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An application of mathematical models to select the optimal alternative for an integral plan to desertification and erosion control (Chaco Area – Salta Province – Argentina)

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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 behaviour. 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 five 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 fully described for La Estrella sub zone, indicating election of weights, Initial Matrixes, algorithms used for PROMETHEE, and the Graph of Expert Choice showing the AHP results. A brief schema of the actions recommended for each of the six different sub zones is discussed.

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.

The Study Area is the central part of "Chaco Salteño" (Figs. 1 and 2) that 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 colonies. 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

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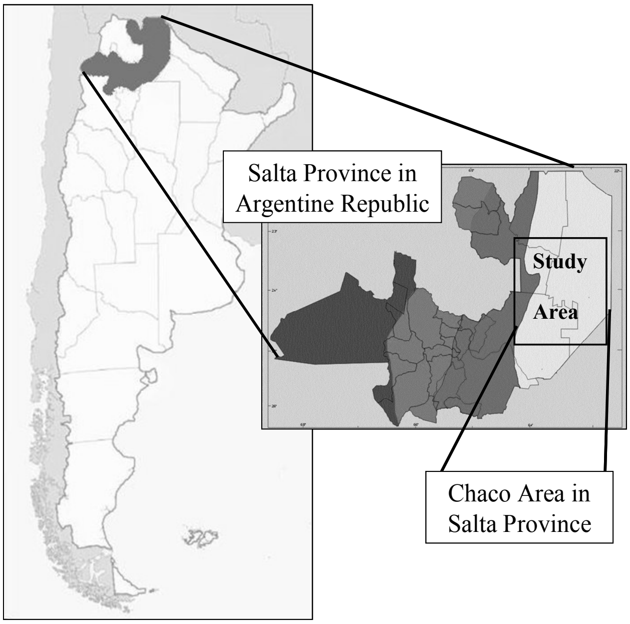

Fig. 1. Location of study area "Chaco Salteño region" in Argentine Republic.

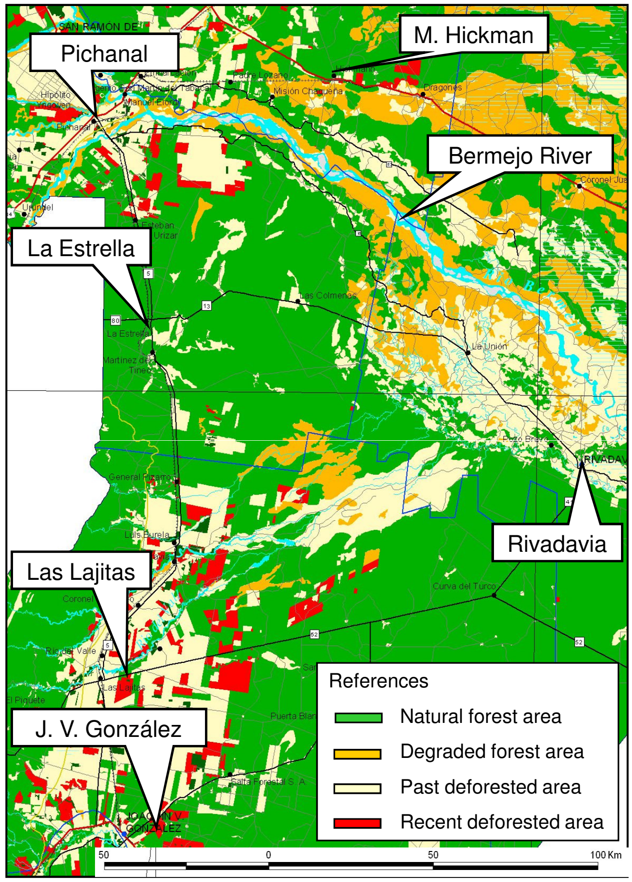

Fig. 2. Study area inside "Chaco Salteño" (Salta Province), with centers of sub zones. From Forest Map of Salta Province. State Secretary of Environmental and Sustainable Development, Argentine Republic, 2002; included in annex.

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 water 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 dredging. The majority and more important rivers drain towards the Paraná through this region, such as Pilcomayo and San Francisco that flows into Bermejo. The whole Chaco Salteño region has climate suffering from the lack of water, even 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 the flood events 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 (Figs. 1 and 2) and the severe problems for desertification and erosion are located in the North, Centre and East of this area.

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 handling 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 extensive crops cultivation with single-crop in some locations do not give solution to the desertification problem.

The authors have studied these problems, considering the educational, economic, sanitary as well as social problems linked to the propriety of the lands. They believe that only one integral plan considering all factors involved and the differences among the subareas 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.

2 Methodology for MCDA

2.1 Study sub zones

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 contributions (Anton, 2009b) and in a report for the Spanish Agency AECID (Anton, 2009a). 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.

2.2 Multi-criteria methods applied

The following discrete MCDM have been applied, they are all outranking methods:

- ELECTRE I, see Roy (1985), Roy and Bouyssou (1993).
- Initial PROMETHEE, see Brans et al. (1985), Brans et al. (1986).
- Weighted PROMETHEE, see Brans and Mareschal (1994), Anton et al. (2006, 2009b) and Grau et al. (2008).
- Analytic Hierarchy Process (AHP), see Saaty (1980, 1996a, 1996b).

For ELECTRE and PROMETHEE methods MATHCAD® software was used (version MATHCAD8PRO that admits programming, with sheets legible with MATHCAD14), from Romero (1993) for ELECTRE, and for AHP method EXPERT CHOICE® software (from EXPERT CHOICE Inc., www.expertchoice.com). These methods got recently varied extensions and also software, but for the goals of this paper the adopted versions were robust and reliable.

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 (Argentina)" (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, 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., 2003, 2007).

2.3 Alternatives and criteria

Since MCDA involves a certain element of subjectiveness, the expertise and knowledge of the persons implementing MCDA in a particular area play a significant part in the accuracy and fairness of MCDA's conclusions. The authors were in relation with the local studies and policies and three of them live and work in Argentina. 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). 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 were very useful in this study (INTA, 2002). First author 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. Bonasso Law (2007) of Argentina, or see 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 structured argentine society originated by previous incorporation of Indians and immigrants and with modern institutions and techniques.

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

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. That includes growing maize, soy, cartamo, wheat, barley, etc... and also cows grazing in open, forage plants as malato and alfalfa.

D. *Erosion control crop with agriculture use*. That includes forage protecting soil, including alfalfa, malato; and cows grazing in open field (≤1 cow/ha).

E. *Erosion control crop with industrial use (biomass)*.

Eight criteria have been applied for the five alternatives in each sub zone following field research, expert panels, social investigation and personal interviews. For these studies about Chaco Area with these much independent alternatives for ELECTRE and PROMETHEE methods it seemed appropriated to obtain in a first stage for each j-criteria and for each i-alternative a qualifying valuation in the range (0–10), that is in itself of "more is better kind" for all, also for erosions that in name are bad by nature (more erosion is worse and thus got a worse valuation) or for water requirements (more requirements got worse valuation), and these valuations were put as Initial Matrix elements ($\mathbf{Im}(i,j)$) for these methods, getting an especial **Im** matrix, with some differences due to diversities, for each sub zone and also for subcase variants of a sub zone.

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

	Criteria							
Alternatives	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

2.3.1 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.

2.3.2 Criterion 2: eolian erosion (EE)

Winds erode, transport and deposit materials, and are effective agents in several areas of this region. Said also as "Wind Erosion" it is of "more is worst" kind for any measure of erosion intensity, but the indexes for it as in the example of Table 1 for a La Estrella case are quality evaluations and are thus in inverse order "more is better" referred to a range (0–10).

2.3.3 Criterion 3: implementation facility (IF)

The indexes in Table 1 were established taking into account actors' opinions, as in Anton et al. (2006 and 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.

2.3.4 Criterion 4: water resources (WR)

The needs of water resources were considered alternative by alternative for each sub zone. The amounts of water needed are of kind "more is worst", but to have valuation indexes in range (0–10) that in themselves are "of kind more is better" we have considered the "Availability of obtaining amounts of water from Water Resources in the zone for a given i-alternative". These amounts needed are lower for Autochthonous forest that got an index 8 in Table 1 for La Estrella sub zone and the other alternatives are here similar in needing aids of irrigation and got intermediate indexes 4 and the last (E) (industrial crop) got 5 has been possible with a little less irrigation.

2.3.5 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.

2.3.6 Criterion 6: hand power (HP)

The social situation in that region of Chaco, including Indians Wichi at SE and along Bermejo river, results in that there is interest in giving employment to the majority of the population, and a valuation in rage (0–10) has been given for each i-alternative being higher if it reduces the existing not employed, considering anyhow this criterion as of "more is better" kind. E.g. the alternative (A) *Autochtonous forest* has got a low 2 in the example La Estrella of Table 1 as it requires less hand power in long periods.

2.3.7 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.

2.3.8 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, and the (C) Traditional Farms got 9 as preferred in these zones.

3 Multi-Criteria Decision Methods applied

3.1 Decisional matrix development

For each sub zone the 5 alternatives and the 8 criteria were considered obtaining an Initial Matrix, also Decisional Matrix, of valuating indexes in 1–10 scale, that was done for all the six sub zones and for the different methods, introducing these Matrixes in MATHCAD® PC sheets (in form $\mathbf{Im}(i,j)=\mathbf{Im}_{ij}$) as in examples of Fig. 3 and of Fig. 6. These values are independent for each sub zone, due to diversities, and in the study some sub-cases were varied for some sub zones. As indicated later in 4.3 Comments the expertise of authors resulted for these global planning decision procedures in such qualifying valuations "of more is better kind", and hence the valuating indexes I_j of ELECTRE and PROMETHEE have all the value +1.

The weights of criteria for ELECTRE were also assessed from results from expert panels and local actors, and they were slightly different for each sub zone, and also for sub-cases in each sub zone.

3.2 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 with data in Table 1, as represented in Fig. 3.

A. Data, $\mathbf{Im}(i,j)=\mathbf{Im}_{ij}$ were in Initial Matrix **Im**. All the j-criteria, called sometimes attributes and with ($j=1\ldots8$), result in all the present study of kind "more is better" and hence the ELECTRE criteria indexes I_j are all 1. The i-alternatives are indicated and correspond to the five (A, B, C, D, E) presented in Sect. 3.3, and are indexed with (i or $k=1\ldots5$).

   The weights $\boldsymbol{w}_j$ of criteria for ELECTRE, that have to quantify the strength of coalitions of criteria if added, were assessed representing the relative importance of each criterion for the authors, as containing their expert opinion about the effect of the criteria on the solution. The weights were normalized so as to add 1 getting $\boldsymbol{W}(j)=\boldsymbol{W}_j$. In this example the first criteria WE was given a higher value 0.2, the two following EE and IF value 0.15, the other 0.1, as relative strengths of the criteria for ELECTRE method attributed by the authors.

   The values in Initial matrix **Im** or of weights were taken with differences for the other sub zones, in calculations done with similar Mathcad sheets, as the sub zones have some peculiarities in soil, rain, floods, slopes, sociology, etc.

B. To obtain preferences first the sheet obtains the Concordance Indexes Matrix $\mathbf{C}_{ik}$, represented as the 5×8-*matrix* **C** in Fig. 3 obtained from

$$\mathbf{C}_{ik}=\text{Sum of the } \boldsymbol{W}_j \text{ for which } (I_j\cdot(\mathbf{Im}_{ij}-\mathbf{Im}_{kj})>0), \text{ adding only } (\boldsymbol{W}_j/2) \text{ if } (\mathbf{Im}_{ij}=\mathbf{Im}_{kj}), \quad (1)$$

   that indicates how much alternative i is better than alternative k adding the weights of the criteria for which that occurs.

C. Now in ELECTRE the obstacles for these preferences, or discordances, are considered. Let first calculate the ranges

$$R_j=\operatorname*{Sup}_{i,k}\left|\mathbf{Im}_{ij}-\mathbf{Im}_{kj}\right| \quad (2)$$

D. Let calculate the Normalised Decisional Matrix $\mathbf{Dm}_{ij}=\mathbf{Im}_{ij}\cdot\boldsymbol{W}_j/R_j$, and let obtain a Discordance Indexes Matrix

$$\mathbf{D}_{ik}=\operatorname*{Sup}_{j}\left[\operatorname{Sup}\left(I_j\cdot\left(\mathbf{Dm}_{kj}-\mathbf{Dm}_{ij}\right),0\right)\right] \Big/ \operatorname*{Sup}_{j}\left|\mathbf{Dm}_{kj}-\mathbf{Dm}_{ij}\right| \quad (3)$$

   represented as the 5×5-*matrix* **D** in Fig. 3.

E. 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, obtaining $ct=0.5$ and $dt=0.806$ as shown in Fig. 3,

F. and with them let have

   a. the Matrix of concordant dominance $\mathbf{Mcd}_{ik}=(1$ if $(\mathbf{C}_{ik}\geq ct)$, otherwise 0) and

   b. the Matrix of discordant dominance $\mathbf{Mdd}_{ik}=(1$ if $(\mathbf{D}_{ik}\leq dt)$, otherwise 0), getting with them the

   c. Matrix of aggregated dominance from $\mathbf{Mad}_{ik}=\mathbf{Mcd}_{ik}\cdot\mathbf{Mdd}_{ik}$ for each (i,k).

G. The diagonal elements of these dominance matrixes do not intervene and let take them as 0, and these obtained matrixes are in Fig. 3 as the 5×5-*matrixes* **Mad**, **Mcd** and **Mdd**. If for a given (i,k) the $\mathbf{Mcd}_{ik}$ is 1, that is an indication of dominance, and if the $\mathbf{Mdd}_{ik}$ is 1 there is no discordance of alternative i over alternative k; and if both are 1, i.e. if $\mathbf{Mad}_{ik}=1$, the alternative i is considered better than the k one.

H. 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) (Autochthonous forest) and (B) (High value forest) as the best for La Estrella sub zone, and Fig. 4 shows the

Name		Symbol	Description	Example Sub zone La Estrella
Initial Matrix		Im(i,j)	i-Alternatives j-Criteria	$\begin{pmatrix} 7 & 6 & 1 & 8 & 5 & 2 & 8 & 6 \\ 7 & 6 & 5 & 4 & 5 & 9 & 6 & 5 \\ 3 & 3 & 6 & 4 & 8 & 9 & 3 & 9 \\ 2 & 2 & 6 & 4 & 5 & 6 & 5 & 6 \\ 3 & 2 & 8 & 5 & 8 & 6 & 4 & 8 \end{pmatrix}$
Weights	*weights*	*w*(j)	Initial weights for each criteria	$(0.2 \quad 0.15 \quad 0.15 \quad 0.1 \quad 0.1 \quad 0.1 \quad 0.1 \quad 0.1)^T$
	Normalized weights	*W*(j)	$\sum W(j) = 1$	$(0.2 \quad 0.15 \quad 0.15 \quad 0.1 \quad 0.1 \quad 0.1 \quad 0.1 \quad 0.1)^T$
Concordance Indexes Matrix		C(i,k)	Preference of alternative i over alternative k	$\begin{pmatrix} 0 & 0.525 & 0.55 & 0.65 & 0.55 \\ 0.475 & 0 & 0.55 & 0.65 & 0.55 \\ 0.45 & 0.45 & 0 & 0.775 & 0.5 \\ 0.35 & 0.35 & 0.225 & 0 & 0.225 \\ 0.45 & 0.45 & 0.5 & 0.775 & 0 \end{pmatrix}$
Discordance Indexes Matrix		D(i,k)	Quantify the error to consider alternative i better than alternative k	$\begin{pmatrix} 0 & 1 & 0.67 & 0.536 & 0.937 \\ 1 & 0 & 0.625 & 0.125 & 0.625 \\ 1 & 1 & 0 & 0.4 & 1 \\ 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0.2 & 0 \end{pmatrix}$
Thresholds	Concordance	*ct*	Taken the average of C(i,k) elements for $i \neq k$ to compare C(i,k) with *ct*	**0.500**
	Discordance	*dt*	Taken the average of D(i,k) elements for $i \neq k$ and compare D(i,k) with *dt*	**0.806**
Dominance Matrixes	Dominance Matrix of concordance	Mcd(i,k)	If Mcd(i,k) = 1 alternative i is better than alternative k for enough weights	$\begin{pmatrix} 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{pmatrix}$
	Dominance Matrix of discordance	Mdd(i,k)	If Mdd(i,k) = 1 alternative i may dominate alternative k as discordances are not excessive	$\begin{pmatrix} 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{pmatrix}$
	Aggregated Dominance Matrix	Mad(i,k)	Mad(i,k) = Mcd(i,k)*Mdd(i,k) for each i and each k	$\begin{pmatrix} 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{pmatrix}$
Kernel		Kern	Alternatives that are better than others not being worse than any of them	In this case looking at Mad(i,k) matrix, alternative i = 1 and i = 2

Fig. 3. Mathematical elements of erosion and desertification integral control plan using ELECTRE-I.

corresponding ELECTRE dominance graph, that indicates the alternatives (A) and (B) are in the kernel. That is for Concordance because they have higher values in **Im** matrix for criteria 1 (Water Erosion Index) and 2 (Eolian erosion index) that have higher weights (0.2 and 0.15), and no very bad values in that matrix for the other criteria.

3.3 Application of PROMETHEE methods

The authors have used the Preference Ranking Organization Method (The PROMETHEE Method for Multiple Criteria Decision-Making) from Brans and Wincke (1985). Following Brans two techniques were adopted, the technique PROMETHEE I provides a partial preorder and PROMETHEE II a total preorder on the set of possible alternatives, in the previous reference total preorder is more

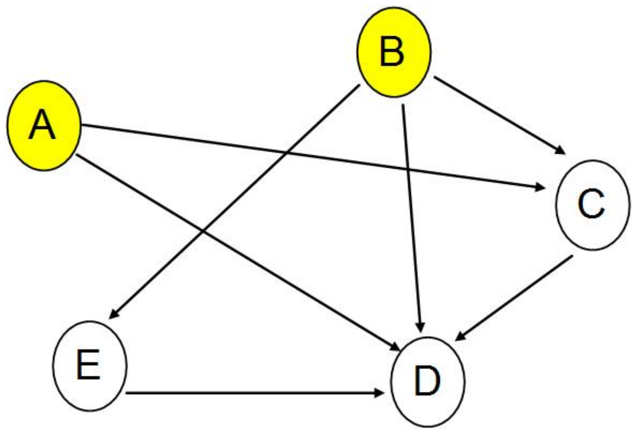

Fig. 4. ELECTRE graph and kernel showing the best alternatives to control of desertification in Salta, sub zone La Estrella.

for the ranking problem of alternatives and partial preorder is more for the choice problem. The criteria and the alternatives are the same as for ELECTRE, and for all the sub zones the Initial Matrixes $\mathbf{Im}_{ij}$, normalized weights $\boldsymbol{W}_j$ and indexes I_j were taken similarly from it, as that election is acceptable and as it gave reasonable results, easing the comparison of methods.

I. For all the cases the subtraction PROMETHEE formula was used as,

$$P(i,k,j) = \text{if}\left[I_j \cdot \left(\mathbf{Im}_{ij} - \mathbf{Im}_{kj}\right) \leq 0\right] \text{ then 0 else } p\left(j, \left|\mathbf{Im}_{ij} - \mathbf{Im}_{kj}\right|\right) \quad (4)$$

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, all the I_j being 1 as before, using for each j-criteria a criteria preference function $p(j,x)$ as follows.

For each j-criteria a j-Type of preference function must be elected following Brans et al. (1985) between 6 Types, and Type I is the "Usual Criterion" and it has been adopted for the j-criteria with $j = (4,5)$ that correspond to WR and EB criteria. It gives a strict preference for the criteria i with the best value index $\mathbf{Im}(i,j)$, it is defined with

$$p(j,x) = (0 \text{ if } (x \leq 0), \text{ otherwise } 1). \quad (5)$$

For the other j-criteria the Type III "Criterion with Linear Preference" was adopted so as the decision-maker prefers progressively alternative i to k for larger deviations between $\mathbf{Im}(i,j)$ and $\mathbf{Im}(k,j)$, with

$$p(j,x) = (|x|/m(j) \text{ if } (|x| \leq m(j)), \text{ otherwise } 1). \quad (6)$$

Using it 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 $j = (1,8)$ or WE and SA criteria, the value 4 for $j = (2,3)$ or EE and IF criteria and the value 6 for $j = (6,7)$ or criteria HP and EI, see Table 2.

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

	Criteria							
Alternatives	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

II. Preference indexes were later defined for Initial PROMETHEE method as

$$q(i,k) = \sum\nolimits_{j=1}^{8} P(i,k,j)/8, \quad (7)$$

and for Weighted PROMETHEE method as

$$q(i,k) = \sum\nolimits_{i=0}^{8} P(i,k,j) \cdot \boldsymbol{W}(j), \quad (8)$$

incorporating the expert assessment of a relative importance of criteria in the values of the weights.

III. The method was applied for all sub zones, and in each for one or more sub-cases; in the Case 1 weights similar as those used in ELECTRE-I method have been adopted and other cases 2 slightly different weights, considering also some modifications in the data of the Initial matrixes and of weights, in view to study the result of varied hypothesis on the influence of the criteria.

   A. Let show some cases that follow for La Estrella sub zone.

   B. 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. Sub-case 1.A: Initial PROMETHEE method by Brans et al. (1985), getting using the technique PROMETHEE II alternatives in order (E, C, A, B, D), alternative (E) being is also well with PROMETHEE I.

      2. Sub-case 1.B: Weighted PROMETHEE modified getting order (B, E, A, C, D) with PROMETHEE II, see later for details.

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

	Criteria							
Alternatives	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

C. Case 2: obtained from Table 2 by changing some criteria and weight values getting Table 3. The Initial Matrix for EB criteria (Economic Benefits) for alternative (A) (Autochthonous forest) was changed from 1 to 5, the non normalised weight for EE (Eolian erosion) was changed from 0.15 to 0.10, getting:

   1. Sub-case 2.A: with Initial PROMETHEE and technique II, the alternative (A) jumps to second place not far from second (E). With PROMETHEE I the (E) is clearly better than (A).
   2. Sub-case 2.B: with Weighted PROMETHEE, the different weights bring much alternative (A) to first place. And with PROMETHEE I the alternative (A) is before the others.

These sub zone La Estrella results for the technique PROMETHEE-II are represented in Fig. 5.

IV. To present the PROMETHEE method let take the Sub-case 1.A and the Sub-case 1.B for sub zone La Estrella that uses Table 2 values of Initial Matrix and of weights, in a procedure resumed in Fig. 6, using thus Initial and Weighted PROMETHEE and for both giving results with PROMETHEE-II and I techniques. In that figure are the Initial Matrix $\mathbf{Im}(i,j)$, and the weights $W(j)$, the indexes I_j being also all 1 as the 8 criteria are of kind "more is better". Preference indexes were calculated, representing incoming flows (more unfavorable for alternative i if higher, all are positive)

$$\mathrm{If}(i)=\sum\nolimits_{k=1}^{5} q(k,i) \tag{9}$$

and out-coming flows (favorable for the alternative i, all are positive)

$$\mathrm{Of}(i)=\sum\nolimits_{k=1}^{5} q(i,k) \tag{10}$$

were calculated, and from them net flows

$$\boldsymbol{P}_i=\mathrm{Tpf}(i)=\mathrm{Of}(i)-\mathrm{If}(i), \tag{11}$$

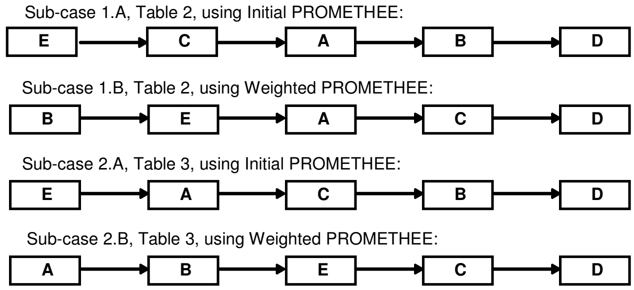

Fig. 5. Pre-order of alternatives selected by PROMETHEE-II methods to sub zone La Estrella.

All the flows resulting for the alternatives (A, B, C, D, E) in these cases are indicated in Fig. 6. For PROMETHEE-II technique, "Ranking the Actions by a Total Preorder", the net flows, or total preorder flows, $\mathrm{Tpf}(i)$ are taken as valuations, they are higher if the i-alternative is better, and a result vector $\boldsymbol{P}$ has been defined. For PROMETHEE-I, "Ranking the Actions by a Total Preorder", a combination of incoming and outcoming flows is considered obtaining a Partial preorder matrix of elements $\mathbf{Cpp}(i,k)$, shown in Fig. 6 for these cases, that are

1. 1 if $\{[\mathrm{Of}(i)>\mathrm{Of}(k)$ and $\mathrm{If}(i)<\mathrm{If}(k)]$ or $[\mathrm{Of}(i)>\mathrm{Of}(k)$ and $\mathrm{If}(i)=\mathrm{If}(k)]$ or $[\mathrm{Of}(i)=\mathrm{Of}(k)$ and $\mathrm{If}(i)<\mathrm{If}(k)]\}$, indicating that "the alternative i outranks the alternative k" ,
2. 0 if $[\mathrm{Of}(i)=\mathrm{Of}(k)$ and $\mathrm{If}(i)=\mathrm{If}(k)]$ indicating that "the alternative i is indifferent to the alternative k",
3. -1 otherwise, indicating that "they are incomparable".

The results are in Fig. 6, first for Initial PROMETHEE and then for Weighted PROMETHEE, that are explained next:

A. For Initial PROMETHEE, Technique PROMETHEE I total preorder, Alternative (E) (Erosion control crop with industrial use) is well preferred, due especially to the criteria (3 Implementation facility; 5 Economical benefits, 8 Social acceptance) that have higher values in matrix **Im**, next is (C) (Traditional farming), then come (A) (Autochthonous forest) and (B) (High value forest). With Technique PROMETHEE II partial preorder the alternative (E) outranks the (A, B, D) and is not outranked, the (C) is not outranked and outranks (B) and (D). The alternative (D) outranks none and is outranked by all.

Name		Symbol	Description	Example: Sub zone La Estrella
Initial Matrix		**Im**(i,j)	*i*-Alternatives *j*-Criteria	$\begin{pmatrix} 7 & 6 & 1 & 8 & 5 & 2 & 8 & 6 \\ 7 & 6 & 5 & 4 & 5 & 9 & 6 & 5 \\ 3 & 3 & 6 & 4 & 8 & 9 & 3 & 9 \\ 2 & 2 & 6 & 4 & 5 & 6 & 5 & 6 \\ 3 & 2 & 8 & 5 & 8 & 6 & 4 & 8 \end{pmatrix}$
Weights	**Weights**	$w(j)$	Initial weights for each criteria	$(0.2 \quad 0.15 \quad 0.15 \quad 0.1 \quad 0.1 \quad 0.1 \quad 0.1 \quad 0.1)^T$
	Normalized weights	$W(j)$	$\sum W(j) = 1$	$(0.2 \quad 0.15 \quad 0.15 \quad 0.1 \quad 0.1 \quad 0.1 \quad 0.1 \quad 0.1)^T$
Criterion parameter function		$p(j,x)$	Quantifies the preference based on criteria *j* and a threshold *m(j)*	$\textit{if } j = 4 \textit{ or } j = 5 \rightarrow p(x,j) \begin{cases} = 0 & x \le 0 \\ = 1 & x > 0 \end{cases}$ $\textit{otherwise} \rightarrow p(x,j) \begin{cases} = \frac{\lvert x \rvert}{m(j)} & \textit{if } \lvert x \rvert < m(j) \\ = 1 & \textit{if } \lvert x \rvert \ge m(j) \end{cases}$ $m(j) = (2 \quad 4 \quad 4 \quad - \quad - \quad 6 \quad 6 \quad 2)^T$
Preference functions, of alternative *i* with respect to alternative *k* for criterion *j*		$P(i,k,j)$	Measures that preference	$P(i,k,j) = \begin{cases} 0 & \textit{if } (I_j \cdot (\mathbf{Im}(i,j) - \mathbf{Im}(k,j)) \le 0 \\ p(j. \lvert \mathbf{Im}(i,j) - \mathbf{Im}(k,j) \rvert) & \textit{otherwise} \end{cases}$
Preference indexes	**Init. Pth. : Initial PROMETHEE**	$q(i,k)$	Preference for *i* alternative with regard to *k* over all *j* criteria	$q(i,k) = \frac{1}{8} \sum_{j=1}^{8} P(i,k,j)$
	Wt. Pt.: Weighted PROMETHEE			$q(i,k) = \sum_{j=1}^{8} P(i,k,j) \cdot \boldsymbol{W}(j)$
Partial preorder matrix, technique PROMETHEE I	**Ini. Prt. : Initial PROMETHEE**	**Cpp**(i,k)	Classifies the *i* alternatives, by indicating if alternative *i* outranks alternative *k*, or is indifferent or incomparable to it	$\begin{pmatrix} 0 & -1 & -1 & 1 & -1 \\ -1 & 0 & -1 & 1 & -1 \\ -1 & 1 & 0 & 1 & -1 \\ -1 & -1 & -1 & 0 & -1 \\ 1 & 1 & -1 & 1 & 0 \end{pmatrix}$ Ranking *i* respectively to *k*, Cpp(i,k) = 0 → indifferent; Cpp(i,k) = -1 → incomparable; Cpp(i,k) = 1 → *i* outranks k
	Wt. Pr.: Weighted PROMETHEE			$\begin{pmatrix} 0 & -1 & -1 & 1 & -1 \\ -1 & 0 & -1 & 1 & -1 \\ -1 & 1 & 0 & 1 & -1 \\ -1 & -1 & -1 & 0 & -1 \\ 1 & 1 & -1 & 1 & 0 \end{pmatrix}$
Flows for *i*-alternatives; *i* = 1,2,3,4,5 for alternatives **(A ,B ,C ,D ,E)** **Partial preorder vector *P*, Technique PROMETHEE II**	**Incoming flows**	If(i)	Expresses the weakness of *i* alternative, its dominated character	**Init. Pth.** $(1.417 \quad 1.073 \quad 0.979 \quad 1.677 \quad 0.990)$
				Wgt. Pth. $(1.333 \quad 0.921 \quad 1.083 \quad 1.779 \quad 1.104)$
	Outgoing flows	Of(i)	Represents the power of dominance of *i* alternative, its dominant character	**Init. Pth.** $(1.573 \quad 1.219 \quad 1.344 \quad 0.365 \quad 1.365)$
				Wgt. Pth. $(1.696 \quad 1.463 \quad 1.213 \quad 0.354 \quad 1.496)$
	Net flows (Total preorder)	P_i = Tpf(i)	Tpf(i) = Of(i) - If(i)	**Ini. Pth.** $(0.156 \quad 0.146 \quad 0.365 \quad -1.313 \quad 0.646)$
				Wg. Pth. $(0.363 \quad 0.542 \quad 0.129 \quad -1.425 \quad 0.392)$
RESULTS	**Initial PROMETHEE, Partial Preorder**		**Alternative *i*=5 and 3 have preferences and are not dominated, D is outranked**	
	Initial PROMETHEE, Total Preorder		**Alternative *i*=5 is well preferred, next *i*=3, and then come *i*=1 and *i*=2**	
	Weighted PROMETHEE, Partial Preorder		**Alternative *i*=5 and 3 have preferences and are not dominated, D is outranked**	
	Weighted PROMETHEE, Total Preorder		**Alternative *i*=2 is preferred, next *i*=5, and then come *i*=1**	

Fig. 6. Mathematical elements of erosion and desertification integral control plan using Partial and Total Preorder for Initial PROMETHEE, and for Weighted PROMETHEE.

B. For Weighted PROMETHEE, the criterion 1 (Water erosion index) has double weight 0.2 and the criterion 2 eolian erosion index) has a weight of 0.15, thus the erosions are given more importance; the criteria 3 has also a weight 1.5, and all the others have weight 0.1. That makes for Technique PROMETHEE I totial preorder that alternative (B) is preferred (High value forest), next is (E) (Erosion

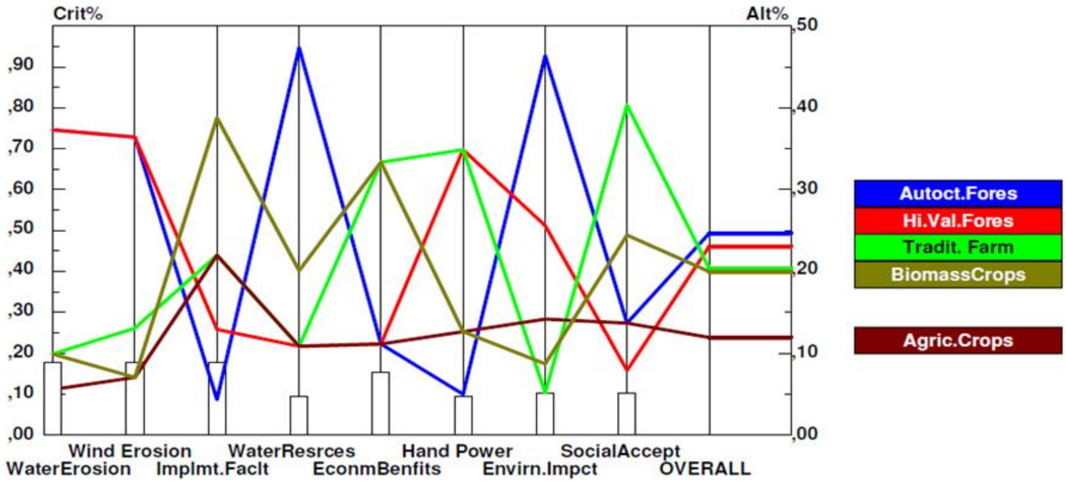

Fig. 7. Graph of Expert Choice AHP application to sub zone La Estrella.

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

	Criteria								
Alternative	WE	EE	IF	WR	EB	HP	EI	SA	Total
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

control crop with industrial use), then (A) (Autochthonous forest), and the alternative (D) (erosion control crop with agricultural use) is by far the last.

C. With Technique PROMETHEE II partial preorder the alternative (D) outranks none and is outranked by all.

D. The weights introduced in Weighted PROMETHEE give importance to erosion, and that is preferable than way because the higher weights for criteria 1 and 2 are due that the authors had given higher importance for erosion criteria when assessing the values of the weights. The Weighted PROMETHEE is preferable that Initial PROMETHEE because the preferences from experts about criteria are incorporated in it.

V. The Weighted PROMETHEE gives preference to alternatives (A) and (B), has was done with ELECTRE, but also to alternative (E), and that is because they take differently into account the criteria for which an it is lower than some others, ELECTRE does by a measure of worst discordance with other criteria and PROMETHEE by adding the unfavorable incoming flows.

3.4 Application of AHP method

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. 7

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, that is more subjective because it starts with decision analyst elicidating subjective degrees of preferences between alternatives.

4 Results and discussion

MCDM has been applied for the six sub zones, and in this work details were given for LA ESTRELLA sub zone. As a result of the whole the Table 5 summarizes the application of MCDM to aid to select alternatives to desertification control and erosion in Salta Province. The large scale results depend much on the sub zone, and the three methods ELECTRE, PROMETHEE and AHP gave results with a significant similarity.

For Las Lajitas sub zone, that is a relatively agricultural flat zone as seen in Fig. 2, the alternative (C) of farms and extensive agriculture is recommended and in fact they grow actually mostly cereals in that area in big plots. A bit at South in J. V. Gonzalez sub zone forest is also recommended, and in fact exist in Fig. 2, irrigation being possible in that area. In La Estrella sub zone the slopes are higher being near elevations at West, and natural or high value forest is recommended by all the methods. The authors have visited South of La Estrella the large farm La Moraleja (of about 40 000 ha), at East of Luis Burela and Apolinario Sarabia small towns, with irrigations from a river, where in alternative (B) they grow trees for wood as teak, cherry tree, walnut tree, in alternative (C) cereals and others including melons and lemons, bringing with buses indian wichi hand power for harvest, and about 30% of surface are original trees in alternative (A).

For Pichanal subzone, in terraces of Bermejo river, the alternative (C) of varied agriculture is found the best, but down river and at NE in M. Hickman natural forest is recommended, it exist being in part degraded. The sub zone Rivadavia is more down river, with less rains and greater danger of floods, primitive occupation with many indian wichi, and much degraded forest, conserving natural forest is recommended, the efforts to enhance quality are difficult in this very large non organized area around Rivadavia.

The design of alternatives and criteria are intended to global studies about the region of study representing Chaco Salteño. The five alternatives represent the real variety of possible farming types that are rather incompatible. The set of eight criteria represents the different consequences when a certain alternative is selected for handling a sub zone. The results depend on the elicitation on the Initial matrixes for ELECTRE and for PROMETHEE methods, and also of the weights. The running of the numerous trials comparing the election of alternatives with the behavior in existing parcels in the field has given reliability and robustness to the results.

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

Sub zone	Method – Better Alternative			
	ELECTRE	Weighted 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

For a special area more detailed sub-alternatives and local properties of soil, rain, floods … will be more precise and can be included adjusting the initial matrixes. The criteria seem robust and include the real scope for decision.

The comparison of the MCDM used was in part done for the sub zone La Estrella case. The results of ELECTRE and PROMETHEE with similar initial data are mainly similar although the presentation is different. The AHP is more subjective in the introduction of data, that could enhance the effect of environmental criteria including erosion and desertification over the economic ones and that has occurred to authors in prior studies for more local especial decisions, but that has not happened in the present study where the environment criteria weights were higher and with decision analysts with deep experience.

The authors have in the past years collected diverse expert information about the area, and they have shown that the MCDM results agree with the real problems for future use of the area and give valuable indications that varies with the sub zone. That included visits to the subareas, meeting with heads of farms, e.g. to the irrigated big farm 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 sub zone is located.

It was necessary as a first step for a large planning process to decide between very different incompatible alternatives, and the discrete methods of MCDM used were adequate for that. The authors have relation with the local universities and agencies, so as to contribute to activities of planning. That planning ought to have a long horizon of 20 years or more and a medium of five years, and indications for a more distant future considering desertification, the different alternatives requiring different periods to be introduced. The future may present differences in agricultural markets, population of the Province and climate. The influence of climate change in the study region as due to the increase of CO_2 in atmosphere is expected to increase slowly temperature and annual rains in actual trends, but surprises may occur, and in fact in Argentina rain will increase and more at NW (e.g. see http://www.ambiente.gov.ar/archivos/web/UCC/File/09ccargentina.pdf). There is a local preoccupation about possible erosions and desertification visible in publications, including webs and journals, and a measured progressive deforestation that has induced conservation laws.

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 Weighted PROMETHEE familiar to 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. The used methods facilitate to enter in contact with the relevant factors that may have an influence on the sustainability of use of the region Chaco Salteño.

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.

A further detailed discussion on the factors introduced on all the Initial matrixes used will be the next step in this research line for a deeper evaluation and comparison among these MCDMs to assess their effectiveness.

Supplementary material related to this article is available online at: http://www.biogeosciences.net/7/3421/2010/ bg-7-3421-2010-supplement.pdf.

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References

Anton, J. M. and Grau, J. B.: The Madrid-Valencia high-speed rail line: a route selection, Transport Journal, Institution of Civil Engineers, UK, 157, 153–161, 2004a.

Anton, J. M., Grau, J. B., and Andina, D.: Electre and AHP MCDM Method Versus CP Method and Official choice Applied to High-Speed Railway Layout alternative election, WSEAS Transactions on Business and Economics, 1(1), 64–69, 2004b.

Anton, J. M., Grau, J. B., and Sánchez, E. M.: Compromise Programming in Financial Analysis for Strategic Management, Transactions of WAC-2004, USA, 17, 555–560, 2004c.

Anton, J. M., Grau, J. B., Tarquis, A. M., and Sanchez, D. C.: MCDM Methods for Territorial Services Planning in an Andine rural area, WAC 2006 Budapest, 24–27 July, IISSCI_13, vol. 5, TSI Press, San Antonio TX (Texas), USA, 2006.

Anton, J. M., Grau, J. B., and Sanchez, E. M.: Compromise programming calibration for financial analysis of firms of a common sector of business, case study for a set of Spanish banks in 1995, Applied Financial Economics, Routledge, UK, 445–461, 2007.

Anton, J. M., Tarquis, A. M., Saa, A., Grau, J. B., and Sanchez, E. M.: Use of Decision Theory for qualification of the lands of the Community of Madrid, Poster in EGU2008, Vienna, 13–18 April, 2008.

Anton, J. M., Grau, J. B., Colombo, F., de los Ríos, L., Cisneros, J. M., Sánchez, M. E., Cabral, C. M., Florentino, R., Tarquis, A. M., and Andina, D.: Elaboración de un modelo matemático para elección de alternativas en un plan integral de lucha contra la desertificación y la erosión en el Chaco Salteño (Argentina), Informe final AECID (Agencia Española de Cooperación Internacional), Final Report for AECI of Project A/013294/07 for 2008, 2009a.

Anton, J. M., Grau, J. B., Colombo, F., de los Rios, L., Tarquis, A. M., and Cisneros, J. M.: Mathematical Model to select the optimal alternative for an integral plan to desertification and control for the Chaco Area in Salta Province (Argentina), oral contribution EGU2009, Vienna, 18–24 April, 2009b.

Bonasso Law: Ley 26.331 – PRESUPUESTOS MINIMOS DE PROTECCION AMBIENTAL DE LOS BOSQUES NATIVOS, Sancionada: Noviembre 28 de 2007, Promulgada de Hecho: Diciembre 19 de 2007, Publicación en B.O.: 26/12/2007, Argentina, 2007.

Brans, J. P. and Vincke, Ph.: A Preference ranking Organization Method, The PROMETHEE Method for Multiple Criteria Decision-Making, Manage. Sci., 31(6), 647–656, 1985.

Brans, J. P., Vincke, Ph., and Mareschal, B.: How to select and how to rank projects: The PROMETHEE method, Eur. J. Oper. Res., 44(1), 138–228, 1986.

Brans, J. P. and Mareschal, B.: The PROMCALC and GAIA Decision Support System for Multicriteria Decision Aid, Decis. Support Syst., 12, 297–310, 1994.

Cisneros, J. M., Cantero, G. A., and Bricchi, E.: Ordenación y Manejo de Cuencas, Una experiencia argentina, in: O solo nos grandes dominios morfoclimaticos do Brasil e o desenvolvimento sustentado, edited by: Alvarez, V. H., Fontes, L. E. F., and Fontes, M. P. F., Vicosa, MG, Brasil SBCS, UFV, 1996.

Colombo Speroni, F., de Viana, M. L., Hernandez, A. M., and Aibar, C.: Native and alien trees in San Lorenzo village, A project with high school students, in: Plant Invasions, Ecological Threats and Management Solutions, edited by: Child, L., Brook, J. H., Brundu, G., Prach, K., Pyseck, P., Wade, P. M., and Williamson, M., Backhuys Publishers, Leiden, The Netherlands, 2003.

Gómez Orea, D.: Evaluación del impacto ambiental, Ediciones Mundi-Prensa, Madrid, 1999.

Grau, J. B.: Curso: Métodos matemáticos para la toma de decisiones, Escuela de Postgrado de la Facultad de Ciencias Naturales, Universidad Nacional de Salta, Argentina, 2003.

Grau, J., Anton, J. M., and Tarquis, A. M.: MCDM Methods for Waste Management Planning in a rural Area, Proceedings of CITSA 2007, session Soft Computing and Signal Processing, Orlando Florida, USA, 15–17 July, 2007.

Grau, J. B., Anton, J. M., Tarquis, A. M., and Andina, D.: Election of water resources management entity using a multi-criteria decision (MCD) method in Salta province (Argentina), Journal of Systemics, Cybernetics and Informatics, available at: www.iiisci.org/Journal/SCI/, First presented in CITSA2008, Orlando, Florida USA, 7(5), 1–7, 2009.

INTA: INTA Cerrillos in Salta Province, Instituto Nacional de Tecnología Agropecuaria, http://www.inta.gov.ar/salta/, 2002.

Paruelo, J.: Elementos conceptuales y metodológicos para la Evaluación de Impactos Ambientales Acumulativos (EIAAc) en los bosques subtropicales, El caso del este de Salta, Fauba, www.agro.uba.ar, also in Agronomía Informa, http://agro.fauba.info, Buenos Aires, 2009.

Romero, C.: Teoría de la decision multicritero: Conceptos, técnicas y aplicaciones, Alianza Editorial, Madrid, 1993.

Roy, B.: Méthodologie Multicritère d'Aide à la Décision, Economica, Paris, 1985.

Roy, B. and Bouyssou, D.: Aide Multicritère à la Décision: Méthodes et cas, Economica, Paris, 1993.

Saaty, T.: The Analytic Hierarchy Process, Mac Graw-Hill, New York, 1980.

Saaty, T.: Multicriteria Decision Making: The Analytic Hierarchy Process, AHP Series (extended edition), Vol. 1, RWS Publications, Pittsburg USA, 1996a.

Saaty, T.: Decision Making for Leaders, AHP Series (extended edition), Vol. 2, RWS Publications, Pittsburgh USA, 1996b.

Salta: Gobierno de la Provincia de Salta Arg., http://www.salta.gov.ar/, 2010.