Discrete Multi-Criteria Methods for lands use and conservation planning on La Colacha in Arroyos Menores (Río Cuarto, Province of Córdoba, Argentina)

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Abstract.

The study area is La Colacha sub-basins from Arroyos Menores basins, natural areas at West and South of Río Cuarto in Province of Córdoba of Argentina, fertile with loess soils and monsoon temperate climate, but with soil erosions including regressive gullies that degrade them progressively. Cultivated gently since some hundred sixty years, coordinated action planning became necessary to conserve lands while keeping good agro-production. The authors had improved data on soils and on hydrology for the study area, evaluated systems of soil uses and actions to be recommended and applied Decision Support Systems (DSS) tools for that, and were conducted to use discrete multi-criteria models (MCDM) for the more global views about soil conservation and hydraulic management actions and about main types of use of soils. For that they used weighted PROMETHEE, ELECTRE, and AHP methods with a system of criteria grouped as environmental, economic and social, and criteria from their data on effects of criteria. The alternatives resulting offer indication for planning depending somehow on sub basins and on selections of weights, but actions for conservation of soils and water management measures are recommended to conserve the basins conditions, actually sensibly degrading, mainly keeping actual uses of the lands.

Keywords: use of lands, water management, soil conservation, discrete multi-criteria methods, environment trend weights.

1. Introduction

The study area is the sub-basin La Colacha (423 km^2) as part at North of Arroyos Menores basin (6753 km^2), containing Rio Cuarto County agro areas at South of Province of Córdoba, in centre of Argentina, at East of an old flat North-South Comechingones chain of mountains with metamorphic rocks, and water flows South-East to the Buenos Aires areas,. Fig. 1 indicates position and erosion aspects of La Colacha, and Fig. 2 the sub-basins of Arroyos Menores, with slopes and types of lands. Rio Cuarto city (33° 08' S lat; 64° 20' W long) is just at East of La Colacha, crossed by Rio Cuarto river that has a flatter basin at North of Arroyos Menores, is head of Rio Cuarto County, contains agro industry, services and the Universidad Nacional de Rio Cuarto UNCR.

The study area is rich for agriculture, as analyzed in (Degioanni, 1998), mainly now with cereals and soybean, and also with cattle, and with trees if slopes are greater. Piedmont strip of lands at West has rocky and sediment soils undulating and erodible, being agricultural frontier, but majority of surfaces are plains formed by agricultural loess with slope gradients varying between 3 % to 0,5 % from West to East, and erosion carry sediments to lowlands at East. Use of land evolves from lands owned by cultivators to the annual renting of lands to agro firms *contratistas*, that produce with few employees winter wheat and transgenic soybean (*Glycine max*) demanded strongly from China to feed cattle. Other products such as cattle have much decreased, partly due to taxes for food exportation. Natural vegetation is only present in mountains, piedmont, river margins, road borders and saline-sodium soils, it varies from open forests and natural low grasses. Biodiversity is reduced in plains by agricultural use, alien species and fire (Cantero et al., 2003).

The upper layers of plains are loess from dust brought by wind from the Andes, of texture sandy loam to loam, of types frequent in Argentine, called Haplustols (Typic) and Entics mainly and Argiudolls Typic and Cumulics in lower parts, with Entisols over old spills and Uptissament Typic and Hapludols entics (belonging to Molisols), and considered in the "Universidad Nacional Rio Cuarto" (UNCR) map of

(Cantero et al., 1986). Climate is sub-humid with monsoon winds with a dry season (June to September), and 70% is concentrated of the 860mm/year rain in hot semester (October to April). Rainfall intensity, has values reaching 100 mm·h^{-1} for 1h rain duration. These loess soils are very fertile but suffer much now in agro areas from water erosions, and especially by regressive erosions that has created hundreds of gullies or "*cárcavas*" through them, such as globally indicated in Fig. 1, being barriers in flat lands, some of more than 3000m length, sometimes increasing 500 m in one year. Some UNRC co-authors of this paper are involved, in relation with Córdoba SECyOT (*Servicio de Conservación y Ordenamiento de Tierras*) officials as in (Cisneros et al., 2012) exposing modern methods for hydro erosion "*Erosion hídrica*" needed now for environmental planning. Earlier from UNCR for such agro areas were (Cisneros et al., 2005, 2008a) and (Cisneros et al., 2011) exposing the GIS (Geographic Information Systems) they had built producing sets of data, used also for the present paper initial matrix (Table 1) for MCDM.

This paper presents a set of DSS (Decision Support Systems) for these Arroyos Menores basins by UNCR and UPM co-authors, with emphasis for La Colacha part. They used discrete multi-criteria models, DMCM, considering a discrete set of alternatives of uses of lands and a discrete sets of criteria that are involved, as they did before in (Grau et al., 2010) for selecting among incompatible alternatives of uses of "Chaco Salteño" soils, following prior uses of these methods as in (Anton et al., 2004a; Anton et al., 2006; Grau et al., 2008). The use of NPV (Net Present Values) or IRR (Internal Rate of Return) was not induced by big investments and profits. Nor the "bayesian" consideration of random external future states, moreover as the "climatic change" from increase of CO_2 is considered relatively soft in Argentina, as causing rather some increases in rain and in temperature.

2. Decision on policies by use of discrete MCDM,

2.1 Multi-criteria methods applied

Following prior experiences, authors used "outranking methods": weighted PROMETHEE and ELECTRE I, adapting MATHCAD ® software as from (Anton et al.; 2004a), (Grau et al.; 2007), (Grau, 2003);

- PROMETHEE from (Brans and Vincke, 1985), (Brans et al., 1986), as weighted PROMETHEE (Brans and Mareschal, 1994), used earlier by authors for Argentina (Anton et al., 2006 and 2010) and (Grau et al., 2008, 2009 and 2010), with lineal initial forms, as in later (Corrente, 2013) e.g..
- ELECTRE I, see Roy (1985), Roy and Bouyssou (1993), adapted to PROMETHEE weights.

They complemented by Analytic Hierarchy Process (AHP), see Saaty (1980, 1996a and 1996b).

For MCDM evolutions as (Figueira, 2006), adaptation to the real situations will guide future MCDM use for these Arroyos Menores areas.

2.2 Alternatives for discrete MCDM

Several general types of use of lands, distinct and not compatible in the same plots or sectors, have been adopted for discrete MCDM studies. That derived from (Grau et al., 2010), but now the deterioration of lands by water is essential, and that induced the adoption of soil conservation (SC) techniques at parcel scale, and of hydrologic management (HM) works at basin scale, also called water management, as from (Zhou et al., 2009). In the presented model a reduced set of uses of soil was adopted:

1. ASP, agro-silva-pastoral use, by combination of {established forests, farming except in mountains, pasture} depending on the capability of soils. May include curtains of forest, alley cropping, bands of forests protecting riversides, forest clumps.

2. ACT, actual soil use, based on actual censed use, e.g. (Cisneros et al., 2008a, 2008b), reference as in (Janssen, 2001). In Arroyos Menores that includes traditional tillage or lands for pasture, following much the natural conditions. The crops are mainly alternation with cereals and soybean in large plots, in general without irrigation. With that climate tillage is often non necessary every year in flat lands. Cattle growing mostly in extensive livestock, with complements as with alfalfa.
3. INT, intensive, more intensive cropping as actual trend (Cisneros et al., 2005; Manuel-Navarrete et al., 2004). Tillage is normal here, irrigation is set if convenient. For cattle in Argentine there is actually tendency to feedlot, where cattle is much concentrated in lots of less fertile lands, nourished with balanced mixtures of maize, soybean and supplements; with controlled systems of waste recycling..

Crop rotation was observed higher with intensification. The crop ratios for soybean to corn ranged from 1:1 to 4:1; the first option was environmentally friendly, and the second is now current in the Pampean region, using genetic modified soybean without tillage, by eliminating previously bad plants with glyphosate.

The alternatives must consider measures classified as:

1. Soils Conservation (SC), especial measures for plots with private investments to prevent erosion including horizontal tillage, but more intensive works may require policies with public administrations. More especial are such as fifty to sixty-meter horizontal interval-graded terraces or pasture buffer strips; binding canals with cover, control of active heads, forestation of basis of gullies, buffer bands of about 14m wide. Other may be regulation ponds (micro-reservoirs) or constructed wetlands (Lasage, 2007) consisted of an earth dam 3 m high with base-spillway discharge for peak runoff reduction. For gullies control by head-cut (point of active retrograde advance, Poesen et al., 2003), maybe by expensive concrete structural spillways or by bioengineering techniques (e.g., Morgan and Rickson, 1995), and gully-floor control.

2. Hydrological Management (HM, *Obras Hidráulicas*), water management, evolving basin-scale technical frameworks designed to reduce peak runoff, increase base flow, reduce sediment (and pollutant) discharge, control gully head-cuts and floor erosion and stabilise the drainage network. Eight types of micro-dams have been designed. At greater scale, dams of some size and descents protected from erosion, some are already done. As examples, Buffer/filter grass and forest riparian strips for permanent streams, intermediate cultivated forest strip and a variable-width native forest strip close to river bed) to reduce meander erosion, Grassed waterways covering temporal streams in the basin.

With the effects of water in that region, the m = 12 adopted i-alternatives were combinations, getting: {1=ASP, 2=ASP+SC, 3=ASP+HM, 4=ASP+SC+HM; 5=ACT, 6=ACT+SC, 7=ACT+HM, 8=ACT+SC+HM; 9=INT, 10=INT+SC, 11=INT+HM, 12=INT+SC+HM}, included in Table 1.

2.3 Criteria for discrete MCDM in Arroyos Menores planning

From UNCR studies on the region, and from MCDM formats from authors for Salta, a comprehensive set of n = 13 j-criteria was adopted and follows, with the j indicated in Table 1, keeping also a balance between agents, as in (Ioris et al., 2008), farmers of high and low basins, agricultural policy makers, environmentalists and other affected social groups as inhabitants of small towns in lowland basins, including all the evident effects. Their relative importance will be mostly considered by sets of weights, adapted to elections of decision maker kind, and a general global long term view will be preferred. The studies from UNCR, in part by co-authors, have obtained reliable values for the criteria, for many from results with units, but others more qualitative got a qualifying index (*qi*.) of valuation in range (1-10) of kind "more is better" elicited by authors. The criteria got indexes $\boldsymbol{I}_j$, elements of a vector $\boldsymbol{I}$, being $\boldsymbol{I}_j$, = 1 for a criterion of kind "more is better" and $\boldsymbol{I}_j$ = -1 for kind "more is worse".

2.3.1 Environmental criteria

A. **Peak runoff (PRU)**, in $m^3.s^{-1}$, maximum runoff of the sub-basin for 80mm rain in 6h, that has approximately 25 years for return period, of kind "more is worse". Runoffs were estimated with a model HEC-HMS (USACE, 2009).

B. **Average annual erosion (ERO)**, mean expected annual soil loss, in $Mg{\cdot}ha^{-1}{\cdot}year^{-1}$; hill-slope erosion is the most used indicator of long-term soil productivity and quality (Agrell et al., 2004; Antoine et al., 1997, Lakshminarayan et al., 1995). Authors used RUSLE 2 (USDA-ARS, 2009) to estimate it, after considering (Dabney et al., 2008).

C. **Sediment delivery (SED)**, in thousands of Mg (metric tons), indicates soil losses getting into a permanent stream, containing also pollutants, of kind "more is worse". Estimated using MUSLE (Williams, 1975), also for deposits in filter strips with (Muñoz-Carpena and Parsons, 2005). Measured differently from ERO.

D. **Index of Environmental Quality (EQI)**, in (*qi.*) range, with maximum value of 6 points, of kind "more is better", derived in the ways with weighted summation of (Gómez Orea, 1999), considering the % of area for pasture, the % for agriculture, diversity in types of vegetation, characteristics of streams, biodiversity, scenic attributes of landscape, margins and corridors with trees, adapted to be used to compare alternatives, not to compare basins.

2.3.2 Economic criteria

Measured for the valuations in this paper in 2010 ARS, "*peso argentino*", when one Euro changed for 5.27 ARS, that shifted reaching 7.55 ARS in September 2013. Capacity for agro exports is essential, Argentina having near 5.5 Mkm^2 with many excellent soils and roughly 40 Mhab.

A. **Investment (INV)**, in millions of ARS, of kind "more is worse", for cost of possible actuations, transformed in annuity in standard ways considering lifetime, not differentiating between public and private sources; 2010 annual opportunity cost under Argentine conditions was taken as 12%.

B. **Maintain costs (MAN)**, in millions of ARS.year^{-1}, of kind "more is worse", annual cost for reparation of works and rural roads, estimated for roads with peak runoff (de Prada et al., 1994).

C. **Soil agricultural loss (SAG)**, in % of the agro surface, of kind "more is worse", estimated from HEC-HMS and VFSMOD (Muñoz-Carpena and Parsons, 2005).

D. **Private benefits (BEN)**, in ARS.ha^{-1}.year^{-1}, private and short term, of kind "more is better", from margin in a typical exploitation (de Prada et al., 2008). The crop-weighted gross margin and the cost values were considered at 2010 prices. Monoculture may increment BEN and degrade more soil, and BEN influences farmers' decisions (Groot et al., 2007; Gil et al., 2008).

2.3.3 Social criteria

A. **Ease for implementation (IMP)**, of kind "more is worse" for the MCDM in this paper, as "time needed for actions" (Degioanni et al., 2000); used also for MCDM in (Grau et al., 2008 and 2009; Antón et al., 2010) indicated in form of a (*qi*.), and used also in (Gonçalves et al, 2007).

B. **Externalities (EXT)**, of kind "more is worse", a measure of off-farm damages effects of agro use, mainly caused from erosion of water from plots, used for multi-criteria studies (de Prada et al, 2008; Paneque Salgado et al., 2006), effects on wetlands below (Cantero et al, 1998; de Prada and Penna, 2009), on roads (Cristeche, 2009).

C. **Social acceptability (SAC)**, necessary for regional planning, e.g. see (Zhen et al., 2007), includes sensibility to environment effects as in (Smith and McDonald, 1998) and about remediation techniques (Gil et al. 2008), measured as in (Grau et al., 2008 and 2009) with a valuation "more is better" scale as (*qi*.) in range (1-10).

D. **Employment impact (EMP)**, measured by the number of jobs generated by an alternative, as principal social criterion, considered of kind "more is better". The employment estimates considered the labour requirements of each crop rotation and forestation. Used similarly with multi-criteria in (Grau et al., 2008 and 2009; Simonovic and Akter, 2006; Paneque Salgado et al., 2006). Estimated following (Llach et al. 2004), depending on type of activity and on the yields of the crops.

E. **Legislation in force (LEG)**, represent the actual legal and administrative support to implementation of an alternative, it was measured by a valuation (*qi*.) in range (1-10) "more is better" scale. The alternative ACT is well for LEG, and actually INT is also well. The conservation of soils is backed by law (Law 8359, Arg., for conservation of soils), but action is voluntary and scarce (Cristeche, 2009). The alternative ASP when getting from farming to forest has legal difficulties, and also Hydraulic Management often needs expropriation.

2.4 Use of discrete MCDM for study area

2.4.1 Initial Matrix

A PROMETHEE Initial Matrix **IM** was adopted for each of the 14 Arroyos Menores sub basins and is indicated in Table 1 for La Colacha, with elements $\mathbf{Im}_{ij}$ valuating the m = 12 i-alternatives for each of the n = 13 j-criteria from the UNCR research, and with files for j-weights.

2.5 System of weights

The authors have tried different systems of weights, normalised to sum 1, that in literature interpret some decision maker DM preferences, as in (Corrente et al., 2013). Previous authors experience is in (Grau et al., 2010), some linked experience is in (Bolte et al., 2006; Janssen et al., 2005), and hypothetical weights distribution has been used to test land management programs (e.g. Prato, 2007). In the real policies and actions necessary for Arroyos Menores there are imprecision on candidates for DM, and the authors have tended to adapt to general planning and actions on uses of soils, long term for conserving lands but with restrictions in use and money. The effects of erosion are evidently important, they had accumulated since the region got agriculture when immigrants settle around 1850 with rail for import of sews and export of products, from Córdoba city areas occupied earlier by Spaniards since about 1573 from Perú, and care with SC and HM appears convenient to avoid spoiling lands. The authors have hence adopted for La Colacha an "environment trend" system of weights EW that is in Table 1.

The criteria are from reality, and some are correlated as ERO, SED and SAG are in part caused by PRU, but ERO and a bit SAG have lower weights, being related to the degradation of soils by erosions, that is to be restricted by actions to continue with agro, making reasonable that system of weights. Other systems were tried, normalised so as to add 1, to study the variation of results, equal weights considered as "social trend weights" SW, and "economic trend weights" RW, taken from "environmental weights" by reducing SED weight and increasing BEN, indicated in Table 1.

2.6 **Application of weighted PROMETHEE method**

I. Adopting PROMETHEE forms J.P. Brans and Vinke (1985), initial "preference functions" $P(i,j,k)$ are

$$P(i,k,j) = \text{if}\left[\ \boldsymbol{I}_j \cdot \left(\mathbf{Im}_{i\,j} - \mathbf{Im}_{k\,j}\right) \le 0\right] \text{ then } 0 \text{ else } p\left(j, \left|\mathbf{Im}_{i\,j} - \mathbf{Im}_{k\,j}\right|\right) \quad ,$$

(1)

where $p(j,x)$ was taken from type "Linear Preference and Indifference Area",

$$p(j,x) = \left\{0 \text{ if } x \le q_j,\ \left(x - q_j\right)/(p_j - q_j),\ 1 \text{ if } x \ge p_j)\right\}, \tag{2}$$

from the 6 types introduced by (Brans et al., 1986), set in modern ways as in (Brans et al., 2005), a rather similar election being in (Corrente et al., 2013), and where q_j is a minimum j-threshold elicited by authors, and p_j a maximum taken for the present paper as

$$p_j = \underset{i,k}{Sup}\ (|\mathbf{Im}_{i\,j} - \mathbf{Im}_{k\,j}|)\,. \qquad (3)$$

where $P(i,j,k)$ is positive if criteria j indicates preference of alternative i over alternative k, null otherwise.

II. Then weighted PROMETHEE defined Preference indexes to have flows as

$$q(i,k) = \sum_{j=1}^{13} P(i,k,j) \cdot w_j \ ,$$

(4)

A. out-going flows favourable for the alternative i as

$$\mathrm{If}(i) = \sum_{k=1}^{13} q(k,i) \ , \qquad (5)$$

B. incoming flows unfavourable for alternative i as

$$\mathrm{Of}(i) = \sum_{k=1}^{13} q(i,k) \ ,$$

(6)

C. and from them net flows (some authors divide all these flows by (m-1), getting lower flows)

$$\boldsymbol{P}_i = \mathrm{Tpf}(i) = \mathrm{Of}(i)\ -\ \mathrm{If}(i)\,. \qquad (7)$$

For PROMETHEE-I technique “Ranking the Actions by a Partial Pre-order”, the elements $\mathbf{CP}_{i,k}$ of a Partial pre-order matrix **CP** are defined as follows:

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

For PROMETHEE-II technique “Ranking the Actions by a Total Pre-order”, the net flows, or total pre-order flows, $\boldsymbol{P}_i$ = Tpf(i) are taken as valuations, they are higher if the i-alternative is better.

The results for La Colacha are in Fig. 3 using the environmental EW weights.

Put in order from PROMETHEE-II P_i , {ACT+SC, ACT+SC+HM} are better, then come {ACT+HM, INT+SC, INT+HM, ASP+SC, INT+HM+SC} grouped, followed by{ASP, ASP+HM, ASP+HM+SC, ACT}, and{INT} is very bad

For La Colacha with SW weights order was {ACT+SC+HM, ACT+SC, INT+HM, ASP+SC} followed by{INT+SC, ACT+HM, INT+SC+HM, ASP+SC+HM, ASP+HM, ACT, ASP, INT}, and for RW weights came {INT+CS, INT+CS+HM, INT+HM, ACT+CS} followed by {ACT+SC+HM, ACT+HM, INT, ASP+SC, ACT, ASP, ASP+SC+HM, ASP+HM} with more differences.

3 ELECTRE and AHP for La Colacha.

3.1 Application of ELECTRE method

The authors applied an older ELECTRE method, following Romero (1993), using MATHCAD with the same data, criteria and alternatives, and sets of weights W_j adding 1, used for PROMETHEE.

A. A Concordance Indexes 12×12 Matrix C_{ik}, valuates advantages of *i*-alternative over *k*-alternative as:

$\mathbf{C}_{i\,k}$ = Sum of the W_j for which ($I_j \cdot (\mathbf{Im}_{i\,j} - \mathbf{Im}_{k\,j}) > 0$), adding only ($W_j / 2$) if ($\mathbf{Im}_{i\,j} = \mathbf{Im}_{k\,j}$), (8)

B. A discordance indexes matrix $\mathbf{D}_{i\,k}$ valuates discordances for that as:

$$\mathbf{D}_{i\,k} = \sup_j \left[\sup \left(I_j \cdot \left(\mathbf{Dm}_{k\,j} - \mathbf{Dm}_{i\,j} \right), 0 \right) \right] \Big/ \sup_j \left| \mathbf{Dm}_{k\,j} - \mathbf{Dm}_{i\,j} \right| .$$

(9)

C. From that, adopting a concordance and a discordance threshold, *ct* and *dt,* authors obtained:

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

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

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

D. If a $\mathbf{Mcd}_{ik} = 1$ there is some dominance of alternative i over alternative k, and if also $\mathbf{Mdd}_{ik} = 1$ there is no discordance for that, and the alternative i is considered preferable to the k one.

An alternative that is better than some of the others and worse to none is "considered in the kernel", as indicated in Fig. 4 for a La Colacha case with the hypothesis and data of Table 1 used for PROMETHEE. The alternative ACT+SC+HM is best for these EW weights, and AST+SC+HM is not dominated, and that was conserved with SW weights, but RW weights give preference for INT+SC+HM. For lower thresholds with the same data other alternatives entered in kernel, all with some SC or HM.

3.2 Application of AHP Method

As in former publications authors used AHP methods, with the alternatives and criteria used before, using their knowledge, reflected earlier in initial matrix data of Table 1, for executing pair-wise comparisons from which EXPERT CHOICE adjusted percentages valuating alternatives for each criteria, and criteria in their superior set, to obtain in upper hierarchy level valuating percentages results for alternatives, the Fig. 5 graphical interface showing columns of valuations, in spirit of "environmental goals" from authors as "Analyst" insisting on avoiding deteriorations of lands. These columns show percentages for each alternative and in last "overall" column the percentages valuating the alternatives listed at right in preference order, obtained with procedures different of precedent methods but with related spirit from the same authors, the ASP+SC+HM getting always a higher value and the ASP lower.

For La Colacha with these "Environmental goals" Fig. 5 preferences end in order {ASP+SC+HM, ACT+SC+HM, INT+SC+HM, ACT, INT, ASP+SC, ASP+HM, INT+HM, ACT+SC, INT+SC, ACT+HM, ASP}. Evaluated for "Social goals" they got more equal {ASP+SC+HM, ACT, ACT+SC+HM, INT+SC+HM, INT, INT+HM, ASP+HM, ASP+SC, ACT+SC, INT+SC, ACT+HM, ASP}, and for "Economic goals" considering more costs and economic results order changed to

{INT+SC+HM, ASP+SC+HM, ACT, INT, ACT+SC+HM, INT+SC, INT+HM, ACT+SC, ASP+SC, ACT+HM, ASP+HM, ASP}.

4 Results for La Colacha

Table 2 contains an extract from precedent results for La Colacha. The Soils Conservation SC and the actions for Water Management HM are recommended and the considered SC enters before HM, Moreover the weighted PROMETHEE method is favourable to ACT, and the ELECTRE and AHP also, but more to ASP or INT depending on the trend or goals. The ELECTRE is marking more ASP, and AHP a bit more with different way for analyst valuations, and the results from PROMETHEE as in Fig. 3 are more clear that results from ELECTRE in Fig. 4. With economic trends the alternatives with INT get at head with the three methods, but the realisation of INT could depend on techniques and markets.

Table 1 contains information from authors from UNCR, and from it effect of changes can be indicated, such as from uses of soils ACT to INT unfavourable for erosions, ACT use to ASP good for them and also for environment and social criteria at serious costs, and the SC and HM favourable effects are measured. The realisation of alternatives in detail will require technical studies and projects, and the authors have done also some quantitative models for La Colacha using continuous MCDM models getting quantities of constructions or percentage for some crops, in ways mostly from (Romero, 1991 and 1993) as was published in (Anton et al., 2012), results being also in (Cisneros et al., 2012) that indicates also research from UNCR for obtaining systems of data for the Arroyos Menores region. La Colacha West part has higher slopes in Fig. 1 and is rather used with ASP, and here separated MCDM will tend in favour of ASP+SC+HM or ASP+SC.

5 Results for all the sub basins of Arroyos Menores

The authors extended such research for all the sub areas of Fig. 2, with adapted Initial Matrixes $\mathbf{Im}_{i\,j}$ as in Table 1, with sets of models {14 sub-basins, 12 alternatives, 3 or 4 methods and 3 weight vectors trends, ... } and a brief summary from results is in Table 3. As sub-areas have differences in soils or slopes some results change, and a little with methods, but moderately. As general preferences: ACT+SC+HM is recommended, SC being before HM, {ACT, ASP, INT} depend on local lands, ASP+HM+SC is good but not for economic trends, INT has problems of environment and costs, economic trends are for it and environment and social trends are against. ASP alone is at worse. There are conflicts of interests of different trends in results, the level of public and private INV has interesting effects on results. ELECTRE is more for ASP than PROMETHEE, and independent AHP has more diverse results.

6 Conclusions

The sub area La Colacha and Arroyos Menores area need active planning and long term actions to adapt productions and to avoid erosions. The authors, after having obtained in UNCR systems of study and data collecting, have incorporated DSS to consider future actions, and expose in this paper a set of discrete MCDM with global alternatives and diverse criteria with evaluated consequences. The results, preferred from weighted PROMETHEE, are in favour of including HM and SC, and recommending ACT use of lands, the ASP use being for higher slopes, the "economy" being in favour of INT indicating rather use of ACT with products well in markets, ELECTRE being less clear and the AHP with different inputs type but with enough concordant results, tending more to include ASP.

These are general indications for a real situation of long term lands management, the DSS situation being imprecise, as officials, land owners, and habitants have diverse goals and money sources, and as the use of lands will depend on evolution of techniques and agro markets. The authors recommend avoiding high land degradation by water erosion by policies with SC and HM, with "environment trend weights" sets, compared with others "social" and "economic" to verify that deviations are prudent. Actuations will by official regulations and credits, but also much by land owners that will produce rentable agro products influenced by markets, HM will be rather by public funds, and SC by private funds aided and regulated by the province, the control of gullies being both by HM and by SC.

There will be a continuous public and private activity on these lands, these MCDM described here being an aid for global indication, that can be followed by adapting models, including the continuous MCDM models tried by authors for special situations, with occasional restrictions on production patterns and on annual expenses e.g..

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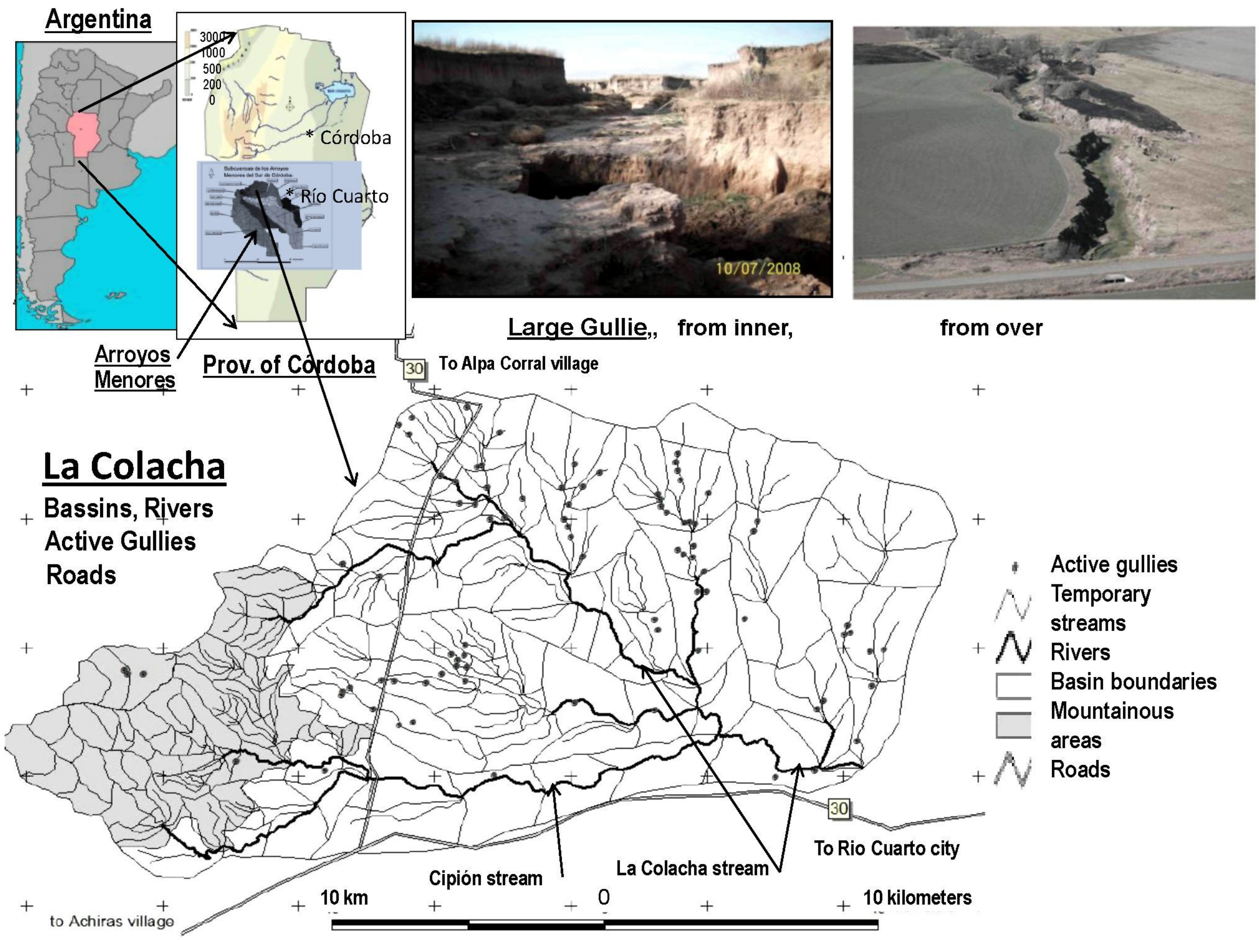
Figure captions

Fig. 1. La Colacha sub-basin of Arroyos Menores, with gullies in loess. .
A North/South chain of old mountains is at West of study areas.

Fig. 2. Slope gradients of La Colacha, and for Arroyos Menores
Slopes, sub-basins, types of lands.
They become flatter down-streams towards SE.

Fig. 3. Results with weighted PROMETHEE I and II techniques
for sub area La Colacha

Fig. 4. Preferences with ELECTRE for La Colacha sub area,
the alternatives in kernel are preferred, and are in grey.



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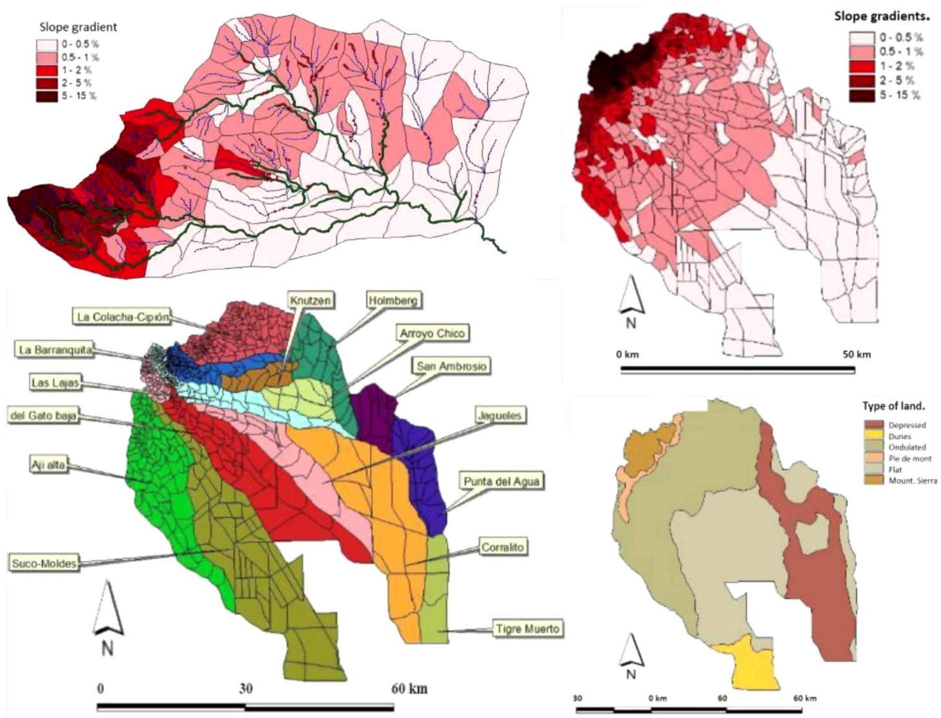

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From Initial Matrix and "Environment trend weights"

I, partial preorder $CP_{i,k}$ matrix, II, total preorder, P_i

1 if altern. *i* outranks *k*, *-1* indeterminate. valuating index

CP=

	1	2	3	4	5	6	7	8	9	10	11	12
1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
2	1	0	1	-1	-1	-1	-1	-1	1	-1	-1	-1
3	-1	-1	0	-1	-1	-1	-1	-1	-1	-1	-1	-1
4	-1	-1	-1	0	-1	-1	-1	-1	1	-1	-1	-1
5	-1	-1	-1	-1	0	-1	-1	-1	1	-1	-1	-1
6	1	-1	1	-1	-1	0	1	-1	-1	1	1	1
7	-1	-1	-1	-1	-1	-1	0	-1	-1	-1	-1	-1
8	1	-1	1	-1	-1	-1	-1	0	1	1	1	1
9	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	-1
10	1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1
11	1	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1
12	1	-1	1	-1	-1	-1	-1	-1	-1	-1	-1	0

P=

	1	**alternative *i***
1	-0.306	ASP
2	0.348	ASP + SC
3	-0.314	ASP + HM
4	-0.451	ASP + HM + SC
5	-0.525	ACT
6	0.912	ACT + SC
7	0.467	ACT + HM
8	0.877	ACT + SC + HM
9	-2.022	INT
10	0.402	INT + SC
11	0.385	INT + HM
12	0.228	INT + SC + HM

Fig. 3. Results with weighted PROMETHEE I and II techniques
for sub area La Colacha

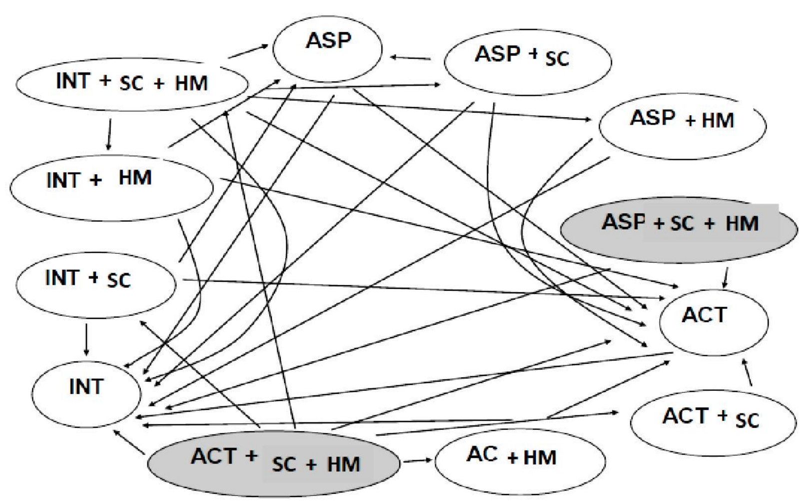

Fig. 4. Preferences with ELECTRE for La Colacha sub area,
the alternatives in kernel are preferred, and **are in grey**

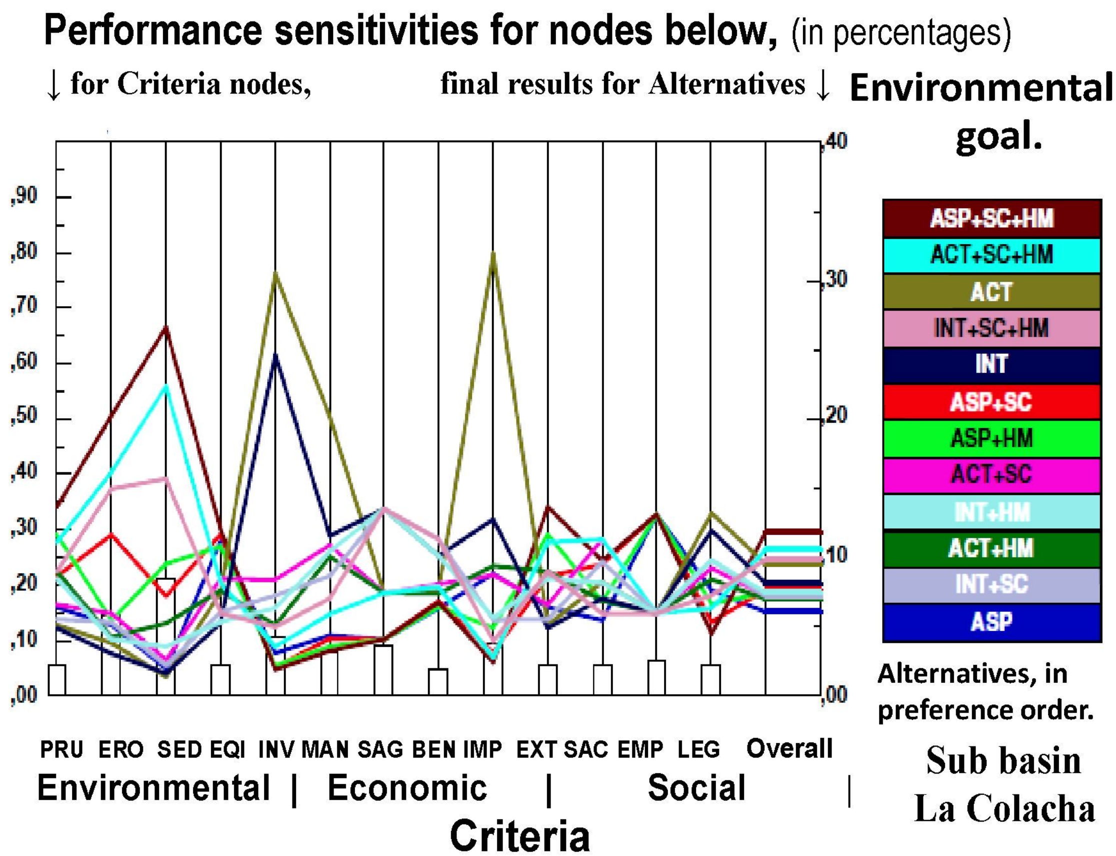

Fig. 5. Graph of an Expert Choice AHP application to sub area La Colacha

Table captions

Table 1. Initial Matrix $\mathbf{IM}_{ij}$ for sub area La Colacha, wit h the "environment trend weights", adding "economic trend weights" and "social trend weights".

Table 2. Compendium of discrete MCDM results for the sub area La Colacha.

Table 3. Summary results of the application of discrete multi-criteria methods to Arroyos Menores basin.

Table 1. Initial Matrix $\mathbf{IM}_{ij}$ for sub area La Colacha, wit h the "environment trend weights", adding "economic trend weights" and "social trend weights".

i	*i*-Alternatives ↓	*j*-Criteria↓; *j*-Weights: W_j; *j*-Indexes: I_j =1 "more is better", I_j = -1 "more is worse" 1 PRU	2 ERO	3 SED	4 EQI	5 INV	6 MAN	7 SAG	8 BEN	9 IMP	10 EXT	11 SAC	12 EMP	13 LEG
1	ASP	337.2	4.2	11.4	6.2	2.3	0.3	41.9	603.7	5.0	30.5	5.0	854.5	6.0
2	ASP+SC	278.1	1.7	4.2	6.6	2.7	0.4	41.9	629.7	9.0	25.1	8.0	854.5	4.0
3	ASP+HM	242.7	3.3	3.0	6.4	3.4	0.6	41.9	603.7	6.0	21.9	6.0	861.9	5.0
4	ASP+SC+HM	213.2	1.0	1.2	6.7	3.9	0.6	41.9	629.7	13.0	19.3	8.0	861.9	3.0
5	ACT	420.5	7.3	23.5	4.6	0.3	0.1	21.0	661.0	1.0	38.0	7.0	382.0	9.0
6	ACT+SC	353.3	3.5	9.7	5.0	0.9	0.2	21.0	705.6	4.0	31.9	9.0	382.0	7.0
7	ACT+HM	278.8	4.7	4.9	4.8	1.4	0.3	21.0	661.0	4.0	25.2	6.0	389.5	6.0
8	ACT+SC+HM	249.8	1.3	1.7	5.0	2.0	0.4	21.0	705.6	8.0	22.6	9.0	389.5	5.0
9	INT	477.3	9.2	33.9	3.6	0.4	0.1	13.0	785.7	3.0	43.1	6.0	382.7	8.0
10	INT+SC	401.6	3.9	11.2	4.1	1.2	0.3	13.0	823.2	6.0	36.3	8.0	382.7	7.0
11	INT+HM	298.8	6.2	7.3	3.8	1.5	0.3	13.0	785.7	6.0	27.0	7.0	390.1	7.0
12	INT+SC+HM	271.8	1.4	1.9	4.1	2.3	0.5	13.0	823.2	10.0	24.6	5.0	390.1	5.0
W_j, environment		**.045**	**.112**	**.209**	**.043**	**.108**	**.077**	**.080**	**.036**	**.089**	**.045**	**.041**	**.066**	**.049**
Wj, social SW		.077	.077	.077	.077	.077	.077	.077	.077	.077	.077	.077	.077	.077
Wj, economy RW		.045	.113	.077	.043	.108	.036	.08	.21	.089	.042	.041	.066	.049
I ; I_j , *j*- indexes		-1	-1	-1	1	-1	-1	-1	1	-1	-1	1	1	1

Table 2. Compendium of discrete MCDM results for the sub area La Colacha.

Discrete MCDM	Set of weights with trend Environmental	Social	Economic
PROMETHEE with weights	**ACT + SC** **ACT + SC + HM**	**ACT + SC+HM** **ACT + SC**	**INT+SC** **INT + SC + HM**
ELECTRE	**ACT + SC +HM**	**ASP + HC + HM**	**INT + SC + HM**
A.H.P.	**ACT + SC + HM** **ASP + SC + HM**	**ASP + SC + HM** **ACT**	**INT + SC + HM** **ASP + SC + HM**

Table 3. Summary results from of discrete multi-criteria methods for Arroyos Menores basin

Sub-basins	**Discrete Multi-criteria Method**								
	ELECTRE			**PROMETHEE**			**AHP**		
	Weight distribution								
	Env.	**Soc.**	**Econ.**	**Env.**	**Social**	**Econ.**	**Env.**	**Social**	**Econ.**
Colacha	**4 – 8**	**4 – 8**	**12** – 10	6 – **8**	6 – **8**	10- **12**	**4-8-12**	4-5-**8**	**12 – 8**
Barranquita	**4 – 8**	**4 – 8**	**10** – 12	**8** – 6	**8** – 6	10-**12**-11	5-**4**-2	**4**-5-**8**	5-**12**-10
Knutzen	**4 – 8**	**4 – 8**	**12 – 8**	6 – **8**	**8**-6-11	**12** - 11	**4-8-12**	**4**-5-**8**	**12-4**-10
Las Lajas	**4 – 8**	**4 – 8**	**12** – 10	**8 – 12**	**8** – 11	**12** – 10	**4-8-12**	**4**-5-**8**	**4-12**-5
A. Chico	**4 – 8**	**4 – 8**	**8 – 12**	**8 – 12**	**8** – 11	**12** - 11	**4-8-12**	**4-8**-5	**4-12-8**
Holmberg	**4 – 8**	**4 – 8**	10 – **12**	**8 – 12**	**8** – 10	**12** - 10	**4-8** -5	**4**-5-**8**	**4**-5-**12**
S. Ambrosio	**4 – 8**	**4 – 8**	**8 – 12**	**8 – 12**	**8** – 10	**12 – 8**	**4-8-12**	**4-8-12**	**4**-12-**8**
P. del agua	**4 – 8**	**4 – 8**	**8**-10-**12**	**8** – 10	**8** – 10	10 – **12**	**4-8-12**	**4**-5-**8**	**4-12-8**
Tigre Muerto	**4 – 8**	**4 – 8**	**8**–10–**12**	**8** – 10	**8** – 10	**12 – 8**	**4-8**-5	**4**-5-**8**	**4-12**-5
Gato Bajo	**4 – 8**	**4 – 8**	10 – **12**	6 – **8**	6-**8**-10	10-**12-8**	**4**-5-**8**	**4**-5-6	5-**12-4**
Corralito	**4 – 8**	**4 – 8**	**8** – 10	**8-12**-10	**8** – 10	**8** – 10	**4-8-12**	**4-8**-5	**4-12**-5
Jagüeles	**4 – 8**	**4 – 8**	**8**-10-**12**	6-**8**-10	6 – **8**	10 – **12**	**4-12**-5	**4**-5-6	**4-12**-5
Suco-Moldes	**4 – 8**	**4 – 8**	10 **– 12**	6-**8**-10	6 – **8**	10 – 6	**4-12**-5	**4**-5-**12**	**12-4**-5
Ají Alta	**4 – 8**	**4 – 8**	**12**	**8** – 6	10 – **8**	10 – **12**	**4-12**-5	**4**-5-**8**	**4-12**-5

Alternatives names replaced by Table 1 numbers:. **4=**ASP+SC+HM, 5=ACT, 6=ACT+SC, 7=ACT+HM, **8**=ACT+SC+HM, 10=INT+SC, 11=INT+HM, **12**=INT+SC+HM. In bold alternatives that include SC+HM. For weights trends: Env. = Environmental, EW; Soc. = Social, SW; Econ.= Economic, RW.