TERRITORIAL PLANNNIG IN A RIVER BASIN WITH HIGH EROSION LEVEL USING MULTICRITERIA DECISION METHODS IN CORDOBA PROVINCE(ARGENTINE)

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ABSTRACT— The erosion-sedimentation-flooding processes in large zones of Argentine are a critical problem that involve complex relationships with technological, economic, social and environmental cause-effect. The increasing of agricultural activities in new areas previously with forestry or pasture could produce irreversible environmental impacts. It is necessary to prepare a spatial plan taking into consideration, economic development, social cohesion, environmental quality and progressive desertification. Multicriteria decision models contribute to the elaboration of that plan and provide an inestimable aid to decision makers. The objective of this paper is to elaborate a multicriteria model applied to the La Colacha Basin (Cordoba-Argentine). La Colacha Basin has 416 km^2, it is a representative basin of a dry-sub-humid area where agriculture practices are progressively increased. Ten alternatives have been evaluated combining: a) **Agro-forest-pastoral** (ASP), **Present use** (ACT) e **Intensive use** (INT), b) with or without **Soil conservation** (CS), y c) with or without **Hydrological arrangement of the basin** (OH). There have been selected 13 criteria. Different Multi-criteria Decision Methods, both of traditional or developed by the authors, have been used.

Key Words: Multi-criteria Decision Methods ,Spatial Planning, Erosion, River Basin Management

1. INTRODUCTION

At present, in Argentine and everywhere the need to develop a strategy to guide the development of the different territories has emerged as an important issue in the policy debate. Governments, International Organizations and Research Institutions are studding the appropriated policies on spatial planning. There is a growing recognition among decision makers at all levels of increasing interdependency between regional policies and spatial planning. It will be necessary to integrate regional or national policies and spatial planning. Within the regional or national policies will be considerate the rural development and the agricultural, environmental, transport, infrastructural, economic and social cohesion, industrial and enterprise policies. Agriculture in developed countries must take into account the food production, profitability, as well as environmental impacts. Environmental impact assessment covers infrastructure investment. Its integration in the decision-making process makes it an important environmental policy tool for influencing the location of projects. It has now become an integral part of land use regulations and permission procedures. The agriculture is ever linked with the use of water resources. The integral water management plans are necessary and consequently so are the river basin management plans. In order to maintain clean waters – surface waters and groundwater-, appropriated regulation must be included in these plans. These regulations have effects on the spatial development, both of urban and rural areas and on the scope and intensity of economic activity. This is true for surface waters and groundwater with increased pollution or eutrophication (agricultural practices, level of waste water treatment).The river basin management plans will require coordination of all measures aimed at water protection including designation of catchment areas subject to or vulnerable to pollution from nutrients. Also, it will require a spatial identification of all activities liable to cause pollution or other impact on water bodies, thus contributing to a more holistic approach to water management.

To aid decision-makers to adopt the best river basin management plans the discrete multicriteria decision methods appear like the most appropriates.

2. OBJECTIVE

The objective of this paper is to develop a Model that try to aid to decision makers to select the best river basin management plan that provide optimal compromise among different policies, agricultural, environmental, transport, infrastructural, economic and social cohesion, industrial, enterprise, tourist policies and rural development. More ambitious than the simple acknowledgement of functional interactions and the development of the synergies which can result, certain activities try to develop integrated and multisectorial approaches with a strong territorial dimension. It is the case of the policy for the integrated development of rural areas and in particular aid for the development and the diversification of agriculture and forestry, development of rural tourism, training measures, etc.

3. STUDY AREA AND METHODOLOGY

3.1 Study area

The La Colacha basin is formed by the junction of La Colacha and El Cipion streams, both being tributary of Santa Catalina stream. It includes an area of 416 km^2 that is extended with altitudes from 560 to 1000 m over sea level (Fig. 1). The relief of that basin is from smooth at East to strongly undulating at West, and has a craggy portion with sierras that has an extension of roughly 17% of the basin (6700 ha).

Fig. 1: La Colacha Basin. Relative location, limits of the sub-basins and drainage network.

The rainfall is on average at 830 mm and concentrated at 80% between October and April. The maximum rains recorded reach 140 mm in 24 hours, and both annual rain and daily maximums have increased in the last years in this region, and that has occurred also in the other wider part of the pampas region.

The soils are loessic, loamy sand to loamy, that originates Typic and Entic Hapludoll.

Actually the use of the land is agricultural-livestock farming on the plains and extensive farming along the mountain ranges. The main degradation processes are the hydrologic erosion originating furrows and with big gullies or ditches ("carcavas"), erosion in permanent rivers, sediments carrying down to the lower basin areas and systematic destruction of road infrastructures, specially the soil ones. In the last years, the tendency of the land use has gone towards more intensive agricultural practices, like wise for the rest of the region.

3.2 Methodology

3.2.1 Multicriteria methods applied

This study has been developed with three MCDM methods adequate for classifying alternatives when the criteria are of rather different nature, and requiring some subjective assignation of values and weights for comparison. Two of them, the ELECTRE-I, used in environmental impact analysis, due to Roy (1985), and the PROMETHEE due to Brans and Vincke (1985), Brans et al. (1986) are outranking methods as using special ranking logics. A version of PROMETHEE modified (see Anton et al. 2007 and 2009, Grau et al. (2008) were also applied. The third is the A.H.P. or "Analytic Hierarchy Process" due to Saaty (1980, 1996a and 1996b), using the commercial software Expert Choice, to ranges alternatives by direct weight assessment comparison made by experts. A comparative exposition of these methods may be found in C. Romero of U.P.M. (1993).

These methods have been used by authors formerly in multiple applications (Anton and Grau 2004a, Anton et al. 2004, 2006, 2007, 2008, 2009; Grau et al. 2007, 2009).

3.2.2 Alternatives

The ten alternatives summarized in Table I have been selected combining the following strategies:

a) Land use.
   - -Agro-forest-pastoral use (ASP)
   - -Actual soil use (ACT)

-Intensive agricultural use (INT)

b) Soil Conservation Practices (CS): Use of techniques for erosion control and to reduce water pollution (terraces and filter strips).
c) River Basin Actions (OH): In order to reduce the flooding, sediment and contaminant load and avoid ditch and stream erosion.

3.2.3 Criteria

Thirteen criteria, and the respectives weights have been applied for the ten alternatives following field research, expert panels, social investigation and personal interviews.

Criterion 1. Peak water flow (QPI): It is the maximum water flow in the basin (m^3/s) due to a maximum rainfall of 80 mm. in 6 hours. This criterion is considered as "more is worst" kind due to a higher peak low imply more hydrologic instability, less water retention and more erosion.

Criterion 2. Erosion rate (ERO): This is the annual average soil lost ($Mg.ha^{-1}.year^{-1}$). It is of "more is worst" kind for any measure of erosion intensity, estimated by RUSLE 2 (USDA, 2009).

Criterion 3. Sediment and pollution rate (SED): It is not redundancy with the criterion 2. It measures the quantity of soil that arrives to the river ($Mg.ha^{-1}.year^{-1}*1000$) It has been considered as of "more is worst" kind.

Tab. I: Alternatives of territorial planning analyzed for the La Colacha river basin

Alternatives	Description
ASP	Agro-forest-pastoral use without spatial planning in the river basin.
ASP + OH	Agro-forest-pastoral use with river basin public planning.
ACTUAL	Actual use(status quo), without soil conservation techniques
ACTUAL+CS	To maintain actual use with active policies of soil conservation
ACTUAL+OH	Actual use jointly with hydrologic river basin planning policies
ACTUAL+CS+OH	Maintaining of actual use jointly soil maintenance and spatial planning policies in the river basin
INTENSIVE	To increase the tendency of the agricultural practice in the use of land
INTENSIVE+CS	Intensive agricultural practices with public policies promoting soil conservation actions in the river basin
INTENSIVE+OH	The intensification of agricultural practices with public hydrologic planning policies
INTENSIVO+CS+OH	Intensive agricultural practices jointly with public policies of soil conservation an spatial planning river basin

Criterion 4. Environment quality rate (CAM): They have been taking into account several factors weighted in a range between 0-1 and as kind "more is better" (dimensionless number, Gómez Orea, 1999).

Criterion 5. Investment in Argentine pesos (INV): The figures (Table II, see below) have been obtained considering only one preliminary action. The investment amount (It has been transformed in a annual payment taking into account the duration of the works and interest 12%. We have considered this criterion as of "more is worst" kind.

Criterion 6. Maintenance cost (MAN): Maintenance cost of the infrastructure on annual basis (In Argentine pesos). For that we have considered this criterion as of "more is worst" kind.

Criterion 7. Agricultural area Loss (SAG): They have been considered the area lost by crops to erosion and sediment control practices (ha). We have used it to calculate the figures HEC_HMS (USACE, 2008) and VFSMOD (Muñoz Carpena y Parsons, 2005). It is considered as "more is worst" kind.

Criterion 8. Short time benefit (BEN): It is a "more is better" kind, (In Argentine pesos).

Criterion 9. Implementation Facility (FIM): It is a "more is better" kind. (In years).

Criterion 10. Long term sustainable productivity (EPR): It is a "more is better" kind. (In years).

Criterion 11. Social Acceptance (ACE): It is a "more is better" kind. (dimensionless number)

Criterion 12. Man Power (EMP): It is a "more is better" kind. (In number of employees).
Criterion 13. Legislation in Force (LEG): The figures have been calculated in a range 0-10. It is a "more is better" kind. (dimensionless number).

4. RESULTS

4.1 Decisional matrix

In the Table II is shown the decisional matrix of alternatives, criteria weights and indexes (- is "more is worst" and + is "more is better").

Table II: Table 2: Decisional matrix for MCD Methods

Alternative	Criteria												
	QPI	ERO	SED	CAM	INV	MAN	SAG	BEN	FIM	EPR	ACE	EMP	LEG
ASP	192	0,94	1,5	6,6	2,38	330,3	24,3	575	8	200	4	956	6
ASP + OH	138	0,94	0,4	6,7	3,38	462,8	24,9	570	10	200	3	970	5
ACTUAL	431	5,39	22,7	4,6	0,24	138,5	18,7	744	1	70	10	475	8
ACTUAL+CS	257	2,40	5,0	5	0,72	163,8	20,1	720	5	150	8	502	9
ACTUAL+OH	272	5,39	5,7	4,8	1,21	229,5	19,5	736	7	70	8	485	7
ACTUAL+CS+OH	170	2,40	1,3	5	1,69	279,6	20,7	712	10	150	7	520	8
INTENSIVO	561	6,49	41,6	3,6	0,30	196,7	6,9	883	3	50	7	270	9
INTENSIVO+CS	431	2,83	10,7	4,15	1,08	294,9	10,4	845	8	100	8	327	7
INTENSIVO+OH	351	6,49	10,4	3,8	1,26	271,5	7,8	873	10	50	8	291	7
INTENSIVO+CS+OH	272	2,83	2,7	4,1	2,03	382,3	11,1	837	10	100	7	336	8
Weights	0,083	0,109	0,063	0,103	0,117	0,033	0,043	0,093	0,038	0,114	0,069	0,076	0,059
Indexes	-	-	-	+	-	-	-	+	-	+	+	+	+

4.2 MCD methods application: ELECTRE-I, PROMETHEE and A.H.P

4.2.1 Application of ELECTRE-I Method

Table II shows the Information Decision Matrix It = (tij) of data elements tij for the 13 jth criteria and the 10 ith alternatives.

The weights of criteria were assessed from results from expert panels and local actors. A weight value Wj, already normalised because sum of j´ was already 1, carefully chosen by the analysts so that the "normalised and reduced j-values $D_{ij}= t_{ij} . w_j / r_j$, where $r_j = (Max_i\ (t_{ij}) – Min\ (t_{ij})>=0$ is the j-variation in the column j of matrix It, have differences D_{ij} - D_{kj}, that are proportional to w_j, trade-off comparable between j-criteria. From these data an alternative i outranks the alternative k, i.e. is ELECTRE preferable to it, if two Concordance and Discordance conditions are both satisfied. For the first a m-square Concordance Matrix C = C_{ik} was obtained, where C_{ik} has been defined as the sum of weights wj for the criteria j in which the value t_{ij} for alternative i is better than the value t_{kj} for the alternative k, adding $w_j/2$ if $t_{ij} = t_{kj}$ if.

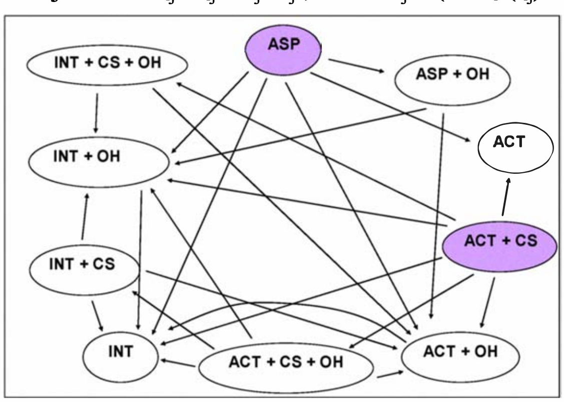

Fig. 1. Graph of ELECTRE I, circles coloured are included in kernel

Note that the amplitudes of differences ($t_{ij} – t_{kj}$) do not interviene. To follow, a Decisional Matrix D=D_{ij}, "normalised and pondered", was obtained by $D_{ij} = t_{ij} . w_j/r_j$

To consider Discordance, an m square Discordance Matrix Dsc = (Dsc_{ij}) was obtained as $Dsc_{ik} = Max_j \{Max[(D_{kj}- D_{ij}) * I_{j,} 0]\}/ Max_j\ [D_{ij}– D_{kj}]$ giving a relative index in range (0,1) telling how worse is the alternative i than alternative k for the single worse j-criteria. Table III shows Concordance and Discordance matrixes, obtained with MATHCAD (version 8 Professional of Mathsoft) , and first values for thresholds ucc and uds. The kernel of ELECTRE I are shown in Fig. 1.

4.2.2 Application of PROMETHEE Method

The authors have used the Preference Ranking Organization Method (The PROMETHEE Method for Multiple Criteria Decision-Making). This is an outranking method, as ELECTRE due to B. Roy or A.H.P. 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.

Type I is the usual criterion, and it has been used in this work. With this criterion if f(a) = f (b) this is indifference between a and b. If this is not the case the decision-maker has a strict preference for the action having greatest value. Let now define preference indexes (0,1) as a measure of the preference of alternative i over alternative k for all n j-criteria, like a flow from i to k in a “valued outranking graph”: the closer to 1, the greater the preference. Let consider for each alternative i an outgoing flow telling about how much it dominates, and an incoming flow telling about how much it is dominated. The alternatives, called now Actions, are PROMETHEE-II ranked by a Total Pre-order by the total flow equal the difference between outgoing and incoming flow.

The authors following have modified the method using for the criteria weights similar as those used in ELECTRE.I Method. Results are shown in Fig. 2.

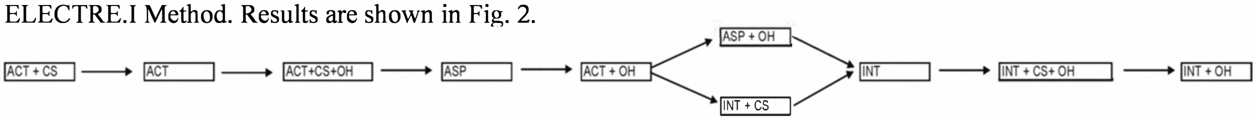

Fig 2. Promethee II ranking of alternatives.

4.2.3 Application of A.H.P. Method

The AHP method relies of successive assessments of experts, and was done using EXPERT CHOICE (EC) software, inspired partly by the ELECTRE, starting with the same list of criteria, called here objectives, that were put in a hierarchical form. In AHP the evaluating team makes at various hierarchical growing levels comparisons about criteria resulting in successive ranking value indexes. Only a relative comparison measure is data for AHP, that is somehow more subjective at start that the precedent methods.

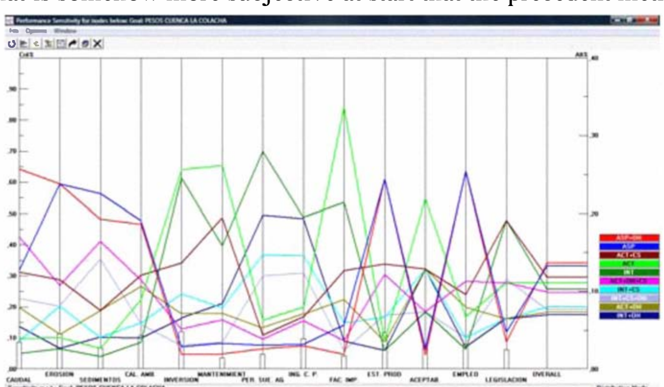

Fig 3. Perfomace sensivity graph of Expert Choice.

The obtained Performance Sensitivity-Graph of Figure 3 contains some data and results, showing that with such more subjective procedure, the alternatives ASP+OH has got a higher preference.

4.3 Selection of alternatives

In Table III are shown the results of application of the different MCDM to selection of alternatives to La Colacha basin.

Tab. III: Summary of results of MCDM application to La Colacha basin.

MCD method	**Alternative choice**
AHP	ASP+OH similar to ASP - ACT+CS
ELECTRE	ASP - ACT+CS
PROMETHEE original	ACT+CS – ACT - ACT+CS+OH
PROMETHEE Modified (Antón et al, 2006)	ACT+CS - ACT+CS+OH – ASP

5. CONCLUSIONS

The outranking methods (ELECTRE and PROMETHEE), for this case, are more appropriated than AHP which require more subjective assignation of values and weights for comparison.

From the results we can conclude that would be necessary to apply soil conservation public policies on the studied river basin. The maintenance of the present agricultural practices jointly with the soil conservation technique could be the best alternative to be included in the provincial government territorial plan.

In spite of the agro-forest-pastoral, jointly with hydrologic planning could be a good alternative and must be considered

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