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Mathematical model to select the optimal alternative for an integral plan to desertification and erosion control for the Chaco Area in Salta Province (Argentine)

J. B. Grau[1], J. M. Anton[1], A. M. Tarquis[1], F. Colombo[2], L. de los Rios[2], and J. M. Cisneros[3]

[1]Escuela Técnica Superior de Ingenieros Agrónomos, Universidad Politécnica de Madrid, Spain
[2]Universidad Católica de Salta Salta, Provincia de Salta, Argentine
[3]Universidad Nacional de Río Cuarto, Provincia de Córdoba, Argentine

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Correspondence to: J. B. Grau (j.grau@upm.es)

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Abstract

Multi-criteria Decision Analysis (MCDA) is concerned with identifying the values, uncertainties and other issues relevant in a given decision, its rationality, and the resulting optimal decision. These decisions are difficult because the complexity of the system or because of determining the optimal situation or behavior. This work will illustrate how MCDA is applied in practice to a complex problem to resolve such us soil erosion and degradation. Desertification is a global problem and recently it has been studied in several forums as ONU that literally says: "Desertification has a very high incidence in the environmental and food security, socioeconomic stability and world sustained development". Desertification is the soil quality loss and one of FAO's most important preoccupations as hunger in the world is increasing. Multiple factors are involved of diverse nature related to: natural phenomena (water and wind erosion), human activities linked to soil and water management, and others not related to the former. In the whole world this problem exists, but its effects and solutions are different. It is necessary to take into account economical, environmental, cultural and sociological criteria. A multi-criteria model to select among different alternatives to prepare an integral plan to ameliorate or/and solve this problem in each area has been elaborated taking in account eight criteria and six alternatives. Six sub zones have been established following previous studies and in each one the initial matrix and weights have been defined to apply on different criteria. Three Multicriteria Decision Methods have been used for the different sub zones: ELECTRE, PROMETHEE and AHP. The results show a high level of consistency among the three different multicriteria methods despite the complexity of the system studied. The methods are described for La Estrella sub zone, indicating election of weights, Initial Matrixes, the MATHCAD8 algorithms used for PROMETHEE, and the Graph of Expert Choice showing the results of AHP. A brief schema of the actions recommended for each of the six different sub zones is reported in Conclusions, with "We can combine Autochthonous and High Value Forest" for La Estrella.

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1 Introduction

The Salta Province (Fig. 1) has 155 000 km^2. It is at NW of Argentina (NOA) having latitudes around 25° S. Some winds from South or SE made climate less hot and bring rain from 400 to 800 mm/year (with peaks of 1200 mm in high altitude places in SO), and altitude has great ranges (at NE are areas at 200 m and at NW a PUNA region with summits higher than 6000 m). With 1 200 000 inhabitants it has a low density of population, and the city of Salta concentrates more or less fifty percent of the total. This nice capital of the Province, developed from a Spanish centre established in 1582, has now the universities UNS and UCASAL.

Part of the population habits in small cities located in important long mountain valleys, in some cities of Spanish foundation as San Román de la Nueva Orán or Orán and other are dispersed in rural areas with some of them related to modern argentine points at the side of the roads. As shown in Fig. 1 the "Chaco Salteño" (Salta part of Chaco), shown somehow in Fig. 2, is at East of Salta Province, a bit at NE of it being a West part of large Chaco's region of South America, and has lower rains decreasing from NO to SE, as does altitude. It has a number of areas used for agriculture, but at East it contains large natural areas degraded and in them dispersed Indians live in small "puestos" or "colonias". Apart from main links roads have low standards and in some parts environment is "deteriorating progressively".

Rivers from elevations cross the area flowing into the important fluvial artery Bermejo River that comes from higher Bolivia at North flowing to distant great Paraná River far at SE. This river presents in Chaco Salteño a zone known as a meander digression area since due to low slopes and sediments its course is forming meanders and changes frequently. That area in rainy period is transformed into an immense sheet of rain that completely isolates the communities living along the river 5 to 10 km from the riverside. It produces constant erosion that makes a great lot of sediments setting down at the Paraná River, generating an important cost in the continuous drainage. The majority and more important rivers drain towards the Paraná through this region,

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such as Pilcomayo and San Francisco that flows into Bermejo. The whole Chaco Salteño region has climate suffering from the lack of water, and that is worse at SE of it. Rainfall comes often from South and is concentrated in the summer time (from January to March). The groundwater resources are poor in volume and in quality (salty and with arsenic). It is possible to find good quality groundwater but in deep levels (100 m) with high operating costs and water is progressively taken from some rivers for irrigation.

Water is one of the most critical factors, as much for human and animal consumption, as for the production system in general and for the floodings due to lack of appropriated infrastructures, and consequently is the main erosion factor.

The area object of this paper is a central part of the Chaco Salteño and is shown in the Figs. 1 and 2 and the big problems for desertification and erosion are located in the North, Centre and East of this area.

2 Problems in Chaco Area of Argentine

One of the most important problems is the erosion, causing progressive desertification and environment degradation.

Besides the water, other factors linked to the human activities have an important influence in the erosion and progressive desertification of this region and environment degradation:

- Historically the human exploitation of natural forest to use in the railway and other activities produced an environment degradation process.
- Later on the autochthonous population in large parts at East followed the irrational wood extraction and did an over pasture by letting to grown wild pigs and goats as "modus vivendi" contributing to make the situation worse.
- Actually the farms and big single-crop exploitations in some locations do not give solution to the desertification problem.

The authors have studied these problems, considering also the educational, economic, sanitary and social problems linked to the propriety of the lands. They consider that only one integral plan considering all factors involved and the differences among the sub-areas will be the starting point to change the direction of the desertification process and environment degradation. In the following lines as a synthesis a set of alternatives will be evaluated in view of relevant criteria using Multi-Criteria Decision Methods MCDM, procedure known as Multi-Criteria Decision Analysis MCDA, as an aid for posterior elaboration of an integral plan for the region.

The authors were in relation with the local studies and policies, three authors are from Argentine universities with important curriculums. F. Colombo S. for environment has participated in books and papers about plants and forests of NOA, e.g. Colombo et al. (2001). L. de los Rios is consultant for agricultural businesses or associations such as PROGRANO, J. M. Cisneros has worked for agricultural planning and genie rural, e.g. Cisneros (1996). Moreover there are numerous official documents, surveys and legislation for the agriculture of this area, such as in research center INTA Cerrillos (Instituto Nacional de Tecnología Agropecuaria just South of Salta) for agriculture, INTA (2002). The author J. B. Grau is in relation with the administration of the province for development of water resources that is expanding as the province gets with more population and activity, in the scope of legislation evolving aiming for sustainable use of territory, e.g. the law Ley Bonasso (2007) of Argentine, or Salta (2010) for a web of the local government of Salta Province. The Paruelo (2009) from FAUBA (Facultad de Agronomía de la Universidad de Buenos Aires) is a survey on the accumulative effects on the forests of this region at East of Salta, connected with official decisions being then imposed for conservation of these forests. The planning for a sustainable development is in the reality as the region is evolving to a more intensely used large territory based on agriculture and forests, that into a well structured argentine society originated by previous incorporation of Indians and immigrants and with modern institutions and techniques.

3 Methodology for MCDA

3.1 Study sub zones

In order to elaborate an integral plan, an initial matrix has been created with the criteria, alternatives and weights.

The zone has been divided in 6 sub zones as representative for study due to the environmental and socioeconomic diversities, as presented in the preliminary contribution Anton (2009b) for EGU2009 and in the longer report Anton (2009a) for the Spanish Agency AECID. The zones have received the name of a local center and are indicated in the Fig. 2 of the Study Area:

- Las Lajitas,
- La Estrella,
- Pichanal,
- Martin Hickmann,
- Rivadavia banda sur,
- Joaquín V. González.

The Fig. 2 is from a part of an official Forest Map of Salta Province Arg. that has been added in form .jpg figure as a supplement to the paper as "Salta-mapa-forestal desmontes", and the lector of the present paper through the e-journal Bioscience has access to it as supplement (see http://www.biogeosciences-discuss.net/7/2601/2010/bgd-7-2601-2010-supplement.zip). Study area may be considered greater than Belgium and the full Province is as the double of Portugal, (but the great West in it is an Andine Puna area in big part over 4000 m altitude).

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3.2 Multi-criteria methods applied

The following discrete MCDM have been applied:

- ELECTRE I see Roy (1985), Roy and Bouyssou (1993).
- PROMETHEE I and II, see Brans et al. (1985), Brans et al. (1986), Brans and Mareschal (1994). A version of PROMETHEE modified (see Anton et al., 2006, 2009b; Grau et al., 2008) with weights were also applied.
- Analytic Hierarchy Process (AHP), see Saaty (1980, 1996a and b).

For ELECTRE and PROMETHEE methods MATHCAD ® software was used (now sold by PTC of USA as in www.ptc.com/products/mathcad/, through ADDLINK Software Científico in Spain), from Romero (1993) for ELECTRE, and for AHP method EXPERT CHOICE ® software (from EXPERT CHOICE Inc., www.expertchoice.com).

These methods have been used by authors formerly in multiple applications such as: "Madrid-Valencia high-speed rail line: a route selection" Anton and Grau (2004a, b), "Election of water resources management entity using a multi-criteria decision (MCD) method in Salta province (Argentine)" Grau et al. (2008), "Compromise Programming Calibration for financial analysis of firms of a common sector of business, case study for a set of Spanish banks in 1995" Antón et al. (2004c) also in (2007), "Use of Decision Theory for qualification of the lands of the Community of Madrid" Anton (2008), "MCDM Methods for Waste Management Planning in a rural Area" Grau et al. (2007), also Grau (2003).

3.3 Alternatives

The five alternatives mentioned below have been selected taking into account in situ studies. The authors have visited diverse exploitations in Salta and have contacted some specific experiments in Agronomical Institutes (INTA Argentine and INIA Spain).

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- A. *Autochthonous forest*: mainly of hardwood trees like "Quebracho Blanco" and "Quebracho Colorado",
- B. *High value forest*: mainly teak, ebony, walnut tree, cherry tree, lignum vitae, eucalyptus, etc. . . ,
- C. *Traditional farms* with extensive agriculture and livestock mixed with autochthonous forest modified and several foraging plants,
- D. *Erosion control crop with agriculture use*,
- E. *Erosion control crop with industrial use (biomass*).

3.4 Criteria, Initial Matrix for La Estrella sub zone

Eight criteria have been applied for the five alternatives in each sub zone following field research, expert panels, social investigation and personal interviews. For each sub zone the 5 alternatives and the 8 criteria were considered obtaining for each case an Initial Matrix of valuating indexes (of "more is better" kind) in 1–10 scale, let made only some comments on that.

3.4.1 Criterion 1: Water Erosion (WE)

The water erosion is very important because the interaction between natural and socioeconomic conditions.

The relative water erosion indexes figure in the Initial Matrix at Table 1. The water erosion is in itself of "more is worst" kind, so the indexes in the table are valuations in inverse order of the erosion expected.

3.4.2 Criterion 2: Eolian Erosion (EE)

Winds erode, transport and deposit materials, and are effective agents in several areas of this region. It is of "more is worst" kind for any measure of erosion intensity. The indexes in Table 1 are quality evaluations and thus in inverse order.

3.4.3 Criterion 3: Implementation Facility (IF)

The indexes in Table 1 were established taking into account actors' opinions, as in Anton et al. (2006, 2009a). It has been considered as of "more is better" kind. To implement crops (D and E) is considered much easier than to obtain a new autochthonous forest A; that got indexes depending on the trees to implement, 1 to 5 in the example that follows in 4.

3.4.4 Criterion 4: Water Resources (WR)

The needs of water resources were considered alternative by alternative. The amounts of water needed are of kind "more is worst". They are lower for autochthonous forest that got an index 8 in Table 1, the other alternatives are similar in needing aids of irrigation and got intermediate indexes 4 and the last E (industrial crop) got 5 as been possible with a little less irrigation.

3.4.5 Criterion 5: Economical Benefits (EB)

The relative economical benefits using each alternative in a period of 25 years have been obtained. We have considered this criterion as of "more is better" kind. All alternatives are beneficial and have got a not bad 5 index in Table 1, the C and E have got 8, as C produces more valuable cattle also, and as E will produce usable crops.

3.4.6 Criterion 6: Hand Power (HP)

The authors have considered that it would be satisfactory to give employment to the majority of the population. For that we have considered this criterion as of "more is better" kind. The alternative A has got a low 2 index as it requires less hand power in long periods.

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3.4.7 Criterion 7: Environmental Impacts (EI)

They have been considered in each sub zone. The environmental impacts have been calculated according to Gomez Orea (1999). In itself impacts are considered as "more is worst" kind, the valuation by indexes in Table 1 is in inverse order, the autochthonous forest has got the best 8 index.

3.4.8 Criterion 8: Social Acceptance (SA)

The figures included in this criterion have been obtained from the results of different forums and meetings with institutions, organizations and native people, as put in Anton et al. (2009a). This criterion has been defined as of "more is better" kind, all alternatives were accepted and got no less than index 5, the C Traditional Farms got 9 as preferred in these zones.

4 MCDM used, results and discussion

4.1 MCDM application

4.1.1 Decisional matrix development

For each sub zone the 5 alternatives and the 8 criteria were considered obtaining an Initial Matrix of valuating indexes in 1–10 scale. The weights of criteria for ELECTRE were assessed from results from expert panels and local actors.

The Table 1 contains the Initial Matrix for La Estrella sub zone used in ELECTRE method; it has been also used for AHP. The Table 2 contains the Initial Matrix for La Estrella sub zone used in PROMETHEE methods.

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4.1.2 Application of ELECTRE Method

The ELECTRE method was applied following Romero (1993) using similar MATHCAD ® sheets for all the sub zones, and let explain it following the case for La Estrella sub zone, indicating in Fig. 3 the procedures, data and results extracted from the sheet. Data were in Initial Matrix $\mathbf{Im}(i,j) = \mathbf{Im}_{ij}$ of indexes, that are in that case of kind "more is better" so as all the ELECTRE criteria indexes I_j are 1, and in weights w_j, all with ($j = 1...8$) and (i or $k = 1...5$). The weights were normalized to $W(j) = W_j$ so as to add 1. To obtain preferences of alternatives let get a Concordance matrix $\mathbf{C}_{ik}$ with $\{\mathbf{C}_{ik} = \text{Sum of the } W_j \text{ for which } (I_j \cdot (\mathbf{Im}_{ij} - \mathbf{Im}_{kj}) > 0)$ adding only $(W_j/2)$ if $(\mathbf{Im}_{ij} = \mathbf{Im}_{kj})\}$ representing how much alternative i is better than alternative k due to these criteria. To represent how much the other criteria are discordant for that preference let have the ranges $R_j = \operatorname{Sup}_{i,k} \left| \mathbf{Im}_{ij} - \mathbf{Im}_{kj} \right|$ to get the Normalised Decisional Matrix $\mathbf{Dm}_{ij} = \mathbf{Im}_{ij} \cdot W_j / R_j$, and let obtain a Discordance Matrix $\mathbf{D}_{ik} = \operatorname{Sup}_j \left(\operatorname{Sup} \left(I_j \cdot \left(\mathbf{Dm}_{ij} - \mathbf{Dm}_{kj} \right), 0 \right) \right) \Big/ \operatorname{Sup}_j \left| \mathbf{Dm}_{ij} - \mathbf{Dm}_{kj} \right|$. Now let take for concordance and discordance thresholds ct and dt the averages of the non diagonal elements of the square Matrixes $\mathbf{C}_{ik}$ and $\mathbf{D}_{ik}$ respectively, and with them let have Matrix of concordant dominance $\mathbf{Mcd}_{ik} = (1 \text{ if } (\mathbf{C}_{ik} \geq ct), \text{ otherwise } 0)$ and Matrix of discordant dominance $\mathbf{Mdd}_{ik} = (1 \text{ if } (\mathbf{D}_{ik} \leq dt), \text{ otherwise } 0)$, getting with them the Matrix of aggregated dominance from $\mathbf{Mad}_{ik} = \mathbf{Mcd}_{ik} \cdot \mathbf{Mdd}_{ik}$ for each (i,k). The diagonal elements of these dominance matrixes do not intervene and let take them as 0. If for given (i,k) the $\mathbf{Mcd}_{ik}$ is 1 that is an indication of dominance and if the $\mathbf{Mdd}_{ik}$ is 1 of not discordance of alternative i over alternative k, and if both are 1, i.e. if $\mathbf{Mad}_{ik} = 1$, alternative i is considered better than the k. An alternative that is better than some of the others and worse to none is considered in the kernel. This method selects as shown in Fig. 3 the alternatives A and B as the best for La Estrella sub zone, and Fig. 4 shows the corresponding ELECTRE dominance graph, that indicates the alternatives A and B are in the kernel.

4.1.3 Application of PROMETHEE Methods

The authors have used the Preference Ranking Organization Method (The PROMETHEE Method for Multiple Criteria Decision-Making) from Brans et al. (1985). This is an outranking method, as are ELECTRE due to B. Roy or AHP due to Saaty. Following Brans two possibilities are offered, PROMETHEE I provides a partial preorder and PROMETHEE II a total preorder on the set of possible alternatives. Let take a case (Case 1, with Table 2 Initial matrix $\mathbf{Im}(i,j)$ and weights $W(j)$) for sub zone La Estrella as example illustrated in Fig. 6 that is extracted from operative MATHCAD sheet. Indexes $I(j) = I_j$ are used to indicate the kind ("more is better" or "more is worse" corresponding to 1 and −1) of the j-criteria, and they were all taken as 1 for the criteria used in the paper that are of kind "more is better".

Type I and Type II of "Promethee criteria" have been adopted for the j-criteria to be used with formula $P(i,j,k) = \text{if}\left[I_j \cdot \left(\mathbf{Im}_{i,j} - \mathbf{Im}_{k,j}\right) \le 0, 0, p\left(j, \left|\mathbf{Im}_{i,j} - \mathbf{Im}_{k,j}\right|\right)\right]$, where the non negative preference function $P(i,j,k)$ is positive if criteria j indicates preference of alternative i over alternative k and 0 if not, using the functions $p(j,x)$ that follow. Type I is the "Usual Criterion" adopted for the j-criteria with $j = (4,5)$, with it if there is a strict preference for the criteria i with the best value index $\mathbf{Im}(i,j)$, it is defined with $p(j,x) = (0 \text{ if } (x \le 0), \text{ otherwise } 1)$. For other j-criteria the Type III "Criterion with Linear Preference" was adopted so as the decision-maker prefers progressively i to k for larger deviations between $\mathbf{Im}(i,j)$ and $\mathbf{Im}(k,j)$, with $p(j,x) = (|x|/m(j) \text{ if } (|x| \le m(j)), \text{ otherwise } 1)$. The preference increases linearly until deviation equals $m(j)$, after this value the preference is strict. For the thresholds $m(j)$ the value 2 was taken for $j = (1,8)$, 4 for $j = (2,3)$ and 6 for $j = (6,7)$, (see Table 2). Preference indexes were later defined as $q(i,k) = \sum_{j=1}^{8} P(i,j,k) \Big/ 8$ following Brans et al. (1985) to have "Results following initial methods of Brans and Winkle", and following Anton et al. (2006) as $q(i,k) = \sum_{j=1}^{8} P(i,j,k) \cdot W(j)$ to get "Results with weights (Anton and Grau)" that were preferred by authors as incorporating expert estimation of relative importance of criteria, using weights similar as those used in ELECTRE-I Method.

The method was applied in two cases, in the Case 1 the same weights for all sub zones have been adopted and in the Case 2 slightly different weights, considering some modifications in the data of the initial matrixes taking variants in the consideration of alternatives.

Sub zone La Estrella

The methods were applied for all sub zones, let show some cases that follow for La Estella sub zone, and the results for PROMETHEE-II methods are represented in Fig. 5.

Case 1: the Initial Matrix was selected taking the same figures as in Table 1 and is shown in Table 2. Two procedures have been applied in order to obtain alternative pre-order:

1 A: initial method by Brans et al. (1985), named PROMETHEE-II original, getting alternatives in order (E,C,A,B,D), alternative E being is also well with PROMETHEE-I.

1 B: modified method by Anton et al. (2006), named PROMETHEE-II modified getting order (B, E, A, C, D).

Case 2: obtained from Table 2 by changing some criteria values and with the same weights getting Table 3, such as from 1 to 5 for EB criteria in Case 1, considering more economic benefits being obtained with different natural forests, with similar procedures:

2 A: with PROMETHEE-II original, the alternative A jumps to second place not far from second E. With Promethee I the E is clearly better than A.

2 B: with PROMETHEE-II modified by authors, the different weights bring much

alternative A to first place. And with Promethee I the alternative A is before the others.

The Fig. 6 is from the MATHCAD used for Case 1, with data in Table 2, showing results for PROMETHEE-II and I.

4.1.4 Application of AHP methods

For the same sub zone La Estrella this method selects A and B alternatives as the best. For that the authors have followed the Expert Choice PC software guided following the Case 1 data and expertise, and in Fig. 7 the EXPERT CHOICE graphical interface is shown for this example. The computations for alternatives and criteria that result from AHP method application are summarized in Table 4, and in it the alternative A gets the higher total score, showing the partial score contributions.

The data were in AHP introduced by pair-wise comparisons of the criteria by the authors with the same conceptual considerations as for elaboration of data in Tables 1 to 3. Some of them had prior experience with combination of these methods, e.g. for Anton (2006) with panels from Salta for AHP comparisons, they tend sometimes be slightly more favorable for environment or EI and less for EB. The Fig. 5 is very expressive about the results of AHP, that tend to the same results as with ELECTRE and PROMETHEE, especially to select good alternatives, but authors have more confidence in the results of ELECTRE methods and especially of "modified PROMETHEE" methods than in AHP.

4.2 Summary results

The authors used these MCDM for the six sub zones, that was a large task and in the paper details were only given for La Estrella sub zone. As a result of the whole the Table 5 summarizes the application of MCDM to select alternatives to desertification control in Salta Province.

4.3 Comments

The authors have in the past years collected diverse expert information about the area, and they feel that the MCDM results agree with the real problems for future use of the area and give valuable indications that vary with the sub zone. That included visits to the sub-areas, meeting with heads of agro exploitations, e.g. to an irrigated exploitation in La Moraleja between La Estrella and Las Lajitas being shown well done cultivations related to several alternatives (mostly to B, C, also to E). Approaching Bermejo river the area becomes more primitive especially at South where Rivadavia Banda Sur is.

5 Conclusions

Following the results mentioned above, the authors obtained as global conclusion that the MCDM is a very useful tool to elaborate an erosion control integral Plan. The PROMETHEE-II modified by the authors using ELECTRE weights with usual type I criterion and type III pseudo-criterion is recommended. It is robust as it was have confirmed by the authors by changing a little the relative preferences.

Finally the authors could recommend to Salta Government the following actions:

- Las Lajitas: extensive farming and livestock. If it is only farming it could be with crop rotation. The livestock with natural forestry and foraging plants.
- La Estrella: we can combine Autochthonous and high value forestry.
- Pichanal: similar to Las Lajitas.
- Martin Hickman: autochthonous forestry.
- Rivadavia Banda Sur: similar to La Estrella.
- Joaquin V. Gonzalez: similar to Las Lajitas combined in some areas with high value forestry.

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Table 1. Initial Matrix for La Estrella sub zone, for ELECTRE.

Alternatives	Criteria							
	WE	EE	IF	WR	EB	HP	EI	SA
A	7	6	1	8	5	2	8	6
B	7	6	5	4	5	9	6	5
C	3	3	6	4	8	9	3	9
D	2	2	6	4	5	6	5	6
E	3	2	8	5	8	6	4	8
Weights	0.2	0.15	0.15	0.1	0.1	0.1	0.1	0.1

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Table 2. Case I, Initial Matrix for La Estrella sub zone, with weights, type of criterion and thresholds, for PROMETHEE.

Alternatives	Criteria							
	WE	EE	IF	WR	EB	HP	EI	SA
A	7	6	1	8	5	2	8	6
B	7	6	5	4	5	9	6	5
C	3	3	6	4	8	9	3	9
D	2	2	6	4	5	6	5	6
E	3	2	8	5	8	6	4	8
Weights	0.2	0.15	0.15	0.1	0.1	0.1	0.1	0.1
Type of criterion	III	III	III	I	I	III	III	III
Thresholds	2	4	4			6	6	2

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Table 3. Case II, Initial Matrix for La Estrella sub zone, with weights, type of criterion and thresholds, for PROMETHEE.

Alternatives	Criteria							
	WE	EE	IF	WR	EB	HP	EI	SA
A	7	6	5	8	5	6	8	6
B	7	6	5	4	5	9	6	5
C	3	3	6	4	8	9	3	9
D	2	2	6	4	5	6	5	6
E	3	2	8	5	8	6	4	8
Weights	0.2	0.15	0.1	0.1	0.1	0.1	0.1	0.1
Type of criterion	III	III	III	I	I	III	III	III
Thresholds	2	4	4			6	6	2

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Table 4. Application of AHP method to select alternatives to desertification control for La Estrella sub zone in Salta Province (Argentine).

Alternative	Criteria								Total
	WE	EE	IF	WR	EB	HP	EI	SA	
A	0.063	0.061	0.007	0.040	0.016	0.004	0.043	0.013	0.246
B	0.063	0.061	0.022	0.009	0.016	0.029	0.024	0.007	0.231
C	0.017	0.022	0.037	0.009	0.048	0.029	0.005	0.037	0.204
D	0.009	0.012	0.037	0.009	0.016	0.011	0.013	0.013	0.119
E	0.017	0.012	0.065	0.017	0.048	0.011	0.008	0.023	0.200
Weights by AHP	0.168	0.168	0.168	0.084	0.145	0.084	0.084	0.093	0.994
Theorical weights	0.150	0.150	0.150	0.100	0.150	0.100	0.100	0.100	1.000

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Table 5. Summary of MCDM application to alternatives to desertification control in Salta province (Argentine).

Sub zone	Method – better alternative			
	Electre	Promethee	AHP	Conclusion
Las Lajitas	C	C	C	C
La estrella	B and A	B and A	A and B	A and B
Pichanal	A, B, C	C	C	C
M. Hickman	A	A	A	A
Rivadavia	A	A and B	A	A and B
J. V. Gonzalez	A, B, C	C and B	C	C and B

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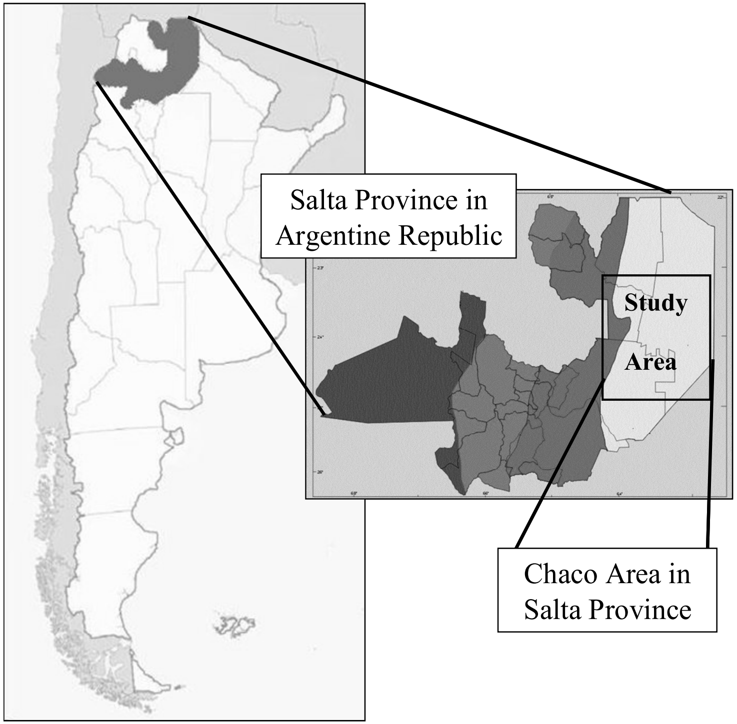

Fig. 1. Location of study area "Chaco Salteño region" in Argentine Republic.

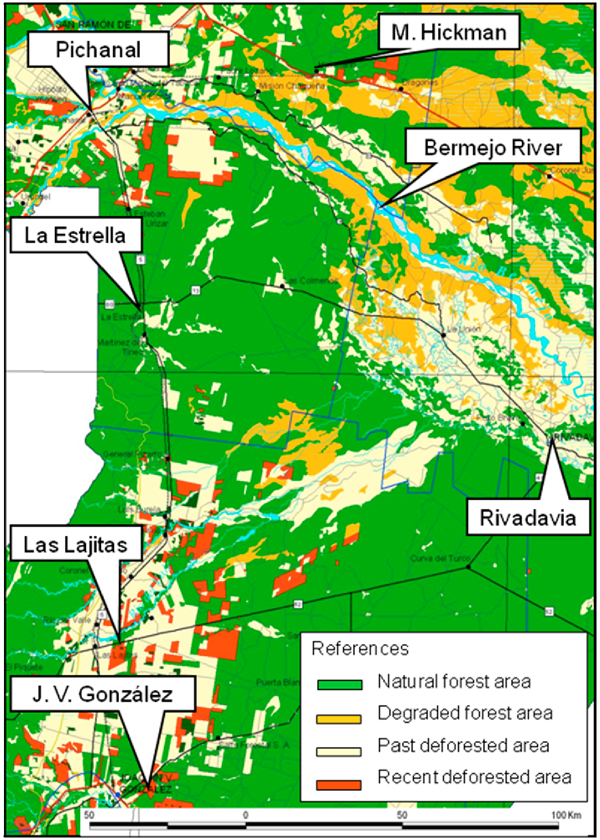

Fig. 2. Study area inside "Chaco Salteño" (Salta Province), with centers of the six considered sub zones (source: Forest Map of Salta Province, State Secretary of Environmental and Sustainable Development, Argentine Republic, 2002).

EROSION AND DESERTIFICATION INTEGRAL CONTROL PLAN USING ELECTRE-I.
SUB ZONE LA ESTRELLA

A. Data

Alternatives : A, B, C, D, E

Initial Matrix Im, Im(i , j):
Criteria (1, ..., 8)

$$Im := \begin{bmatrix} 7 & 6 & 1 & 8 & 5 & 2 & 8 & 6 \\ 7 & 6 & 5 & 4 & 5 & 9 & 6 & 5 \\ 3 & 3 & 6 & 4 & 8 & 9 & 3 & 9 \\ 2 & 2 & 6 & 4 & 5 & 6 & 5 & 6 \\ 3 & 2 & 8 & 5 & 8 & 6 & 4 & 8 \end{bmatrix}$$

i-Alternatives (1,...,m) : $m := 5$
j-Criteria (1,...,n), or k: $n := 8$

'or each j-criterion the j-index I(j) is +1, because all the aluating indexes in range (0...10) are of kind "more is better"

CRITERION:
1.- Water erosion index
2.- Eolian erosion index,
3.- Implementation facility
4.- Water resources,
5.- Economical benefits,
6.- Hand power,
7.- Environmental impacts,
8.- Social acceptance

Weights :
j-weights initial : $w^T = (0.2 \ \ 0.15 \ \ 0.15 \ \ 0.1 \ \ 0.1 \ \ 0.1 \ \ 0.1 \ \ 0.1)$

Normalised adding 1: $W^T = (0.2 \ \ 0.15 \ \ 0.15 \ \ 0.1 \ \ 0.1 \ \ 0.1 \ \ 0.1 \ \ 0.1)$

B. Matriz C or Concordancy Indexes Matrix C:

In what follows the diagonals of the i-k-square matrixes are not used and were given the value 0.

$$C = \begin{bmatrix} 0 & 0.475 & 0.45 & 0.35 & 0.45 \\ 0.525 & 0 & 0.45 & 0.35 & 0.45 \\ 0.55 & 0.55 & 0 & 0.225 & 0.5 \\ 0.65 & 0.65 & 0.775 & 0 & 0.775 \\ 0.55 & 0.55 & 0.5 & 0.225 & 0 \end{bmatrix}$$

The index C(i,k) is a measure of preference of alternative i over alternative k that is the sum of the j-weights W(j) for the j-criteria for which the i index Im(i , j) is better than the k index Im(k , j), adding only half j-weight W(j) if both alternatives are equal for that weight.

C. Normalised Decisional Matrix Dm(j,i) :

Let R(j) be the range or maximum variation in each j-criterion column of Initial Matrix Im.

$R = (5 \ \ 4 \ \ 7 \ \ 4 \ \ 3 \ \ 7 \ \ 5 \ \ 4)$

Let Dm (i , j) = Im(i , j)·W(j) / R(j)

D. Discordancy Indexes Matrix D :

the index D(i , k) measures how much incorrect or discordant it is to consider i better than k, and is the quotient of the j-worse (difference in their "j-indexes in the normalised decisional matrix Dm" divided by the j-greatest absolute difference of them R(j)) or j-sup(sup(I(j)*(Dm(k, j)-Dm(i, j)), 0) / (j-sup(abs(Dm(k, j)-Dm(i, j)))).

$$D = \begin{bmatrix} 0 & 1 & 0.67 & 0.536 & 0.937 \\ 1 & 0 & 0.625 & 0.125 & 0.625 \\ 1 & 1 & 0 & 0.4 & 1 \\ 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0.2 & 0 \end{bmatrix}$$

E Thresholds : Concordancy threshold : $ct = 0.5$ Discordancy threshold : $dt = 0.806$
Taken hier as average of non-diagonal elements of matrixes C and D respectively.

F Dominance matrixes :

matrix of concordant dominance:
Mcd(i,k) is 1 if C(i,k) >= ct, otherwise Mdc(i,k) = 0 .

matrix of discordant dominance:
Mdd(i,k) is 1 if D(i,k) <= dt, otherwise Mdd(i,k) = 0 .

Aggregated dominance matrix:
Mad(i,k) = Mcd(i,k)*Mdd(i,k)

$$Mcd = \begin{bmatrix} 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix} \quad Mdd = \begin{bmatrix} 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix} \quad Mad = \begin{bmatrix} 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix}$$

Alternatives :
A Autochthonous forest
B High value forest
C Traditional farms
D Erosn. cntrl. crop wt. agr. use
E Erosn. cntrl. crop wt. indt. use

If Mad(i,k) = 1 the alternative i dominates the alternative 1, as being enough dominant for some criteria, whose weights add more than ct, and as having with discordant criteria a discordance low enough.

G. Kernel : the alternatives A and B are in the kernel because each one is better than some alternative not being worse than any of them, for aggregate dominance matrix.

Fig. 3. ELECTRE for desertification control plans in La Estrella, Salta, with MATHCAD .

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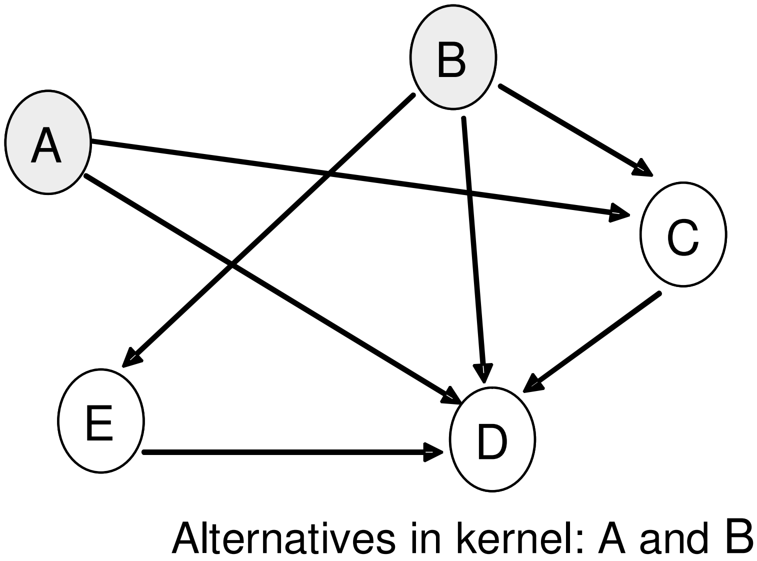

Fig. 4. ELECTRE graph and kernel showing the best alternatives to control of desertification in Salta, sub zone La Estrella.

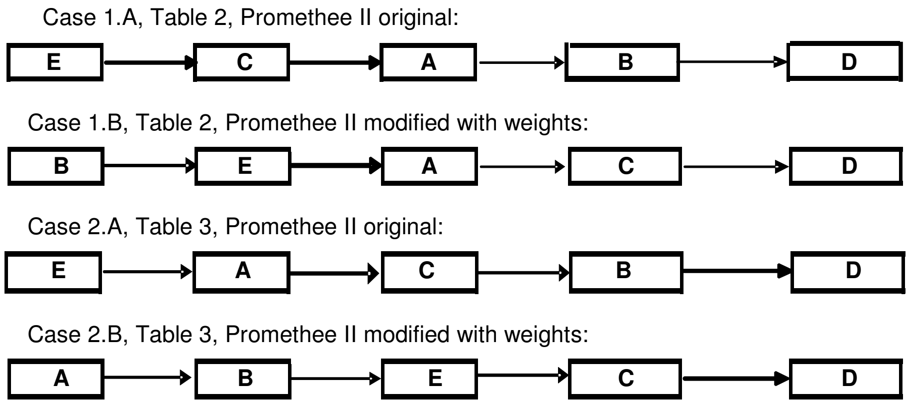

Fig. 5. Pre-order of alternatives selected by PROMETHEE-II methods to sub zone La Estrella.

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EROSION AND DESERTIFICATION INTEGRAL CONTROL PLAN USING PROMETHEE

SUB ZONE LA ESTRELLA

A. Data, Promethee criteria functions

i-Alternatives : A, B, C, D, E

Initial Matrix Im, Im(i , j): j-Criteria (1, ..., 8)

$$Im = \begin{pmatrix} 7 & 6 & 1 & 8 & 5 & 2 & 8 & 6 \\ 7 & 6 & 5 & 4 & 5 & 9 & 6 & 5 \\ 3 & 3 & 6 & 4 & 8 & 9 & 3 & 9 \\ 2 & 2 & 6 & 4 & 5 & 6 & 5 & 6 \\ 3 & 2 & 8 & 5 & 8 & 6 & 4 & 8 \end{pmatrix}$$

j-CRITERION:
1.- Water erosion index
2.- Eolian erosion index,
3.- Implementation facility
4.- Water resources,
5.- Economical benefits,
6.- Hand power,
7.- Environmental impacts,
8.- Social acceptance

j-Weights :

$$W = \begin{pmatrix} 0.2 \\ 0.15 \\ 0.15 \\ 0.1 \\ 0.1 \\ 0.1 \\ 0.1 \\ 0.1 \end{pmatrix}$$

j-Indexes :

$$I = \begin{pmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{pmatrix}$$

All j-Criteria were given Im(i,j) valuation indexes of kind "more is better", hence I(j) = +1 for any j.

Criterion-parameter functions, p(j,x) following Brans @ Vincke : if j = 4 or 5 , Type I, p(j,x) = (0 if (x<=0), otherwise 1) .

Type III, p(j,x) = (y/m(j) if (y<m(j)), otherwise 1) with y = abs(x). For j = 1 or 8 m(j) = 2 .
For j = 2 or 3 m(j) = 4 . For j = 6 or 7 m(j) = 6 . Used both in "preference functions P(i,k,j): "

$$P(i,k,j) := \mathrm{if}\left[I_j \cdot \left(Im_{i,j} - Im_{k,j} \right) \le 0, 0, p\left(j, \left| Im_{i,j} - Im_{k,j} \right| \right) \right]$$

$$q(i,k) := \left(\sum_{j=1}^{8} P(i,k,j) \right) \cdot 8^{-1}$$

B.- Results following initial methods of Brans&Vinkle:

Indexes q(i,k) of (j-added)-preferences i over k, (π(i,k) in Brans&Vincke) .
Outgoing flow or (+) fp(i) = k(1 to 5)-Sum(q(i,k)), larger as i dominates other(k's) for some j-criteria
Incoming flow or (-) fq(i) = k(1 to 5)-Sum(q(k,i)), lower as i is less dominated by other(k's) for j-crtr.

i-Outgoing flows : Of = (1.573 1.219 1.344 0.365 1.635)

i-Incoming flows : If = (1.417 1.073 0.979 1.677 0.99)

Net flows : Tpf := Of − If

PROMETHEE II (clasification of alternatives by Total Preorder : Tpf = (0.156 0.146 0.365 - 1.313 0.646)
Each i-alternative obtain one value Tpf(i) (more is better).

PROMETHEE I (clasification of alternatives by Partial Preorden Cpp):
Cpp(i,k) is 0 if ((Of(i) = Of(k) and (If(i) = If(k)) as "i is indiferent to k",
is 1 if ((Of(i) => Of(k) and (If(i) => If(k)) as "i outranks k".
is -1 otherwise and then "they are incomparable".

$$Cpp = \begin{pmatrix} 0 & -1 & -1 & 1 & -1 \\ -1 & 0 & -1 & 1 & -1 \\ -1 & 1 & 0 & 1 & -1 \\ -1 & -1 & -1 & 0 & -1 \\ 1 & 1 & -1 & 1 & 0 \end{pmatrix}$$

Alternative E is well preferred, next is C. then come A and B

C. Results (Anton&Grau) weighting criteria ELECTRE-I weights W(j) :

$$q(i,ii) := \sum_{j=1}^{8} P(i,ii,j) \cdot W_j$$

i-Outgoing flows Of: Of = (1.696 1.463 1.213 0.354 1.496)

i-Incoming flows If : If = (1.333 0.921 1.083 1.779 1.104)

PROMETHEE II (clasification of alternatives by Total Preorder Tpf):
Tpf = (0.363 0.542 0.129 - 1.425 0.392)

PROMETHEE I (clasification of alternatives by Partial Preorden Cpp):

$$Cpp = \begin{pmatrix} 0 & -1 & -1 & 1 & -1 \\ -1 & 0 & 1 & 1 & -1 \\ -1 & -1 & 0 & 1 & -1 \\ -1 & -1 & -1 & 0 & -1 \\ -1 & -1 & -1 & 1 & 0 \end{pmatrix}$$

Alternative B is preferred, next is E, then A; much last is D.

Fig. 6. Example of original and modified PROMETHEE (Anton et al., 2007) application to La Estrella sub zone to select alternatives of desertification control, Cases 1B and 1C, with Mathcad .

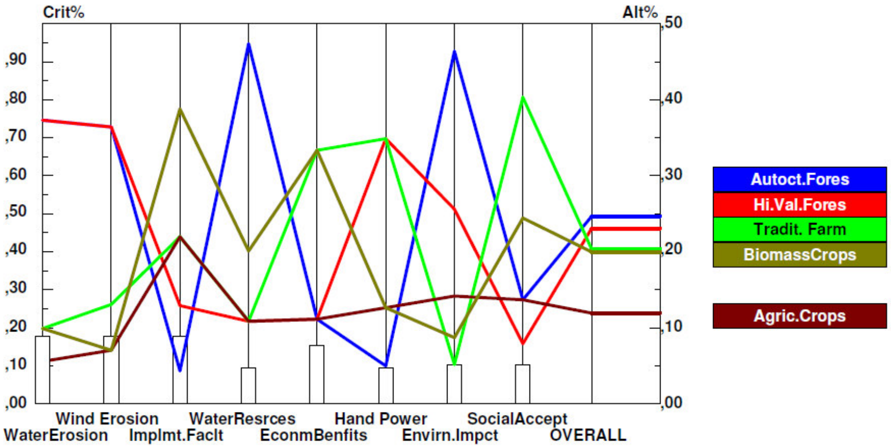

Fig. 7. Graph of Expert Choice AHP application to sub zone La Estrella.