mention that this decision-aiding problem was firstly analyzed by using the ELECTRE III method [32, 33]. The decision-aiding sorting model proposed in this paper follows a different approach in comparison to the one used in the ELECTRE III method framework. Each farming parcel is only compared to the characteristic reference parcels for judging its intrinsic character, which does not depend on the remaining farming parcels. Thus, an absolute comparison approach is used instead of a relative one.

Fig. 3 Qualitative statements on g_3

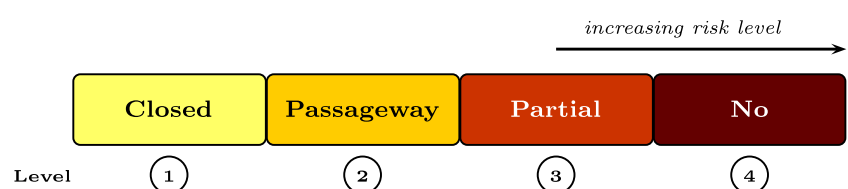
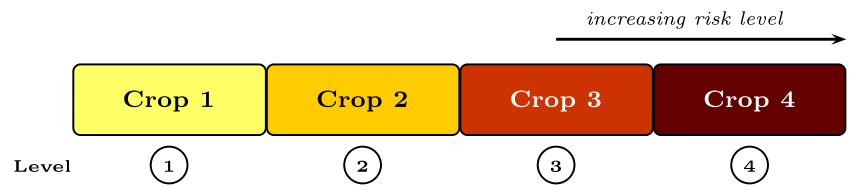


Fig. 4 Qualitative statements on g_4



2.6 Modeling the Imperfect Knowledge of the Data

For modeling the imperfect knowledge of the data, the ELECTRE family of methods makes use of thresholds, which are associated to each one of the criteria [34, 37]. These thresholds are known as *indifference thresholds*, denoted q_j , $j = 1, \dots, 5$, and *preference thresholds*, denoted p_j , $j = 1, \dots, 5$. This section shows how these thresholds can be defined for each one of the five chosen criteria. The way to proceed is not the same for a quantitative criterion (g_1) or a qualitative criterion (g_2, g_3, g_4 , or g_5).

2.6.1 Managing a Quantitative Criteria

Taking into account the imperfect knowledge on the definition of the criterion g_1 , we must consider that if two farming parcels, a and a' , exist, such that the difference $g_1(a) - g_1(a')$ is too small, then we cannot conclude that the parcel with the greater sloping surface is significantly more risky than the one with the lesser sloping surface. From the point of view of the risk due to such a sloping surface, we must say that these two farming parcels, a and a' , are indifferent. The indifference threshold, q_1 , is the maximal value of the difference, which is compatible with such an indifference on the criterion g_1 .

When $g_1(a) - g_1(a')$ is not too much greater than q_1 , we hesitate to conclude that parcel a , taking into account the sloping surface, presents a risk level significantly higher than a' . The preference thresholds, p_1 , are the minimal value of the difference, which must be exceeded for becoming convincing of the strict preference. In other words, we prefer without hesitation as less risky a sloping surface $g_1(a')$ over $g_1(a)$.

The range $[q_1, p_1]$ allows to model a hesitation, or an ambiguity zone, such that if $g_1(a) - g_1(a')$ belongs to this range, it is not justified to consider that the more risky value corresponds to a risk significantly higher than the other one. In such a case, we cannot conclude about an indifference of the two risk levels.

The value of q_1 (as well as that of p_1) does not seem to be the same when the sloping surface is strong or weak. The ELECTRE family of methods makes use of variable thresholds as affine functions. This functions are defined as follows: $q_1(g_1(a)) = \alpha_q g_1(a) + \beta_q$ and $p_1(g_1(a)) = \alpha_p g_1(a) + \beta_p$. Assigning numerical values to the coefficients of these affine functions requires the participation of the environmental experts. This participation was performed as follows:

1. The analysts asked the experts to choose two different values of $g_1(a)$, which must be clearly distinct from the worst and the best possible performances on the criterion g_1 . The chosen values were $g_1(a) = 100$ and $g_1(a) = 200$.
2. The analysts asked the experts to choose convenable values for q_1 and p_1 with respect to sloping surfaces of 100 and 200. The chosen values were:
 - For $g_1(a) = 100$: $q_1(g_1(a)) = 1$ and $p_1(g_1(a)) = 5$. This means that $1 = 100 \alpha_q + \beta_q$ and $5 = 100 \alpha_p + \beta_p$, respectively.
 - For $g_1(a) = 200$: $q_1(g_1(a)) = 2$ and $p_1(g_1(a)) = 10$. This means that $2 = 200 \alpha_q + \beta_q$ and $10 = 200 \alpha_p + \beta_p$, respectively.
3. Based on the two above points, one defines two systems of two equalities, where the unknown variables are, on the one hand, α_q and β_q and, on the other hand, α_p and β_p . The solutions of such systems are $\alpha_q = 0.01$ and $\beta_q = 0$ as well as $\alpha_p = 0.05$ and $\beta_p = 0$.

These coefficient values mean that the indifference range is very small and differences on the performances strictly greater than 5 % are significant for defining a risk level of a farming parcel on the criterion g_1 .

2.6.2 Managing a Qualitative Criteria

The aim of this section is to present a *coding procedure*, which allows to associate numerical values with the experts'

Fig. 5 Qualitative statements on g_5

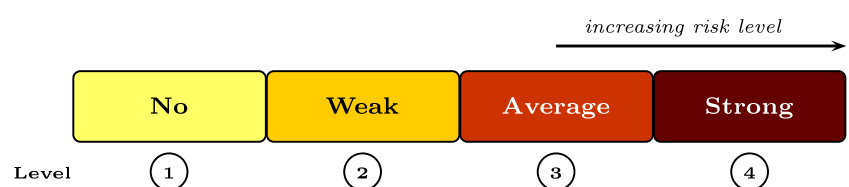


Table 1 Four categories of risk in environmental analysis

Meaning	Category			
	C_1	C_2	C_3	C_4
Risk level	Very high risk	High risk	Intermediate risk	Low or no risk
Improvement works	Absolute priority	Priority	Nonpriority	No action

qualitative statements for the criteria $g_j, j = 2, \dots, 5$, and, at the same time, to make easier the definition of numerical values to be assigned to the indifference and the preference thresholds. The meaning of these thresholds remains the same as for the case of a quantitative criterion. Only the way of proceed is different. Let us notice that the assigned numerical values do not have a cardinal meaning (e.g., a value of 4 does not necessarily mean the double of a value of 2). There is only an ordinal meaning with respect to the differences between any two consecutive levels [38].

Taking into account the knowledge of the studied watershed, the environmental experts defined a unique situation where two farming parcels are indifferent on any criterion of the subset of qualitative criteria, i.e., when they have the same performances. In such a case, the indifference thresholds are null, $q_j = 0, j = 2, \dots, 5$. Nevertheless, a hesitation between indifference and strict preference situations can occur, when the difference between two consecutive levels is too small, which means that the preference thresholds are not null. If two farming parcels have distinct performances with respect to this subset of four criteria, we cannot consider them as indifferent, taking into account the risk levels on such criteria. There exists an intuition in which the parcel better evaluated than the other one is without doubt less risky.

However, taking into account that the environmental experts can hesitate between two consecutive levels for assessing the performances of each farming parcel, it is necessary to differentiate the cases where the differences of performances are really significative of a strict preference, which implies a minimal level of risk. This differentiation can be obtained by coding numerically each scale level of the qualitative criteria. Thus, we can easily choose a (constant) preference thresholds in which the following assertion can be considered as true: *on the comparison of two farming*

parcels, the better evaluated one (the better performance) with respect to the considered criterion is significantly less risky if and only if the difference of the assigned numerical values associated with the performances is strictly greater than the preference threshold p .

In the next paragraphs, we present the coding procedure and the preference threshold, which were chosen in interaction between the environmental experts and the decision-aiding analysts for each one of the qualitative criteria. The analysts decided to assign the lowest value to the lowest risk situation (e.g., level 1 corresponds to the numerical value 1). Thus, all the criteria are to be minimized (decreasing preference direction), since the most preferred risk category is the least risky (C_4) and the least preferred one is the most risky (C_1).

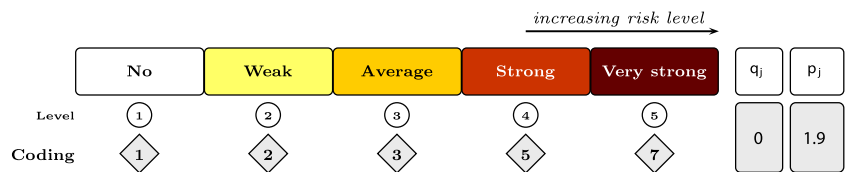
Criterion g_2 —connectivity In this criterion, the environmental experts judged the difference between levels 1 and 2, as well as between levels 2 and 3, as nonsignificant of strict preference, which means that there is a hesitation between indifference and strict preference. But, on the remaining eight pairwise combinations, the strict preference has been judged as significant. Based on these statements, the decision-aiding analysts in interaction with the environmental experts coded the five qualitative levels as presented in Fig. 6, where the preference threshold, p_2 , must verify the inequality $1 < p_2 < 2$. Finally, a value of 1.9 has been chosen as the most appropriate for the role played by this threshold on the definition of the concordance indices (see Appendix 1).

Criterion g_3 —embankment In this criterion, the environmental experts only judged the difference between levels 1 and 2 as nonsignificant of strict preference. But, on the remaining five pairwise combinations, the strict preference has been judged as significant. Based on these statements,

Table 2 Performance of the characteristic reference parcels

C_h	Risk level meaning	b_h	Criteria				
			g_1	g_2	g_3	g_4	g_5
C_1	Very high risk	b_1	200	Very strong	No	Crop 4	Strong
C_2	High risk	b_2	150	Strong	Partial	Crop 3	Average
C_3	Intermediate risk	b_3	100	Average	Passageway	Crop 2	Weak
C_4	Low or no risk	b_4	50	Weak	Closed	Crop 1	No

Fig. 6 Coding procedure and thresholds on g_2



the decision-aiding analyst in interaction with the environmental experts coded the four qualitative levels as presented in Fig. 7, where the preference threshold, p_3 , must also verify the inequality $1 < p_3 < 2$.

Criterion g_4 —crop In this criterion, the environmental experts only judged the difference between levels 3 and 4 as nonsignificant of strict preference. But, on the remaining five pairwise combinations, the strict preference has been judged as significant. Based on these statements, the decision-aiding analyst in interaction with the environmental experts coded the four qualitative levels as presented in Fig. 8, where the preference threshold, p_4 , must also verify the inequality $1 < p_4 < 2$.

Criterion g_5 —bank alteration In this criterion, the environmental experts only judged the difference between levels 1 and 2 as nonsignificant of strict preference. But, on the remaining five pairwise combinations, the strict preference has been judged as significant. Based on these statements, the decision-aiding analyst in interaction with the environmental experts coded the four qualitative levels as presented in Fig. 9, where the preference threshold, p_5 , must verify the inequality $1 < p_5 < 3$.

The numerical value assigned to each preference threshold p depends on the manner in which such a threshold is used on the computation of the credibility indices according to the pairwise comparison framework (see Appendix 1). Thus, a numerical value of 1.9 was chosen for preference threshold associated to the three criteria and a value of 2 for one criterion.

2.7 Modeling the Role of the Criteria

The aim of this section is to provide the *weights of the criteria*, denoted $w_j, j = 1, \dots, 5$, and the *veto thresholds*, denoted $v_j, j = 1, \dots, 5$, which are used for characterizing the respective role of each criterion in the computation of the credibility indices (see Section 2.2).

The relative importance coefficient of each criterion, usually called *weight of the criterion*, has an intrinsic character,

which can be interpreted as a voting power of such a criterion. The higher the intrinsic weight, the more important the criterion is. This means that the numerical value assigned to each intrinsic weight neither depends on the range of the criterion scale nor on the way of coding such a criterion scale [39]. Several techniques can be used for assigning numerical values to the weights of the criteria [40–42].

The chosen technique based on the interaction process between the decision-aiding analyst and the environmental experts was the one which is supported by the SRF software [40]. First, the names of the criteria are written in “white cards” by the analyst. The experts must rank them from the least important criterion to the most important one according to the decision-aiding context (some criteria may have the same importance). Then, the difference of importance between successive levels of the rank obtained previously is expressed through a number of “white cards” introduced between those levels, and it is also recorded how many times the most important criterion is considered to be more important than the least important one in the ranking (Z value). These inputs are introduced in the SRF software, which contains an algorithm for assigning a numerical value to the weights of the criteria by determining the nonnormalized and the normalized weights (see Table 3).

The obtained weights were validated by the environmental experts, after some experiments by spatial visualization of the risk level and taking into account their knowledge about the studied watersheds. Thus, $w_1 = 0.154, w_2 = 0.154, w_3 = 0.231, w_4 = 0.154,$ and $w_5 = 0.307$.

The ELECTRE TRI-C method allows to associate with all or some of the criteria an additional feature, the so-called *veto power*. Giving a veto power to a criterion means that only this criterion has the possibility to disagree with an assignment of a farming parcel to a given category. In this case, the performance of the farming parcel on such a criterion corresponds to a higher risk level than the one defined by the category. The environmental experts have judged that a farming parcel with a *strong bank alteration* cannot be assigned to C_3 or C_4 , and it is necessarily assigned to C_1 or C_2 . Similarly, a farming parcel with an *average*

Fig. 7 Coding procedure and thresholds on g_3

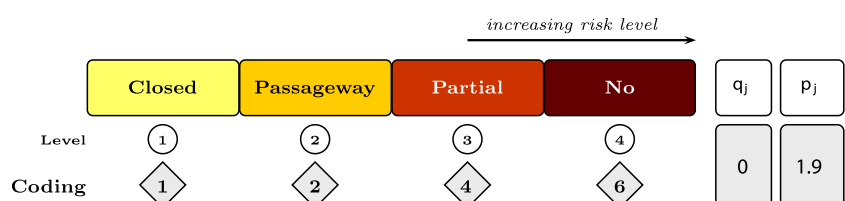
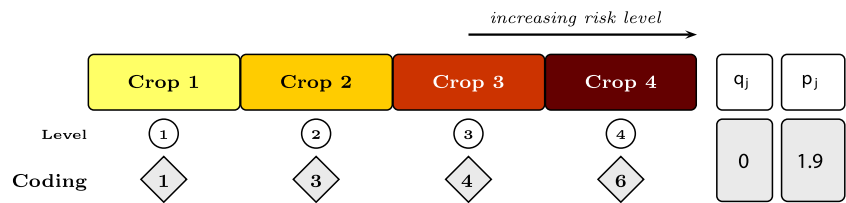


Fig. 8 Coding procedure and thresholds on g_4



bank alteration cannot be assigned to C_4 . These three situations are appropriately modeled by a *veto threshold* on the criterion g_5 , taking into account the risk level associated with each category. In this criterion g_5 , the environmental experts judged that the difference between levels 1 and 3, levels 1 and 4, as well as levels 2 and 4 can produce a veto effect. Based on these statements, the veto threshold, v_5 , must verify the inequality $3 < v_5 < 4$. Finally, $v_5 = 3.9$ has been validated by the environmental experts as the most appropriate within our modeling framework. Moreover, it was not relevant to assign veto thresholds to the criteria $g_j, j = 1, \dots, 4$.

2.8 Relationship between the GIS and the MCDA Model

As stated in Section 2.4, the farming parcels are the objects of the decision concerning the risk of erosion and corresponding damage on the streams. The aim of this section is to present the relationship between the GIS and the decision-aiding sorting model on the evaluation of the farming parcels.

The linking between GIS and environmental assessing models applied within an agricultural watershed was previously made in many situations: implementing an MCDA in order to assess the impact of agricultural practices on the environmental components [6]; locating wind farms in the UK [43]; evaluating and mapping erosion and landslide hazards [44]; identifying suitable areas for the production of maize and potato crops in Central Mexico [45]; identifying priority areas for soil and water management in a watershed [46]; assessing nonpoint source pollution [47]; assessing an integrated river basin [48]; and evaluating risk of soil loss, water ponding, and sediment deposition in an agricultural Mediterranean watershed [16].

The relationship between the GIS and the MCDA model is presented in Fig. 10. Different types of geographic cover were developed by using ArcInfo® and ArcGis®,

including the digitization of the cadastral plan and networks by making use of the DEM of 50 m interpolated to 10 m. For building the GIS, the data concerning, for instance, topography, land use, practices of each farming parcel, and microrelief (embankments) were spatially analyzed. The observations in the field of the streams, the hydrographic network, the road network, the deterioration of the banks, and other relevant elements were performed by the agronomists from the team. Some inquiries were applied to the farmers for getting the information regarding the practices. The local environmental actors have explained the last arrangements made into the streams.

Figure 11 presents the spatial visualization of the performances of the farming parcels according to the criteria $g_j, j = 2, \dots, 5$, for the last year of observations in the fields (2008), after several arrangements from the previous year (2007). The GIS was used for supporting the evaluation of the farming parcels according to the criterion g_1 (sloping surface) as well as for the spatial visualization of the performance of each farming parcel and the related risk category provided by the ELECTRE TRI-C method. Therefore, the MCDA model and the geomatics model (GIS) were used in a complementary way.

The values of slope indicator were extracted from the DEM with the GIS. For the remaining criteria, their values were obtained from the observations in the field of each farming parcel. Such observations were introduced on the GIS for a spatial visualization and control. Then, each observation was included in the performance table according to the set of criteria, which is presented in Appendix 2, regarding the watershed of Violettes, which is the object of the analysis in this paper. In such a performance table, a coding procedure (see Section 2.6.2) was used for replacing the experts' qualitative statements (see Figs. 2, 3, 4, and 5) by numerical values in order to facilitate the pairwise comparison within the ELECTRE framework. After the modeling procedure, the GIS was used for representing the risk

Fig. 9 Coding procedure and thresholds on g_5

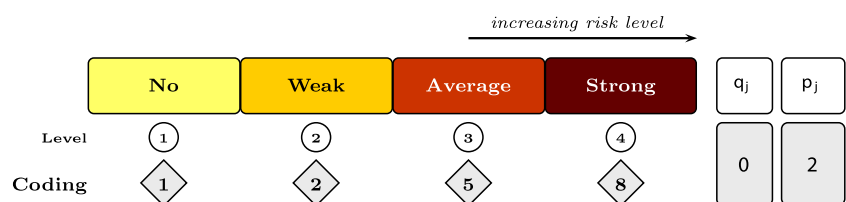


Table 3 On providing the weights of the criteria

Criteria	Rank ^a	White cards ^b	Nonnormalized weights	Normalized weights ^c
g_1	1		1	0.154
g_2	1		1	0.154
g_4	1		1	0.154
		2		
g_3	2		1.5	0.231
		2		
g_5	3		2	0.307

^aWorst rank = 1 and best rank = 3

^bZ value = 2

^cFor obtaining a set of weights summing up to 1

evaluation and assignment of each farming parcel to a risk category.

3 Results and Discussion

The aim of this section is to present the assignment results, including their spatial visualization, and to discuss some particular points of the decision-aiding sorting model defined in Section 2.

3.1 Choosing a Credibility Level

Before presenting the assignment results, a crucial step is related to the analysis of the chosen credibility level, denoted λ . This level is a minimum degree of credibility according to the risk of erosion, which is considered or judged necessary by the environmental experts to validate or not the statement “ a outranks a' ” (meaning that a is not more risky than a' , taking into account conjointly the five performances of the two farming parcels to be compared).

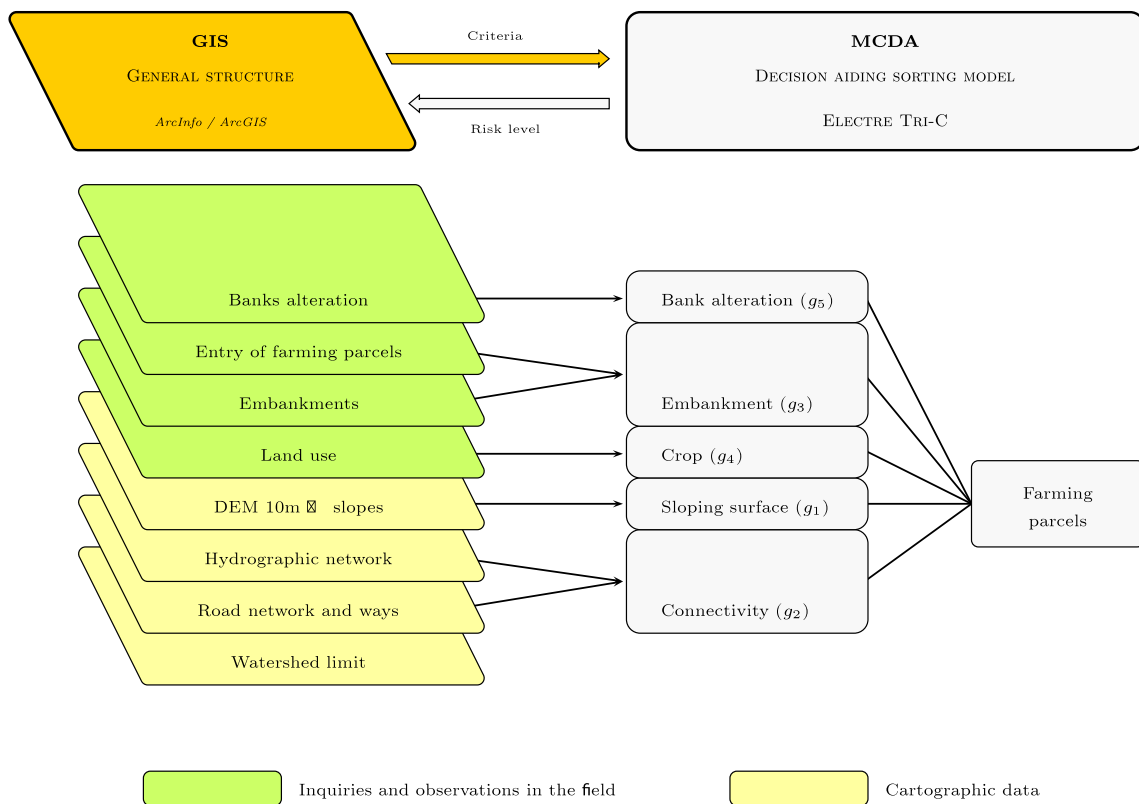
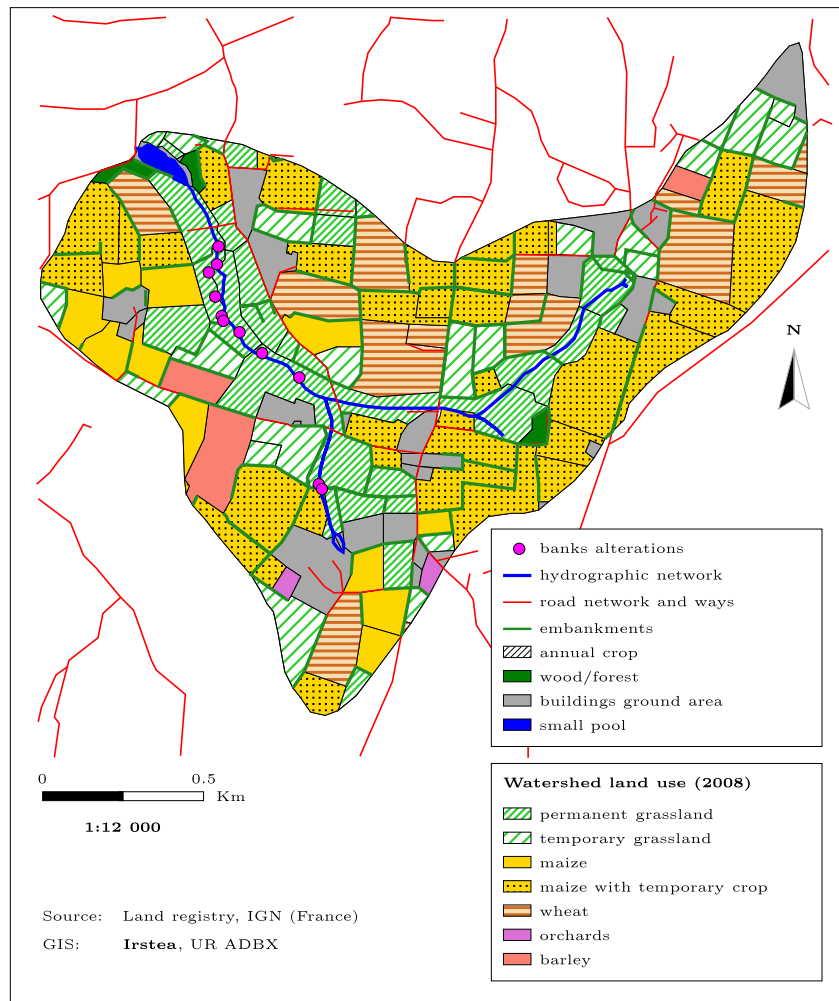


Fig. 10 The GIS general structure and the links to the MCDA model

Fig. 11 Land use in the watershed of Violettes



In other words, a could not be assigned to a category more risky than the one a' is assigned to). This minimum credibility level takes a value within the range $[0.5, 1]$ (see Appendix 1 and Definitions 1 and 2).

According to some preliminary assignment results, a credibility level, λ , was chosen by the decision-aiding analysts in interaction with the environmental experts, taking into account the following considerations:

1. An outranking statement cannot be validated in the two following cases:
 - (a) When only a subset of two criteria, including g_5 , is favorable with such an outranking statement.
 - (b) When only a subset of three criteria, except g_5 , is favorable with such an outranking statement.
2. An outranking statement must be validated according to one of the two following cases:
 - (a) When at least a subset of three criteria, including g_3 and g_5 , is favorable with such an outranking statement.

- (b) When the subset of the remaining four criteria, except g_5 , is favorable with such an outranking statement.

Taking into account the weights assigned to the criteria (see Table 3), cases (a.1) and (a.2) imply that $\lambda > 0.307 + 0.231 = 0.538$ and $\lambda > 0.231 + 0.154 + 0.154 = 0.539$, respectively. In other words, 0.54 is the lowest credibility level accepted for λ . Cases (b.1) and (b.2) imply that $\lambda \leq 0.307 + 0.231 + 0.154 = 0.692$ and $\lambda \leq 0.231 + 0.154 + 0.154 + 0.154 = 0.693$, respectively. In other words, 0.69 is the highest credibility level accepted for λ . Based on this analysis, a credibility level can be chosen within the following range: $0.54 \leq \lambda \leq 0.69$.

However, some of such credibility levels can allow to validate an outranking statement (see case (b.1) or (b.2)), when a criterion contributes to the computation of the concordance index (see Appendix 1) with a weak percentage of its weight. This is true when there is a hesitation between indifference and strict preference, which opposes to such an outranking statement. For this reason, the environmental

experts validated $\lambda = 0.60$ as the minimum value for the credibility level. Another possible credibility level was chosen by environmental experts, $\lambda = 0.65$, after some tests regarding the spatial visualization of the assignment results.

3.2 ELECTRE TRI-C Assignment Results

Taking into account two validated chosen credibility levels, $\lambda = 0.60$ and $\lambda = 0.65$, the ELECTRE TRI-C assignment results and the validated risk category by the environmental experts (after knowing the results of ELECTRE TRI-C) are presented in Table 8 (see Appendix 3). A brief summary of these assignment results is presented in Table 4. A farming parcel can be assigned to one risk category by ELECTRE TRI-C or to a range of at least two consecutive risk categories. However, the environmental experts can validate or not these assignment results. If the validated category is the same as the one provided by ELECTRE TRI-C or if it belongs to the range of categories, then no disagreement occurs.

Based on the assignment results validated by the environmental experts, the categories C_1 and C_2 represent 16 (14.3 %) of the farming parcels, where the risk is significant for immediate arrangements. The category C_4 , where there is no problem of risk of erosion, has received almost 43 (38.4 %). The category C_3 has received 53 (47.3 %) of the farming parcels. When $\lambda = 0.60$, the number of disagreements corresponds to 6 (5.4 %) of the farming parcels, where ELECTRE TRI-C provides C_3 and the environmental experts validate C_2 . When $\lambda = 0.65$, such disagreements decrease to 1 (0.9 %). Additional justifications will be provided in Section 3.4.

3.3 Spatial Visualization of the Assignment Results

This section presents the spatial visualization of the ELECTRE TRI-C assignment results by using the interaction between the MCDA model and the GIS spatial structure (see Fig. 10).

Figure 12 presents the assignment results, which were validated by the environmental experts as analyzed in Section 3.2. Before trying to establish some types of farming parcels, this figure clearly shows that the *very-high- and high-risk areas* are located alongside or closer to the stream. On the contrary, the *low- or no-risk area* are mainly located far from the stream. Moreover, the *intermediate-risk area* occupies a significant part of the watershed.

Figure 12 also allows to visualize the annual crop area from the studied watersheds. This area represents 57.2 % of total number of farming parcels from the watershed of Violettes. The assignment results allow to conclude that no annual crop area was assigned to C_1 , 4.5 % to C_2 , 37.5 % to C_3 , and 15.2 % to C_4 .

Based on the validated assignment results, according to the risk levels, the farming parcels can be characterized a posteriori as follows:

1. *Very high risk*: Pasture, crossed by or alongside the stream, with uncontrolled access to animal drinking area, which produces damage on the banks
2. *High risk*: Cultivated (maize), close to the stream, with no downstream embankment.
3. *Intermediate risk*: Cultivated, not far from or connected to the stream by a road or a way
4. *Low risk*: Cultivated, far from the stream, with no downstream embankment, but connected by a road or a way

3.4 Discussion and Validation of the Model

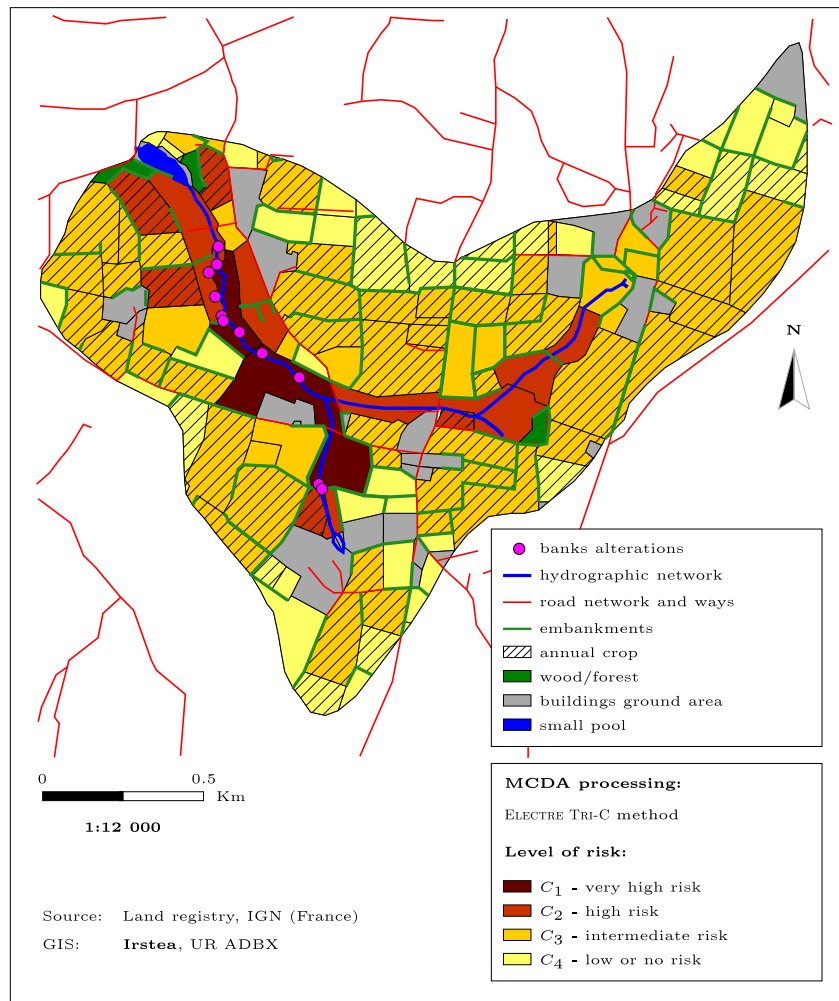
The aim of this section is to discuss the assignment results in interaction with the environmental experts and local actors (briefly presented in Sections 3.2 and 3.3) and the validation of the model.

Many authors in the world use the Universal Soil Loss Equation (USLE) equation, an empirical model created by Wischmeier and Smith in the USA for quantify the soil erosion [14]. This model is built to calculate average soil losses in a long period, in specific situations of the sheet erosion

Table 4 Summary of the assignment results

C_h	ELECTRE TRI-C ($\lambda = 0.60$)		ELECTRE TRI-C ($\lambda = 0.65$)	
	Farming parcels, no. (%)	Disagreements, no. (%)	Farming parcels, no. (%)	Disagreements, no. (%)
C_1	3 (2.7)	0 (0.0)	3 (2.7)	0 (0.0)
C_2	4 (3.6)	0 (0.0)	4 (3.6)	0 (0.0)
[C_2, C_3]	5 (4.5)	0 (0.0)	15 (13.4)	0 (0.0)
C_3	55 (49.1)	6 (5.4)	47 (42.0)	1 (0.9)
[C_3, C_4]	11 (9.8)	0 (0.0)	5 (4.5)	0 (0.0)
[C_2, C_4]	0 (0.0)	0 (0.0)	2 (1.8)	0 (0.0)
C_4	34 (30.3)	0 (0.0)	36 (32.1)	0 (0.0)
Total	112 (100.0)		112 (100.0)	

Fig. 12 Spatial visualization of the assignment results (with annual crop)



and rill. But, it cannot be used for assessing the production of particles coming from the banks of streams or rivers.

In our study, the erosion of banks due to the cattle is essential in the grasslands affected by this phenomenon. We were concerned with the assessment of the degree of the alteration banks, the state of embankments, and the presence or not of temporary crops, which contributes to the TSS transfers. This explains the choice of an MCDA model and its application to our small watershed. Another important aspect is that the USLE equation is generally used on a large watershed, but with difficulties in small watersheds as the Violettes Watershed (225 ha), because data are not often available, and results are not reliable in this case [49, 50]. Consequently, since a model cannot be used to validate the results of another model, we could not use the USLE equation to compare zoning risk maps obtained with an MCDA model.

Before knowing the assignment results provided by ELECTRE TRI-C, the environmental experts and local actors provided a first proposal of the assignment of each one of the 112 farming parcels. This first holistic assignment

was mainly based on the analysis of the one or the two most important criteria. The comparison of such assignment results to the ones provided by ELECTRE TRI-C is presented in Table 5.

After the presentation of the ELECTRE TRI-C assignment results, the environmental experts and local actors have changed the assignment of several farming parcels. The impact of such changes is presented in Table 6, which must be compared to similar results in Table 5. Moreover, the assignment results presented in Table 6 clearly show an increasing degree of accuracy in comparison to the first proposal of the environmental experts and local actors.

According to the ACR I measure, when using $\lambda = 0.65$, the sorting accuracy has increased from 52.7 to 79.5 %, which means that for the subset of farming parcels assigned to only one category (80.4 %), the overall accuracy is 98.9 %. With the same chosen credibility level, according to the ACR T measure, the sorting accuracy has increased from 67.9 to 99.1 %. These simple results show that ELECTRE TRI-C can become a useful tool for analyzing environmental risk problems.

Table 5 Preliminary accuracy results

Version	UC ^a , no. (%)	ACR I ^b , no. (%)	MC ^c , no. (%)	ACR II ^d , no. (%)	ACR T ^e , no. (%)
$\lambda = 0.60$	96 (85.7)	59 (52.7)	16 (14.3)	15 (13.4)	74 (66.1)
$\lambda = 0.65$	90 (80.4)	59 (52.7)	22 (19.6)	17 (15.2)	76 (67.9)

^aUC = Farming parcels assigned to a unique category by ELECTRE TRI-C

^bACR I = Sorting accuracy of the type I: when ELECTRE TRI-C provides a unique category (UC), which is the same as the one validated by the environmental experts

^cMC = Farming parcels assigned to more than one category by ELECTRE TRI-C

^dACR II = Sorting accuracy of the type II: when ELECTRE TRI-C provides a range of at least two categories (MC), which contains the one validated by the environmental experts

^eACR T = ACR I + ACR II

According to the assignment results finally validated by the environmental experts and local actors ($\lambda = 0.65$), only the farming parcel a_{110} was assigned to a category outside the respective range provided by ELECTRE TRI-C, i.e., C_2 instead of C_3 . In such a case, a_{110} was empirically assigned, taking into account the land use of the adjacent farming parcels. The farming parcel a_{23} is crossed by the hydrographic network and the assignment validated by the environmental experts and local actors was C_3 , which belongs to the range [C_2, C_3] provided by ELECTRE TRI-C. In such a case, a_{23} is located at the beginning of the stream and it is well protected by the embankments since 2007. These two examples of farming parcels allow to highlight the validation logic of the environmental experts and local actors. This validation is based on a good knowledge of the studied watershed with respect to the erosion phenomena, the comprehensive role of the two most important criteria, and the configuration of the spatial visualization of the assignment results.

Our study was done after some improvement works implemented in 2007: enclosures around the stream and drinkers for animals, which have decreased the risk. However, some watering places persist (e.g., see the banks alteration in Fig. 12), where the level of risk is very high or high (C_1 and C_2 , respectively). The farming parcels assigned to C_4 are covered with grassland and cultures, but mainly far from the stream. There is no risk problems with them. A considerable number of farming parcels were assigned to C_3 , since such a risk category has some borderlines effects for changing from C_2 or C_4 .

The size of the farming parcels has often a weak influence on the results. In such a case, the risk of erosion depends on two main factors: the vulnerability of soils and the pressure due to the land use and practices. The partition of the studied area was made with respect to the exploitation criterion and to the type of land use. A third reason can also be added to this analysis, which is related to a national agricultural environmental campaign in France. Thus, it seems more easy to protected a small farming parcel than a largest one.

4 Conclusions

The assignment results were provided within a constructive approach, which means that the decision-aiding sorting model was co-constructed by interaction between the decision-aiding analysts and the environmental experts. In our study, a major part of this interaction was done during several years (from 2003 to 2008), within a framework of a relative comparison approach instead of an absolute one. Due to some difficulties related to a considerable number of farming parcels, a different decision-aiding model was proposed, which represents a major advantage for zoning the farming parcels to several risk categories.

We have shown that ELECTRE TRI-C can become an useful tool for assigning the farming parcels to a set of environmental risk categories. The farming parcels are evaluated on a set of criteria. The validation of the assignment results was made on two watersheds. Moreover, in this paper, we only presented the ones from the watershed

Table 6 Validation of the credibility level, λ

Version	UC ^a , no. (%)	ACR I ^a , no. (%)	MC ^a , no. (%)	ACR II ^a , no. (%)	ACR T ^a , no. (%)
$\lambda = 0.60$	96 (85.7)	90 (80.4)	16 (14.3)	16 (14.3)	106 (94.6)
$\lambda = 0.65$	90 (80.4)	89 (79.5)	22 (19.6)	22 (19.6)	111 (99.1)

^aSee remarks in Table 5

of Violettes. According to the accuracy sorting results from Table 6, the proposed decision-aiding sorting model is well adapted to the environmental decision problems. Thus, several types of farming parcels were characterized a posteriori, and several arrangement works were made to restore the best agricultural practices for protecting the habitat of the salmonid fishes.

Despite the recommendations of this study mainly based on the ELECTRE III method in 2008 [32], the assignment results provided by ELECTRE TRI-C were validated by the same environmental experts. The results already have a strong impact on the agricultural practices of the farmers belonging to the studied watersheds, and relevant arrangements (fences along the banks, rehabilitation of embankments, drinking trough beside the streams) were made since 2006. The results of this study were also applied for other adjacent watersheds as a useful tool for implementing public agricultural policies to help the environmental managers in protecting the reproduction habitat of the salmonid fishes as well as in preserving the rural landscape in the Low Normandy (France) region.

For a new project in the same problem, it could be possible to assign the farming parcels to five risk categories. This possibility could increase the accuracy of results. In such a way, the qualitative scale of evaluation of each farming parcel must take into account a reasonable number of possible performances in which the characteristic reference actions must play a relevant role when applying ELECTRE TRI-C.

For future research, we intend to apply the same methodology provided in this paper to other largest watersheds for assessment of the risk zones, with other issues as pesticides and nitrogen. This methodology could be applied to bigger watersheds with a scaling change that means that the basic geographical units (here farming parcels) could be replaced by others, for instance, by groups. In the same time, the problem of changing scale will be in the debate.

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Appendix 1: Definition of the Outranking Credibility Index

Let us assume, without loss of generality, that all the criteria $g_j \in F$ are to be maximized, which means that

the preferences increase when the criteria performances increase too. Consider two farming parcels, denoted a and a' . When using the discriminating thresholds defined in Section 2.6, the following binary relations can be derived for each criterion [30]:

1. If $|g_j(a) - g_j(a')| \leq q_j$, then a is indifferent to a' according to g_j , denoted $a I_j a'$. Let $C(a I a')$ be the subset of criteria such that $a I_j a'$.
2. If $g_j(a) - g_j(a') > p_j$, then a is strictly preferred to a' according to g_j , denoted $a P_j a'$. Let $C(a P a')$ be the subset of criteria such that $a P_j a'$.
3. If $q_j < g_j(a) - g_j(a') \leq p_j$, then a is weakly preferred to a' (a hesitation between indifference and strict preference), denoted $a Q_j a'$. Let $C(a Q a')$ be the subset of criteria such that $a Q_j a'$.

The credibility of the comprehensive outranking of a over a' , denoted $\sigma(a, a')$, which reflects the strength of the statement “ a outranks a' ” (a is at least as good as a') when taking all the criteria from F into account, is defined as follows:

$$\sigma(a, a') = \begin{cases} c(a, a') \prod_{j=1}^n \frac{1 - d_j(a, a')}{1 - c(a, a')} & \text{if } d_j(a, a') > c(a, a'), \\ c(a, a') & \text{otherwise,} \end{cases} \tag{1}$$

where,

$$d_j(a, a') = \begin{cases} 1 & \text{if } g_j(a) - g_j(a') < -v_j, \\ \frac{g_j(a) - g_j(a') + p_j}{p_j - v_j} & \text{if } -v_j \leq g_j(a) - g_j(a') < -p_j, \\ 0 & \text{if } g_j(a) - g_j(a') \geq -p_j. \end{cases} \tag{2}$$

$$c(a, a') = \sum_{j \in C(a P a')} w_j + \sum_{j \in C(a Q a')} w_j + \sum_{j \in C(a I a')} w_j + \sum_{j \in C(a' Q a)} w_j \varphi_j, \tag{3}$$

$$\varphi_j = \frac{g_j(a) - g_j(a') + p_j}{p_j - q_j} \in [0, 1]. \tag{4}$$

Therefore, $\sigma(a, a')$ is obtained from an overall aggregating function, which is based on a concordance and nondiscordance principle. This credibility index represents the sum of the voting power of the criteria, which is concordant with the assertion “ a is at least as good as a' ,” while taking into account the reducing effect by the criteria which are discordant with such an assertion. As presented above, this aggregation procedure requires the performances of each farming parcel on each criterion, denoted $g_j(a)$, $j = 1, \dots, n$; the weights of the criteria, denoted w_j (we assume, without loss of generality, that $\sum_{j=1}^n w_j = 1$); the indifference, the preference, and, possibly, the veto thresholds, denoted q_j , p_j , and v_j , respectively, such that $v_j \geq p_j \geq q_j \geq 0$.

Appendix 2: Performances of the Farming Parcels from Violettes

Table 7 Performances of the farming parcels

Farming parcel	Criteria					Farming parcel	Criteria				
	<i>g</i> ₁	<i>g</i> ₂	<i>g</i> ₃	<i>g</i> ₄	<i>g</i> ₅		<i>g</i> ₁	<i>g</i> ₂	<i>g</i> ₃	<i>g</i> ₄	<i>g</i> ₅
<i>a</i> ₁	1.0	2	4	3	1	<i>a</i> ₅₇	214.4	3	4	6	1
<i>a</i> ₂	10.1	2	1	1	1	<i>a</i> ₅₈	124.7	5	4	1	1
<i>a</i> ₃	8.3	2	6	1	1	<i>a</i> ₅₉	576.6	7	6	1	5
<i>a</i> ₄	20.3	2	4	1	1	<i>a</i> ₆₀	228.0	5	4	1	1
<i>a</i> ₅	219.5	3	4	4	1	<i>a</i> ₆₁	76.6	3	6	1	1
<i>a</i> ₆	49.9	7	6	4	2	<i>a</i> ₆₂	360.5	3	1	4	1
<i>a</i> ₇	208.9	7	6	1	8	<i>a</i> ₆₃	87.7	1	4	4	1
<i>a</i> ₈	67.7	2	1	4	1	<i>a</i> ₆₄	144.9	2	2	3	1
<i>a</i> ₉	141.1	3	4	4	1	<i>a</i> ₆₅	57.3	5	2	1	1
<i>a</i> ₁₀	533.6	3	4	4	1	<i>a</i> ₆₆	52.6	5	6	1	1
<i>a</i> ₁₁	134.9	1	4	4	1	<i>a</i> ₆₇	249.7	3	4	3	1
<i>a</i> ₁₂	91.6	1	4	4	1	<i>a</i> ₆₈	121.1	3	4	4	1
<i>a</i> ₁₃	129.7	1	4	4	1	<i>a</i> ₆₉	110.2	1	6	1	1
<i>a</i> ₁₄	44.8	1	4	3	1	<i>a</i> ₇₀	97.6	1	4	1	1
<i>a</i> ₁₅	8.3	1	4	3	1	<i>a</i> ₇₁	0.9	1	4	4	1
<i>a</i> ₁₆	14.8	1	6	1	1	<i>a</i> ₇₂	244.2	2	4	4	1
<i>a</i> ₁₇	53.8	1	1	1	1	<i>a</i> ₇₃	184.3	2	4	1	1
<i>a</i> ₁₈	124.9	1	1	1	1	<i>a</i> ₇₄	72.4	2	6	1	1
<i>a</i> ₁₉	89.4	1	1	4	1	<i>a</i> ₇₅	273.9	7	6	1	1
<i>a</i> ₂₀	289.2	1	4	3	1	<i>a</i> ₇₆	289.6	7	6	1	8
<i>a</i> ₂₁	66.4	1	6	1	1	<i>a</i> ₇₇	260.9	5	1	1	1
<i>a</i> ₂₂	128.5	5	4	1	1	<i>a</i> ₇₈	225.8	3	4	3	1
<i>a</i> ₂₃	176.4	7	6	1	1	<i>a</i> ₇₉	50.1	2	2	6	1
<i>a</i> ₂₄	55.0	3	4	1	1	<i>a</i> ₈₀	29.3	1	4	1	1
<i>a</i> ₂₅	135.4	7	6	1	2	<i>a</i> ₈₁	143.2	1	4	6	1
<i>a</i> ₂₆	161.4	7	6	1	2	<i>a</i> ₈₂	111.9	1	2	6	1
<i>a</i> ₂₇	163.1	7	6	1	1	<i>a</i> ₈₃	84.5	1	6	6	1
<i>a</i> ₂₈	244.8	5	4	4	1	<i>a</i> ₈₄	80.0	2	4	4	1
<i>a</i> ₂₉	215.1	3	4	4	1	<i>a</i> ₈₅	264.8	1	6	4	1
<i>a</i> ₃₀	49.8	3	4	6	1	<i>a</i> ₈₆	120.8	1	6	4	1
<i>a</i> ₃₁	66.4	3	1	1	1	<i>a</i> ₈₇	103.7	1	6	6	1
<i>a</i> ₃₂	150.4	3	1	6	1	<i>a</i> ₈₈	33.8	1	1	1	1
<i>a</i> ₃₃	63.0	2	6	6	1	<i>a</i> ₈₉	54.3	5	2	4	1
<i>a</i> ₃₄	141.1	2	4	1	1	<i>a</i> ₉₀	75.9	3	1	1	1
<i>a</i> ₃₅	33.4	2	6	1	1	<i>a</i> ₉₁	0.5	1	4	6	1
<i>a</i> ₃₆	30.5	2	6	4	1	<i>a</i> ₉₂	12.0	7	6	1	1
<i>a</i> ₃₇	100.5	7	6	4	2	<i>a</i> ₉₃	8.0	5	6	1	1
<i>a</i> ₃₈	59.9	7	6	1	2	<i>a</i> ₉₄	51.6	7	6	1	1
<i>a</i> ₃₉	99.3	5	1	1	1	<i>a</i> ₉₅	4.4	3	6	4	1
<i>a</i> ₄₀	24.7	3	4	1	1	<i>a</i> ₉₆	38.9	3	6	1	1
<i>a</i> ₄₁	33.0	3	4	4	1	<i>a</i> ₉₇	4.8	1	4	3	1
<i>a</i> ₄₂	117.6	5	4	4	1	<i>a</i> ₉₈	66.0	1	4	3	1
<i>a</i> ₄₃	207.0	7	6	1	2	<i>a</i> ₉₉	50.8	3	4	3	1
<i>a</i> ₄₄	431.3	5	4	3	1	<i>a</i> ₁₀₀	104.0	3	4	4	1
<i>a</i> ₄₅	62.0	3	6	3	1	<i>a</i> ₁₀₁	45.9	2	6	6	1

Table 7 (continued)

Farming parcel	Criteria					Farming parcel	Criteria				
	g_1	g_2	g_3	g_4	g_5		g_1	g_2	g_3	g_4	g_5
a_{46}	283.9	5	2	1	1	a_{102}	187.1	2	4	3	1
a_{47}	170.0	3	4	3	1	a_{103}	12.0	1	1	1	1
a_{48}	54.1	2	6	3	1	a_{104}	39.0	1	4	4	1
a_{49}	43.2	2	2	4	1	a_{105}	257.0	7	6	1	1
a_{50}	21.8	2	6	4	1	a_{106}	91.4	7	6	1	2
a_{51}	15.8	2	2	4	1	a_{107}	135.8	5	6	6	1
a_{52}	6.7	1	4	1	1	a_{108}	108.2	5	6	4	1
a_{53}	31.3	2	1	4	1	a_{109}	213.4	5	6	3	1
a_{54}	98.6	1	1	3	1	a_{110}	155.6	5	6	4	1
a_{55}	60.4	2	6	4	1	a_{111}	95.9	5	6	1	1
a_{56}	112.7	2	6	4	1	a_{112}	466.6	7	6	1	1

Appendix 3: Assignment Results

Table 8 ELECTRE TRI-C versus environmental expert’s assignment results

Farming parcel	Annual crop	ELECTRE TRI-C ($\lambda = 0.60$)				ELECTRE TRI-C ($\lambda = 0.65$)				Environmental experts
		No. of I^λ	No. of R^λ	No. of C_h	Category	No. of I^λ	No. of R^λ	No. of C_h	Category	
a_1	Yes	2	0	2	$[C_3, C_4]$	0	0	1	C_4	C_4
a_2	No	1	0	1	C_4	1	0	1	C_4	C_4
a_3	No	1	0	1	C_4	1	0	1	C_4	C_4
a_4	No	1	0	1	C_4	1	0	1	C_4	C_4
a_5	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a_6	Yes	0	0	1	C_2	0	1	1	C_2	C_2
a_7	No	1	0	1	C_1	1	0	1	C_1	C_1
a_8	Yes	1	0	1	C_4	1	0	1	C_4	C_4
a_9	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a_{10}	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a_{11}	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a_{12}	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a_{13}	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a_{14}	Yes	1	0	1	C_4	0	0	1	C_4	C_4
a_{15}	Yes	1	0	1	C_4	0	0	1	C_4	C_4
a_{16}	No	1	0	1	C_4	1	0	1	C_4	C_4
a_{17}	No	1	0	1	C_4	1	0	1	C_4	C_4
a_{18}	No	1	0	1	C_4	1	0	1	C_4	C_4
a_{19}	Yes	1	0	1	C_4	1	0	1	C_4	C_4
a_{20}	Yes	1	0	1	C_3	0	0	1	C_3	C_3
a_{21}	No	1	0	1	C_4	0	0	1	C_4	C_4
a_{22}	No	0	0	1	C_3	0	0	1	C_3	C_3
a_{23}	No	0	1	2	$[C_2, C_3]$	0	1	2	$[C_2, C_3]$	C_3
a_{24}	No	0	0	1	C_3	0	0	1	C_3	C_3
a_{25}	No	0	0	1	C_3	0	1	2	$[C_2, C_3]$	C_2
a_{26}	No	0	1	1	C_2	0	1	1	C_2	C_2
a_{27}	No	0	1	2	$[C_2, C_3]$	0	1	2	$[C_2, C_3]$	C_2

Table 8 (continued)

Farming parcel	Annual crop	ELECTRE TRI-C ($\lambda = 0.60$)				ELECTRE TRI-C ($\lambda = 0.65$)				Environmental experts
		No. of I^λ	No. of R^λ	No. of C_h	Category	No. of I^λ	No. of R^λ	No. of C_h	Category	
a28	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a29	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a30	Yes	1	0	1	C_3	0	0	1	C_3	C_3
a31	No	1	0	1	C_4	1	0	1	C_4	C_4
a32	Yes	2	0	2	$[C_3, C_4]$	1	0	1	C_3	C_3
a33	Yes	1	0	1	C_3	0	2	2	$[C_2, C_3]$	C_3
a34	No	2	0	2	$[C_3, C_4]$	0	1	2	$[C_3, C_4]$	C_4
a35	No	1	0	1	C_4	1	0	1	C_4	C_4
a36	Yes	2	0	2	$[C_3, C_4]$	0	0	1	C_4	C_4
a37	Yes	0	0	1	C_2	0	1	1	C_2	C_2
a38	No	1	0	1	C_3	0	1	2	$[C_2, C_3]$	C_2
a39	No	1	0	1	C_4	1	0	1	$0C_4$	C_4
a40	No	1	0	1	C_4	1	0	1	C_4	C_4
a41	Yes	1	0	1	C_3	1	0	1	C_3	C_3
a42	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a43	No	0	1	1	C_2	0	1	1	C_2	C_2
a44	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a45	Yes	1	0	1	C_3	1	0	1	C_3	C_3
a46	No	1	0	1	C_3	1	0	1	C_3	C_3
a47	Yes	1	0	1	C_3	0	0	1	C_3	C_3
a48	Yes	1	0	1	C_3	0	0	1	C_3	C_3
a49	Yes	2	0	2	$[C_3, C_4]$	1	0	1	C_4	C_4
a50	Yes	2	0	2	$[C_3, C_4]$	0	0	1	C_4	C_4
a51	Yes	2	0	2	$[C_3, C_4]$	1	0	1	C_4	C_4
a52	No	1	0	1	C_4	1	0	1	C_4	C_4
a53	Yes	1	0	1	C_4	1	0	1	C_4	C_4
a54	Yes	1	0	1	C_4	1	0	1	C_4	C_4
a55	Yes	1	0	1	C_3	0	0	1	C_3	C_3
a56	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a57	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a58	No	0	0	1	C_3	0	0	1	C_3	C_3
a59	No	0	0	1	C_1	0	0	1	C_1	C_1
a60	No	0	0	1	C_3	0	0	1	C_3	C_3
a61	No	0	0	1	C_3	0	0	1	C_3	C_3
a62	Yes	2	0	2	$[C_3, C_4]$	1	0	1	C_3	C_3
a63	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a64	Yes	1	0	1	C_3	1	0	1	C_3	C_3
a65	No	0	0	1	C_4	0	0	1	C_4	C_4
a66	No	0	0	1	C_3	0	1	1	C_3	C_3
a67	Yes	1	0	1	C_3	0	0	1	C_3	C_3
a68	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a69	No	1	0	1	C_4	0	1	2	$[C_3, C_4]$	C_4
a70	No	1	0	1	C_4	0	0	1	C_4	C_4
a71	Yes	1	0	1	C_4	0	0	1	C_4	C_4
a72	Yes	0	0	1	C_3	0	0	1	C_3	C_3
a73	No	2	0	2	$[C_3, C_4]$	0	1	2	$[C_3, C_4]$	C_4
a74	No	1	0	1	C_4	0	0	1	C_4	C_4

Table 8 (continued)

Farming parcel	Annual crop	ELECTRE TRI-C ($\lambda = 0.60$)				ELECTRE TRI-C ($\lambda = 0.65$)				Environmental experts
		No. of I^λ	No. of R^λ	No. of C_h	Category	No. of I^λ	No. of R^λ	No. of C_h	Category	
a75	No	0	1	2	[C ₂ , C ₃]	0	1	2	[C ₂ , C ₃]	C ₂
a76	No	1	0	1	C ₁	1	0	1	C ₁	C ₁
a77	No	1	0	1	C ₄	1	0	1	C ₄	C ₄
a78	Yes	1	0	1	C ₃	0	0	1	C ₃	C ₃
a79	Yes	2	0	2	[C ₃ , C ₄]	1	0	1	C ₄	C ₄
a80	No	1	0	1	C ₄	1	0	1	C ₄	C ₄
a81	Yes	0	0	1	C ₃	0	0	1	C ₃	C ₃
a82	Yes	1	0	1	C ₃	1	0	1	C ₃	C ₃
a83	Yes	0	0	1	C ₃	0	2	2	[C ₂ , C ₃]	C ₃
a84	Yes	1	0	1	C ₃	0	0	1	C ₃	C ₃
a85	Yes	0	0	1	C ₃	0	1	2	[C ₂ , C ₃]	C ₃
a86	Yes	0	0	1	C ₃	0	0	1	C ₃	C ₃
a87	Yes	0	0	1	C ₃	0	1	2	[C ₂ , C ₃]	C ₃
a88	No	1	0	1	C ₄	1	0	1	C ₄	C ₄
a89	Yes	1	0	1	C ₃	1	0	1	C ₃	C ₃
a90	No	1	0	1	C ₄	1	0	1	C ₄	C ₄
a91	Yes	1	0	1	C ₄	0	1	2	[C ₃ , C ₄]	C ₄
a92	No	1	0	1	IC ₄	0	2	3	[C ₂ , C ₄]	C ₄
a93	No	1	0	1	C ₄	0	1	2	[C ₃ , C ₄]	C ₄
a94	No	0	0	1	C ₃	0	2	2	[C ₂ , C ₃]	C ₃
a95	Yes	1	0	1	C ₃	1	0	1	C ₃	C ₃
a96	No	1	0	1	C ₄	1	0	1	C ₄	C ₄
a97	Yes	1	0	1	C ₄	0	0	1	C ₄	C ₄
a98	Yes	0	0	1	C ₃	0	0	1	C ₃	C ₃
a99	Yes	1	0	1	C ₃	1	0	1	C ₃	C ₃
a100	Yes	0	0	1	C ₃	0	0	1	C ₃	C ₃
a101	Yes	2	0	2	[C ₃ , C ₄]	0	2	3	[C ₂ , C ₄]	C ₄
a102	Yes	1	0	1	C ₃	0	0	1	C ₃	C ₃
a103	No	1	0	1	C ₄	1	0	1	C ₄	C ₄
a104	Yes	1	0	1	C ₄	0	0	1	C ₄	C ₄
a105	No	0	1	2	[C ₂ , C ₃]	0	1	2	[C ₂ , C ₃]	C ₃
a106	No	1	0	1	C ₃	0	1	2	[C ₂ , C ₃]	C ₂
a107	Yes	0	0	1	C ₃	0	1	2	[C ₂ , C ₃]	C ₂
a108	Yes	0	0	1	C ₃	0	0	1	C ₃	C ₃
a109	Yes	0	0	1	C ₃	0	1	2	[C ₂ , C ₃]	C ₂
a110	Yes	0	0	1	C ₃	0	0	1	C ₃	C ₂
a111	No	0	0	1	C ₃	0	1	1	C ₃	C ₃
a112	No	0	1	2	[C ₂ , C ₃]	0	1	2	[C ₂ , C ₃]	C ₂

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