An operative Decision Support System for Integrated Coastal Management: An application to the Reghaïa lake, Algeria

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Abstract

In this paper, a decision support system (DSS) for an integrated coastal management (ICM) is developed, where decisions arise from a maximisation algorithm, the stakeholders' involvement in the choice among alternative management strategies is favoured, complicated assessment procedures for non-economical indicators or relative weights to combine economic, social and environmental indicators are not used, the integration between economic activities and environmental status is depicted by referring to initial and sustanability conditions, both human and environmental dynamics are taken into account, a spatial structure is adopted, by finding a compromise between economic information (available at macro-level) and ecological information (available at micro-level), several economic, social and environmental policies are considered, predictions are based on a knowledge base that can be easily collected and that is reasonably reliable, by calculating the confidence level of results. Its application to Reghaïa and Heraoua municipalities, Algeria, suggests that the suggested DSS for an ICM meets all design and role characteristics required by Westmacott (2001) *Journal of Environmental Management* 62: 55-74.

Keywords: decision support system, integrated coastal management

1.Introduction

Intensive efforts by scholars in different disciplines has allowed to achieve a comprehensive definition of the Integrated Coastal Management (ICM): a dynamic, multidisciplinary, iterative and participatory process to promote sustainable management of coastal and ocean areas, by balancing environmental, economic, social, cultural and recreational objectives over long-term, and by taking into account the relevant ecological, social, cultural and economic dimensions and the interactions between them within a defined geographical limit (Chua, 1993). More recently, it has been stressed that all ICM initiatives must be designed to meet the following three requirements (Olsen, 2002): they must be sustainable over long periods of time (see also Hanson, 2003); they must be adaptable to conditions that often change rapidly (see also Zagonari, 2007); they must provide mechanisms that encourage or require particular forms of resource use and collaborative behaviour among institutions and user groups (see also Stojanovic *et al.*, 2004).

On the contrary, spare efforts did not allow to develop an agreed decision support system (DSS) taking into account both economic and environmental, as well as social dimensions (Westmacott, 2001).

In particular, within recent **papers by academic researchers**, for example, Peng et al (2006) suggest a cost-benefit analysis (CBA) approach to assess the overall benefits associated with an ICM programme, by measuring the net present value of both economic and environmental effects. However, they do not apply a maximisation algorithm (but a discounted sum of differences), they rely on the standard evaluation procedures of environmental benefits and costs (e.g. replacement costs such as the cost of beach nourishment, and market prices such as the value of lost land), and they do not consider interactions between environmental and economic issues. See also De Kok et al. (2001), Daniel and Abkowitz (2005), Christie (2005), and Sardà et al. (2005).

Moreover, within recent **reports by international institutions**, for example, UNESCO (2006) suggests to refer to a driver-pressure-state-impact-response (DPSIR) framework to analyse linkages among socio-economic trends, ecological phenomena and institutional responses, and to move away from purely environmental and process-oriented indicators (such as ecosystem-based approaches) in order to integrate governance, ecological and socio-economic dimensions into outcome-oriented frameworks (i.e. a sustainable development approach), by providing a menu of indicators. However, it does not suggest a maximisation procedure (but a management fine-tuning based on an implementation monitoring), and it provides a list of significant (at all spatial scale and temporal scale) indicators that are difficult to measure (e.g. loss of natural barriers, surface and groundwater depletion, social cohesion, cultural integrity). See also CBD (2004) and CEC (1999).

Finally, within recent **DSS packages by international institutions or academic researchers**, SIMLUCIA refers to land uses, it focuses on climate change and it has two scales of operation, but it is not objective driven and a limited number of criteria can be considered; CORAL identifies the least-cost solution, includes different growth scenarios and management policies, and predicts average water quality, but it utilises stakeholders interviewers for the model development and expert judgements for the model calibration, and it deals with limited data in ecological components; SIMCOAST associates a level of confidence to each rule and parameter, but it is unable to account for trans-boundary issues, because interconnections are defined between one factor and one activity; NOAA ICM TOOL determines the total values or scores under alternative scenarios, but it does not consider interactions between environmental and economic issues. See also WADBOS, MANS, Rasch et al. (2005) and Vallega (2005).

The purpose of this paper is to develop a DSS for an ICM that exploits the potentials highlighted above (a CBA outcome-oriented approach, the economic, social, and environmental indicators within a DPSIR framework, alternative spatial and temporal scales as well as alternative scenarios and policies, a level of confidence of outcomes, an overall value of management strategies), and that deals with the inadequacies sketched above (the lack of optimisation procedures, the application of disputable evaluation procedures, the use of problematic indicators, the use of limited number of economic and ecological criteria, the reference to stakeholders for the model development and calibration, the lack of interactions between economic and environmental issues), in order to meet the requirements specified in the definition stated above.

Although Prato (2007) does not include social indicators, it applies relative weights within a Multi-Criteria Analysis (MCA), it does not formalise the integration between the economic activities and environmental status, it refers to private resources, and it does not consider human and natural dynamics, its recent contribution to the Multi-Objective Land Use (MOLU) literature by will represent the stating point here: indeed, he provides decisions on which project to choose, based on a multi-objective max-min approach, given characteristics of patches and objectives of decision-makers. See also Wang et al. (2004) and Matthews et al. (2006).

Two main kinds of interactions between economic activities and the environment can be observed: coastal erosion, subsidisation, sea level rise, flooding, salt water intrusion affect coastal economic activities, which in turn might lead to different surface and ground water depletion, solid, liquid and aerial pollutions, and land degradation; alternatively, coastal economic activities affect the environment through solid, liquid and aerial pollutions as well as through water and land exploitation, which in turn might impact the same or other local economic activities. The focus here will be on the second kind of interactions, and specifically on surface and ground water depletion and pollution.

Therefore, this paper aims at setting up a spatial simulation model with the following features:

- Decisions arise from a maximisation algorithm, with an elicitation of future decisions (including the acceptance of the status quo) as well as a check for past decisions
- Several economic activities are considered (e.g. agriculture, industry, tourism, fishery), in order to favour the stakeholders' involvement in the choice among alternative management strategies
- Several environmental and social indicators are considered, without referring to complicated assessment procedures for non-economical indicators, and without using relative weights to combine economic, social and environmental indicators
- The integration between economic activities and environmental status is depicted objectively, by referring to initial and sustanability conditions: both private and public environmental resources can be analysed
- A long-run perspective is adopted, in order to take into account both human dynamics (e.g. population or sectoral growth), and environmental dynamics (e.g. coastal erosion, saltwater intrusion, subsidence, flooding)
- In order to take into account peculiarities of the areas analysed, a spatial structure is adopted, by finding a compromise between economic information, available at macro-level, and ecological information, available at micro-level: both a large or a small scale can be applied
- An overall value is attached to each alternative management strategy, by highlighting its social and environmental impacts
- Several economic, social and environmental policies are considered, in order to identify their impacts on optimal decisions
- In order to balance generality, precision and realism, predictions are based on a knowledge base that can be easily collected and that is reasonably reliable, by calculating the confidence level of results
- The suggested decisions and the performed assessements are presented within the Geographical Information System (GIS), in order to make them immediately intelligible.

The main results produced by the analysis in this paper can be summarised as follows. An optimal land use allows to achieve a remarkable increase in total GDP; water policies affecting its quantity appear to be more urgent than those affecting its quality; all quantity water policies combined allow to reach the sustainability of optimal land use in dry and very dry years, where groundwater shortages arise; the industry sector is held back by its groundwater demand rather than its environmental impacts, the urbanisation sector should be developed to meet social dynamics, the agriculture sector is residual, and the tourism sector should be developed, provided both quantity and quality water policies are implemented; a greater attention should be paid to BOD discharged in the aquifer and in the sea with respect to COD discharged in the aquifer, the lake or the sea.

The structure of the paper is as follws. Section 2 develops the model, while in section 3 the case study selection is motivated. Section 4 calibrates the model, while in section 5 the main results of numerical simulations are presented. Section 6 summarises the main insights, while an overall assessement of the model is discussed in section 7.

2.The model development

The purpose of this section is to develop a DSS that meet all requirements identified in section 1. Let us preliminary observe that normal small letters will refer to parameters, while bold and normal capital letters will be used for decision and state variables, respectively.

Let us assume that there are *I* areas *i*, (say, *i* = 1, 2, …, *I*) where potential alternative activities *j* (say, *j* = agr, ind, tou, fis, urb, … *J*, for agriculture, industry, tourism, fishery, urbanisation, …) can be undertaken. For example, in area 1 one must choose between agriculture and industry, in area 2 between agriculture and urbanisation, in areas 3 one must choose between tourism and urbanisation. A GDP per Km2 is attached to each area (similarly to Gao et al., 2007), according to the potential activity to be undertaken. The reference to several economic activities will allow to represent local stakeholders.

Notice that this procedure will assess direct values of each area only, while an Input-Output approach could be used for indirect value assessments. Moreover, this makes the model an area based planning tool. Finally, this structure can be expanded to any number of areas, with many areas if a micro spatial scale is chosen.

Next, let us assume that there are some environmental sites *s* (say, *s* = riv, lak, sea, coa, …, *S*, for river, lake, sea, coast, …), around which potential alternative activities *j* can be undertaken, according to the environmental status *k* (*k* = 1, 2, … *K*) characterising them. For example, around a lake, either tourism or agriculture can be planned, according to the lake water quality; along a coast, tourism or urbanisation initiatives could be compared; in the sea, either fishery or marine protected areas can be planned, according to the sea water quality. A single parameter is introduced for evaluating one Km2 of pure environment, in order to avoid the reference to complicated assessment procedures for non-economical indicators.

Notice that this structure can be expanded to any number of activities, in order to take also into account several types of urbanisation, several types of crop patterns, … Moreover, the identification of the alternative possible activities for each area depends on the assumed time horizon, with a longer horizon allowing a larger set of potential activities to be implemented. Finally, values of activities are often known at a larger spatial scale than the scale actually chosen, typically at regional rather than at municipal level, but a statistical test can be developed, by relating the variance of each activity value around the applied mean and the significance of overall model outcomes.

The decision to be taken at time t+1 is about which activity *i* to undertake in each site *j* identified by decision-makers $\mathbf{D_{i,j}(t+1)}$, such that $\mathbf{D_{i,j}(t+1)} = 1$ if it is chosen to do activity *j* in area *i* at time t+1, while $\mathbf{D_{i,j}(t+1)} = 0$ if it is chosen otherwise. An activity chosen at time t+1 might be different from an activity chosen at time t: for example, $\mathbf{D_{i,j}(t+1)} = 1$ and $\mathbf{D_{i,j}(t)} = 0$. The activity change in area *i* produces a value change of area i $\Delta V_i(t)$, that depends on the difference in GDP per Km2 between the new and the old activities ($v_{j'}$ and v_j), and on the extension of the area under consideration (A_i), so that $\Delta V_i(t) = A_i\,[v_{j'}\,\mathbf{D_{i,j'}(t+1)} + v_j\,\mathbf{D_{i,j}(t+1)} - v_j\,\mathbf{D_{i,j}(t)}]$ is the value change of area *i* if the activity *j* at time t is replaced by the activity *j'* at time t+1. The activity change in area *i* produces a change in total pollution *k* in site s (with *k* = biologic, chemical, metallic, …) such that $\Delta P_{k,s}(t) = A_i\,[p_{k,j'}\,\mathbf{D_{i,j'}(t+1)} + p_{k,j}\,\mathbf{D_{i,j}(t+1)} - p_{k,j}\,\mathbf{D_{i,j}(t)}]$ is the the change in the k-th pollution, if the activity j at time t is replaced by the activity *j'* at time t+1, where $p_{k,j}$ is the k-th pollution per Km2 characterising the activity j.

Notice that this structure can be expanded to any number of environmental indicators for each site, in order to take also into account solid and air quality status. Moreover, the linkages between activities undertaken in area *i*, and the pollution discharged in site *s*, are based on hydrological analysis, i.e. the model is intrinsically a multidisciplinary model. Finally, environmental indicators are chosen for their patent impacts on activities to be considered.

The total additional pollution in each enviromental site *s* has an effect on values of activities j relying on it, so that v_j is reduced by multiplying it by the factor $E_{k,s} = (\max P_{k,s} - P_{k,s}(t) - \Delta P_{k,s}(t))/(\max P_{k,s} - P_{k,s}(t))$, where $P_{k,s}(t))$ and $\max P_{k,s}$ are the current *k*-th pollution and the maximum sustainable *k*-th pollution in site *s*: indeed, $E_{k,s} = 1$ if $\Delta P_{k,s}(t)) = 0$, while $E_{k,s} = 0$ if $\Delta PK_s(t) = \max PK_s - PK_s(t)$.

Notice that $E_{k,s}$ represents the *integration* between economic activities and the environmental deterioration, by internalising its effects: for example, the value of GDP per Km2 for tourism must be reduced to take into account the public health issues linked to the pollution level in the sea. Moreover, $E_{k,s}$ depends on initial conditions: indeed, a given environmental deterioration should show a small impact in case the initial pollution level is low, and a large impact in case the initial pollution level is close to its sustainable maximum. Finally, $\max PK_s$ depicts the *sustainability* of economic activities, by making static a concept that is intrinsically dynamic: for example, international, national or regional institutions might have assessed that the pollution load per year in the sea can not exceed a specified level, once all environmental features are taken into account.

The following *simplifying assumptions* are made:

- The integration factor $E_{k,s}$ is assumed to be linear in $\Delta P_{k,s}(t)$, but alternative functional forms could have been adopted.
- The impact of pollution on economic activities is instantaneous, while it takes $h_{j'}$ periods for the activity $j' \neq j$ to produce the value difference in site *i*: $\Delta V_i(t) = (1/(1+r)^\wedge(t+h_{j'}))\, A_i\, [v_{j'}\, \mathbf{D_{i,j'}(t+1)} + v_j\, \mathbf{D_{i,j}(t+1)} - v_j\, \mathbf{D_{i,j}(t)}]$, where r is the interest rate
- The value of economical activities in site *i* is evaluated per year, hence the value of the pure environment in site *i* is also evaluated per year.

Several *economic constraints* could be considered. For example, the demographic pressure is met:

$$\sum i\ A_i\, \mathbf{D_{i,urb}(t+1)} \geq H(t+1)/h$$

where H is the additional inhabitant expected at time t+1, due to human dynamics, and h is the inhabitant per Km2. Similarly, an expected industrial growth could be depicted.

Several *social constraints* could be considered. For example, unemployment level must be fixed:

$$\sum i\ A_i\, [\sum j\ ej\, \mathbf{D_{i,j}(t+1)} - ej\, \mathbf{D_{i,j}(t)}] \geq 0$$

where ej is the employment per Km2 characterising the economic activity j. Analougously, an even distribution among stakeholders of benefits arising from alternative management strategies could be included.

Several *environmental constraints* could be considered. For example, the use of water must be sustainable:

$$\sum i\ A_i\, [\sum j\ wj\, \mathbf{D_{i,j}(t+1)} - wj\, \mathbf{D_{i,j}(t)}] \leq \Delta W(t+1)$$

where wj is the water use (CM/Km2) characterising the activity j, while ΔW(t+1) is the expected change in available water at time t+1, potentially affected by natural dynamics. Additionally, sea level rise or subsidence could have been depicted, by introducing constraints arising from expected changes in coastal lines.

Notice that considering economic, social and environmental indicators as contraints avoids to refer to complicated assessment procedures for non-economical indicators.

Therefore, the DSS for an ICM can be formalised as the choice of decisions $D_{i,j}(t+1)$ for each site *i* and activity *j* in order to maximise the additional value per year:

$$\text{Max} \sum i\ A_i \sum j\ (1/(1+r)^\wedge(t+h_j))\, [\textstyle\prod_k E_{k,s}\, v_{j'}\, \mathbf{D_{i,j}(t+1)} + \prod_k E_{k,s}\, v_j\, \mathbf{D_{i,j}(t+1)} - \prod_k E_{k,s}\, v_j\, \mathbf{D_{i,j}(t)}] -$$
$$- \sum i\ A_i \sum_k \sum_s c_k\, \Delta P_{k,s}(t)\, \mathbf{D_{i,env}(t+1)}$$

Subject to:

$$\sum i\ A_i\, \mathbf{D_{i,urb}(t+1)} \geq H(t+1)/h$$
$$\sum i\ A_i\, [\sum j\ ej\, \mathbf{D_{i,j}(t+1)} - ej\, \mathbf{D_{i,j}(t)}] \geq 0$$

$$\sum i \; A_i \left[\sum j \; w_j \, \mathbf{D_{i,j}(t+1)} - w_j \, \mathbf{D_{i,j}(t)}\right] \leq \Delta W(t+1)$$

where c_k is the cost to clear each *k*-th pollution unit, and $\sum i \; A_i \sum_k \sum_s c_k \, \Delta P_{k,s}(t) \, \mathbf{D_{i,env}(t+1)}$ is the cost to be borne if an environmental use is chosen for area i.

Five observations are worthy here. First, several numerical simulations with alternative values attached to the pure environment (equal to the objective values of economic activities) avoid the use of relative weights to combine economic, social and environmental indicators. Second, the application of the model to times t and t-1 would allow to assess the overall values of decisions taken in the past. Third, the suggested framework and the applied procedure are straightforward, while the only parameter that is not objectively specified is the value of the pure environment in terms of the values of the alternative economic activities: this favours the discussion between stakeholders. Fourth, simulations performed with and without alternative environmental policies (say, an increase in depuration rate, an increase in water saving, …) would assess their impacts on optimal decisions as well as their overall benefits or costs. Fifth, results of numerical simulations can be easily depicted within a GIS framework, where different decisions in each area can be represented in different colours, while histograms can be superimposed to represent changes in economic, social or environmental indicators in each area.

3.The case study selection

In order to meaningfully apply the DSS for an ICM developed in section 2, we looked for a case study characterised by the following essential features:

- The presence of some crucial economic activities: e.g. tourism, industry, agriculture, urbanisation, fishery
- The existence of some essential environmental functions: e.g. river, lake, coast, sea
- The prediction of some human dynamics: e.g. population and industry growth
- The existence of some social constraints: e.g. overall unemployment level, net benefit distribution among stakeholders
- The prediction of some environmental constraints: e.g. groundwater and surface water availability, seismic areas
- The estimation of some environmental dynamics: groundwater reduction (due to climate change and salinity intrusion), coastal erosion (due to sand extraction and subsidisation)
- The presence of some environmental policies already under discussion: a decrease in water pollution (due to an increase in the depuration rate), a decrease in water consumption (thank to new irrigation technologies in agriculture), an increase in water availability (through an increase in desalinisation or a re-use of waste water in agriculture)

These features have been identified in Reghaïa and Heraoua municipalities, in the Province of Alger, Algeria. Indeed, as far as *the geographical characteristics* depicted above, these two municipalities include the Reghaïa lake and they have the beach of Boumerd: the lake is a Ramsar site, i.e. it shows an acknowledged environmental value, and it is currently used for water to agriculture mainly by Reghaïa municipality, and it could potentially represents the stimulus for a tourism development mainly for Heraoua municipality; next, the beach of Kadous is in front of the Ile Aguéli marine protected area, i.e. it shows a certified environmental value, and it could further exploited to move from a trip tourism to a residential tourism by both municipalities.

Notice that Heraoua well represents an agriculture-driven economy, while Reghaïa well depicts an industry-driven economy.

As far as *the base of knowledge* highlighted above, these two municipalities have been included in several research projects (e.g. the Algerian coast Management through Integration and Sustainability, AMIS, within the Short and Medium Action Plan, SMAP, supported by the European Union, and the Programme d'Amenagement Cotier, PAC, within the Plan Bleu, supported by the United Nations) so that a lot of information is available, often at municipality level, sometime at provincial or regional level.

Three observations are worthy here. We chose to carry out the analysis at municipality level, but the introduction of a continuous control variable will show that a larger scale could be considered too, by specifying the relative importance of economic activities or environmental functions in each area. Moreover, the chosen area does not allow to focus on fishery activities, because there is no aquaculture near the coast; similarly, a river is not significant, while other issues are not considered because of the lack of reliable information. Finally, we chose to apply the model to a developing country, where decisions have to be taken about future uses in some areas, but the reference to past decisions will show that a developed country could also be considered, by identifying areas where a restructuring process should take place.

4.The model calibration

The purpose of this section is to calibrate the model developed in section 2, by referring to data for the municipalities identified in section 3, at municipal (Commune) level, if possible, and at Provincial (Willaja) or Regional (PAC) level, otherwise. Let us preliminary observe that the industrial oriented economy and the agricultural oriented economy characterizing Reghaïa and Heraoua, respectively, suggested to carry out separate calculations for these municipality, and then to take an average for each indicator, by referring all indicators to one Km2.

In particular, as far as **water uses**, PAC, *Gestion integree des resources en eau at assainissement liquide* (2004) specifies the amount of water used and paid by industry, service and urban sectors both in Reghaïa and Heraoua (28044, 127688, 899972 CM, and 454, 38213, 183284 CM, respectively), as well as the leakage rate (50%) and the coverage rate of the public water network both in Reghaïa and Heraoua (54.7% and 62%, respectively): this allowed to calculate the amount of surface water used in sectors other than agriculture. It is then assumed that the complementary amount of water for the urban and service sectors is obtained from groundwater with no leakages, while groundwater use for the industry for both Reghaïa and Heraoua is set to 6 MCM, as suggested by PAC, *Rapport finale integre* (2006).

Besides, PAC, *Action pilote: site du lac de Reghaïa* (2005) shows the agricultural patterns in Reghaïa and Heraoua as well as the average use of water in agriculture per hectare (4000 CM): combined with information about land use, this lead to the amount of surface water used in agriculture, by applying the ratio between surface and groundwater uses (1/3), as suggested by PAC, *Rapport finale integre* (2006) at regional level to Reghaïa, and the opposite ratio to Heraoua, as suggested by local hydrological analysis.

Table 1. Surface and groundwater uses, for agriculture, industry, service, and urbanization sectors.

CM/Year	Reghaïa	Heraoua	Total	Reghaïa CM/Km2	Heraoua CM/Km2	Average CM/Km2
Surface water						
Agr	4.104.621	838.662	4.943.284	300.000	100.000	**200.000**
Ind	102.537	1.465	104.002	32.903	18.939	**25.921**
Ser	466.793	123.268	590.061			
Urb	3.290.574	591.239	3.881.813	541.851	230.687	**386.269**
Total surface water	7.964.526	1.554.633	9.519.159			
Groundwater						
Agr	1.368.207	2.515.987	3.884.194	100.000	300.000	**200.000**
Ind	61.907	1.195	6.000.000	19.865	15.450	**1.878.686**
Ser	281.828	100.561	382.388			
Urb	1.986.693	482.326	2.469.019	327.144	188.192	**257.668**
Total groundwater	3.698.635	3.100.068	12.735.602			

Notice that PAC, *Le cout de la degradation de l'environnement cotier en Algerie* (2005) seems to validate the above procedures and assumptions, because its assessment of water uses for Reghaïa and Heraoua municipalities in sectors other than agriculture, combined together and approximated to MCM, are consistent with the water uses obtained by the calibration suggested above: indeed, the total amount of water used is said to be around 14 MCM (which is similar to 14.427.284). **Next**, for the sake of simplicity, water uses by the tourism sector will be assumed to be equal to those for the urban sector.

As far as **pollution**, PAC, *Gestion integree des resources en eau at assainissement liquide* (2004) specifies the total discharge per year of BOD and COD for the industrial district of Reghaïa (11.687 ton and 9.740 ton, respectively): this allowed to calculate the liquid discharge for the industrial sector. Moreover, PAC, *Maitrise de l'urbanisation e de l'artificialisation des sols* (2004) identifies the discharge per inhabitant per day of BOD and COD (50 g and 60 g, respectively), the total amount of solid waste per inhabitant per year (474 Kg and 442 Kg, respectively), and the percentage not collected (10% and 46%, respectively): combined with data on the average inhabitants per Km2 at regional level (4000) specified by PAC, *Rapport finale integre* (2004), this allowed to calculate the liquid and solid discharge for the urban sector. Finally, liquid pollution coefficients for the agriculture sector are based on information about stock-farms in Reghaïa and Heraoua (so that 1% of discharges are assumed to be dairy farm wastewater), and solid pollution coefficients for agriculture and industry are assumed to be 1/10 and 10 times those of the urban sector, respectively.

Notice that industrial pollution heavily depends on the industrial pattern, and the main activity in Reghaïa is foundry (3.117 Km2): the lack of information about the tiny industrial activity in Heraoua (0.077 Km2) suggested to apply the same pollution coefficient to both municipalities. Next, for the sake of simplicity, water pollutions by the tourism sector will be assumed to be equal to those for the urban sector.

Table 2. Pollution coefficients for agriculture, industry, service, and urbanization sectors.

	BOD/Km2 (ton)	COD/Km2 (ton)	Solid/Km2 (ton)
Agr	2.065	9.995	50.1
Ind	3.050	3.659	5010
Ser	73.000	87.600	501
Urb	73.000	87.600	501

Next, the maximum additional pollution charges in the aquifer, the lake, and the sea, are calculated by referring to data on the total BOD and COD discharged at regional level (88.377 ton and 106.050 ton, respectively) as recorded by PAC, *Gestion integree des resources en eau at assainissement liquide* (2004), and by rescaling them for Reghaïa and Heraoua municipalities according to data on population: this lead to assess 1.747 ton and 2.096 ton of BOD and COD total discharges in these municipalities. These figures are then combined with data on total water uses (both for surface and groundwater) and water discharges (in aquifer, lake, sea) at municipal level, and referred to average water quality indicators specified in PAC, *Gestion integree des resources en eau at assainissement liquide* (2004): 10 mg/l and 40 mg/l for BOD and COD, respectively, with 5 mg/l and 20 mg/l as references for good water quality.

Table 3. Maximum pollution loads in aquifer, lake and sea.

	Max additional BOD (ton)	Max additional COD (ton)
Aquifer	30,0436	121,153
Lake	96,139	387,689
Sea	24,034	96,922

Notice that 100% of agricultural, 20% of urban and 0% of industrial pollution is likely to be discharged in aquifer, while 0% of agricultural, 80% of urban and 100% of industrial pollution is likely to be discharged in the lake. Next, only activities based near the coast are likely to discharge directly into the sea. For the sake of simplicity, 20% pollution discharge is assumed to affect aquifers, while 80% and 20% of the remaining 80% is assumed to be discharged into the lake and the sea, respectively: costs for liquid pollution depuration and for solid pollution management are assumed to be 0.634 EURO/CM and 0.634 EURO/CM, respectively, as suggested by PAC, *Etude prospective de l'urbanisation* (2004).

As far as **economic indicators,** we used the sectoral GDP percentages (12, 47, 41 for agriculture, industry and service) and the per-capita income (99098 DA = 1040 EURO) in 1998 at national level (DGE, *Communication national initiale*, 2001) in order to identify the contribution of agriculture, industry and service to the formation of the average income of each Algerian inhabitant. We then multiplied these figures by the population of Reghaïa and Heraoua (66215 and 18167) in 1998. These would be the sectoral GDP levels in these two municipalities if the economic structure in these two municipalities were the same as the average Algerian one: the income level is irrelevant within a maximisation algorithm. *But* this is not the case, since Reghaïa is a highly industrial municipality, while Heraoua is a highly agricultural municipality: indeed, agriculture and industry activities cover 58% and 13% of total area in Reghaïa, while they cover 75% and 1% in Heraoua. *Thus*, we firstly calculated the sectoral GDP per Km2 in both Reghaïa and Heraoua, and we secondly worked out the mean: this lead to 437, 62613 and 24481 EURO/Km2 for agriculture, industry and service, respectively, where the extension of the service activities is assumed to amount to 20% of the condensed urban area. *However*, we are interested in tourism rather than in service, and we have no information about Reghaïa, while we know that the single hotel in Heraoua collapsed due to the 2003 earthquake. *Thus*, we assumed that GDP per Km2 for tourism is the same as for service.

Moreover, we applied the activity rate (20%), the sectoral occupation percentages (17, 18, 18, and 14, in agriculture, industry, service and construction, respectively), and the employment rate (80%) in 1998 at national level (DGE, *Communication national initiale*, 2001) to the population in Reghaïa and Heraoua in order to obtain the occupational structure: these would be the sectoral occupation levels in these two municipalities if the economic structure in these two municipalities were the same as the average Algerian ones. But this is not the case, as clarified above. *Again*, we firstly calculated the sectoral occupation per Km2 in both Reghaïa and Heraoua, and we secondly worked out the mean: this lead to 97, 3648, 338 and 40 employee per Km2 in agriculture, industry and service sectors, respectively, where all buildings are assumed to be constructed by local firms, and are assumed to require refreshments every five years.

Finally, we used the average number of people per house (6) and the average number of houses per Km2 (4000), as suggested by PAC, *Maitrise de l'urbanisation e de l'artificialisation des sols,* (2004), and we assumed that 20% of per-capita income is related to house expenditure, in order to obtain the average value of condensed urbanised area per Km2: this lead to 4992000 EURO/Km2.

Table 4. The economic indicators

	GDP/Km2 (€)	EMPLOYEE/Km2 (N)	Required extension of areas in 2020 (Km2)
Agr	437	97	
Ind	62613	3648	0.551
Ser	24481	338	
Urb	4992000	40	0.413 - 1.208

As far as **current land uses,** we referred to google earth in 2004, where areas devoted to agriculture and industry activities are specified, as well as areas covered by urbanisation, beaches and forests are identified (see Map 1).

As far as **potential land uses**, PAC, *Action pilote: site du lac de Reghaïa* (2005) specifies the dune extension (1 Km2, approximately evenly split into Reghaïa and Heraoua municipalities), the location and extension of the area for tourism development (1.04 Km2 on the west side of the lake), and the extension of the sea park (8.630 Km2). Moreover, a questionnaire submitted to technical offices of both municipalities allowed to take into account the land management plan. Finally, an aimed realistic analysis suggested to predict also the industry growth, as well as to depict the current (illegal) urbanisation, although not prescribed by the land management plan. This lead to identify 7 areas (see Map 2), where in areas 1 and 3 an urban area could replace an agricultural area; tourism or urbanisation or environment could be developed in the agricultural area 2; in area 4 and 5 either tourism or environment could be implemented; industry or urbanisation could be developed in the agricultural areas 6 and 7.

Map 1. Land uses in 2004.

Legend. Black = industry and the sea, white = agriculture, light grey = forest, dark grey = urbanisation, large pattern = the lake, small pattern = public equipment

Map 2. Potential land uses in 2020.

As far as **economic dynamics**, we applied a 1% yearly industrial growth rate, as suggested by PAC, *Impacts des activites anthropiques* (2005), to the industrial extension in 2005 in order to obtain the required extension of the industrial area in 2020: this lead to 0.551 Km2 (i.e. 17% of current extension).

As far as **social dynamics**, we used the estimated population of Reghaïa and Heraoua in 2005, suggested by PAC, *Maitrise de l'urbanisation e de l'artificialisation des sols* (2005), in order to make consistent land use (observed in 2005) with population level (recorded in 1998), and we then applied the maximum and minimum estimated population increase in 2020, suggested by PAC, *Maitrise de l'urbanisation e de l'artificialisation des sols* (2005), to these figures, together with the average number of people per house (6) and the average number of houses per Km2 (4000), in order to obtain the required maximum and minimum extension of the urban area in 2020: this lead to 1.208 and 0.413 Km2 (i.e. 14% and 5% of current extension).

Five observations are worthy here. First, PAC, *Impacts des activites anthropiques* (2005) assesses the coastal loss rate in 0.45 m/year (presumably without sand extraction) up to 1.9 m/year (presumably with sand extraction), which leads to an estimated beach loss in 2020 of 6.75 m up to 28.5 m, and, consequently, to an estimated beach extension in 2020 of 43.25 m up to 11.50 m: for the sake of simplicity, it is assumed that tourism is not affected by coastal loss. Second, we assumed that it takes 5 years to set up an industry and a tourism activity, 2 years to construct an urban area, and it takes 1 year to develop an environmental protected area: a 5% discount rate is applied. Third, the plan to favour urbanisation away from coastal areas, as discussed by PAC, *Impacts des activites anthropiques* (2005), has not been taken into account here, in order to avoid other areas to bear population pressure of the two municipalities under consideration. Forth, for the sake of simplicity, we did not distinguish the rural and urban population, and we did not apply different expected growth rates to different current population observed in the whole area under consideration; similarly, we did not differentiated the relationship between water uses (by alternative sectors from alternative sources) and pollution discharges (by alternative sectors to alternative sites) for different parts of the area under consideration. Fifth, the applied procedures and assumptions suggest that it possible to calibrate the ICM model even where local data are not available, although more detailed information at local level would improve its reliability. However, the most tentative parameters are the GDP values attached to the economic activities (i.e. these parameters could be considered stochastic variables whose means are known and variances can be guessed only), and the suggested model makes differences between these variables, whose covariance is positive (i.e. an increase in variability of GDP around the regional mean in one sector is likely to be associated to an increase also in other sectors). Thus, by assuming a normal distribution, we calculated the upper bound of the variance of each GDP value involved in each numerical simulation in order to have a 90% significance of outcomes, to be compared with the unitary variance of the standardised normal distribution.

5.Main results from numerical simulations

The maximisation of the additional value obtained by changing the current land uses, according to the potential land uses, by taking into account economic (industry growth in 2020), and social dynamics (population growth in 2020), as well as social (employment maintenance) and environmental constraints (surface and groundwater sustainability, as well as pollution sustainability in the aquifer, the lake, and the sea), lead to land uses which depend on the value attached to the environment. Sub-sections below will present optimal land uses, where environment values are alternatively set to be equal to values evaluated for the agriculture, urban, tourism and industry sectors.

In particular, in order to highlight the potentials of the model developed in section 2 and calibrated in section 4 for the case study identified in section 3, we performed four main groups of numerical simulations: those presented in sub-section 5.1 aim at testing the sensitivity of results in alternative environmental conditions; those in sub-section 5.2 aim at assessing the impacts of policies affecting water quantity; those discussed in sub-section 5.3 aim at measuring the impacts of policies affecting water quality; those in sub-section 5.4 combine policies affecting water quantity and quality.

Notice that PAC, *Gestion integree des resources en eau at assainissement liquide* (2004) admits that it is difficult to evaluate the potential of groundwater in Reghaïa and Heraoua, although it could be reasonably stated that the aquifer is exploited at almost its maximum level: we will assume that an additional 25% of groundwater is available with respect to current uses. Next, for the sake of simplicity, the potential surface water is similarly evaluated: this assumption will turn out to be irrelevant.

5.1.Optimal land uses in alternative scenarios without water policies

Table 5 presents optimal land uses in the average year.

Table 5. Optimal land uses in **the average year** without water policies.

Environment values		= agr	= urb	= tou	= ind
A1	agr	0.957	0.823	0.545	0.948
	urb	0.042	0.175	0.454	0.050
A2	agr	0.002	0	0	0
	urb	0	0	0	0
	tou	0.009	0	0	0
	env	0.988	1	1	1
A3	agr	1	1	1	1
	urb	0	0	0	0
A4	tou	0	0	0	0
	env	1	1	1	1
A5	tou	0	0	0	0
	env	1	1	1	1
A6	agr	0.134	0.362	0.823	0.271
	ind	0.414	0.357	0.145	0.381
	urb	0.451	0.279	0.030	0.346
A7	agr	0.834	0.352	0.027	0.690
	ind	0.057	0.434	0.650	0.101
	urb	0.108	0.213	0.322	0.208
Δ GDP (1000 €)		36	82	102	99
Δ Employment (N)		3462	5843	5869	3538
Δ urb land use (Km2)		1.208	1.208	1.208	1.208
Δ ind land use (Km2)		0.982	1.647	1.655	1.005
Δ groundwater use (MCM)		1.314	2.561	2.574	1.353
Δ surface water use (MCM)		-0.350	-0.337	-0.336	-0.353
Δ solid pollution (ton)		5319	8613	8649	5425
Δ BOD aquifer (ton)		17	17	17	17
Δ COD aquifer (ton)		14	13	13	13
Δ BOD lake (ton)		46	46	46	46
Δ COD lake (ton)		37	34	34	36
Δ BOD sea (ton)		14	14	14	14
Δ COD sea (ton)		11	10	10	11
Variance of economic parameters if	ρ=0.30	0.213	0.244	0.227	0.214
	ρ=0.60	0.372	0.427	0.397	0.375
	ρ=0.90	1.489	1.708	1.587	1.500

Agriculture, urbanisation, tourism and industry values are set to.0.437, 4896, 24481 and 62.613 Thousand EURO, respectively. Next, the variance of the normally distributed economic parameters (GDP per Km2 for activities involved in the estimation) smaller than 1 means a more condensed distribution than the standardised normal distribution.

Seven main remarks are worthy highlighted here:

- the available groundwater is always exploited to its maximum level (3.184 MCM), while the surface water is redundant: this is due to the larger groundwater coefficient characterising the industry sector with respect to the agriculture sector, together with the conversion to industry of several areas originally devoted to agriculture
- the additional pollution never reaches its maximum sustainable level, although BOD discharged in the aquifer and the sea should be kept under greater control
- the urban extension reaches its maximum level (1.208 Km2), while the industry extension ranges between 2 to 4 times the minimum required (0.551 Km2)

- the tourism activity is never suggested, while the environment preservation is prescribed instead
- the agriculture and industry activities show an opposite (although non-linear) changes: this is due to the larger value coefficient characterising the industry sector with respect to the agriculture sector, together with the absence of assumptions about the minimum extension of agriculture activities
- the employment preservation does not represent a constraint
- the additional value is significant, and it (non-linearly) increases with the value attached to the environment.

Section 2 emphasised the long-run perspective of an ICM-DSS: indeed, planning land use is a long-run decision making process. Thus, a sensitivity analysis in alternative scenarios has been performed. In particular, DGE, *Communication national initiale* (2001) specifies the percentages of precipitations in dry and very dry years with respect to average years in the Province of Alger (74% and 63% respectively), and, consequently, the reduced total amount of surface and groundwater: numerical simulations presented above suggest that a groundwater shortages in dry years will hamper the industry development. Moreover, DGE, *Communication national initiale* (2001) assesses the reduction of surface water due to climate change (from 15% to 30%), but this impact seems to be negligible. Finally, PAC, *Impacts des activites anthropiques* (2005) assesses the potential coastal losses (from 43.25 m up to 11.50 m): numerical experiments discussed above suggest that coastal shrinkages will not prevent the reckless tourism development.

5.2.Optimal land uses in the average year with quantity water policies

Three main water policies affecting its quantity are suggested by PAC reports for Reghaïa and Heraoua: a 20% water saving in agriculture, due to the introduction of innovative irrigation techniques; a 20% additional water from the empowerment of the desalinisation facilities; a 20% water saving in industry, arising from the re-use of some water processed by the depurator. Table 6 presents the numerical simulations depicting all these policies combined.

Table 6.Optimal land allocations in the average year with water **quantity** policies.

Environment values		= agr	= urb	= tou	= ind
A1	agr	0.788	0.804	0.994	0.997
	urb	0.211	0.195	0.005	0.002
A2	agr	0	0	0	0
	urb	0	0	0	0
	tou	0.052	0	0	0
	env	0.947	1	1	1
A3	agr	0.677	0.672	0.672	0.672
	urb	0.322	0.327	0.327	0.327
A4	tou	0.036	0.004	0	0
	env	0.963	0.995	1	1
A5	tou	0.005	0.002	0	0
	env	0.994	0.997	1	1
A6	agr	0	0	0	0
	ind	0.847	0.844	0.749	0.999
	urb	0.152	0.155	0.250	0
A7	agr	0	0	0	0
	ind	1	1	1	0.748
	urb	0	0	0	0.251
ΔGDP (1000 €)		179	183	190	228
Δ Employment (N)		13752	13700	12992	12981
Δ urb land use (Km2)		1.208	1.208	1.208	1.208
Δ ind land use (Km2)		3.842	3.837	3.640	3.638
Δ groundwater use (MCM)		6.169	6.137	5.766	5.760
Δ surface water use (MCM)		-0.786	-0.817	-0.824	-0.824
Δ solid pollution (ton)		19540	19476	18498	18482
ΔBOD aquifer (ton)		19	18	17	17
ΔCOD aquifer (ton)		11	10	10	10
ΔBOD lake (ton)		51	48	47	47
ΔCOD lake (ton)		30	27	27	27
ΔBOD sea (ton)		15	14	14	14
ΔCOD sea (ton)		9	8	8	8
Variance of economic parameters if	$\rho=0.30$	0.127	0.130	0.130	0.130
	$\rho=0.60$	0.222	0.228	0.228	0.228
	$\rho=0.90$	0.889	0.911	0.913	0.913

Three main differences with respect to insights obtained in sub-section 5.1 with no water policies are worthy noticed here. The suggested industry extension is almost eight times with water quality policies, although decreasing with the value attached to the environment. Pollution indicators are slightly lower everywhere. Tourism appears as a marginal activity (around the lake only), provided the value attached to the environment is sufficiently low.

5.3.Optimal land uses in the average year with quality water policies

A single main water policy affecting its quality is at stake for Reghaïa and Heraoua: an 80% depuration rate for water discharged in the lake (with respect to the current 15%). Table 7 presents the numerical simulations depicting this policy.

Table 7.Optimal land allocations in the average year with water **quality** policies.

Environment values		= agr	= urb	= tou	= ind
A1	agr	0.791	0.875	0.588	0.844
	urb	0.207	0.123	0.410	0.154
A2	agr	0	0.2160	0	0
	urb	0	0	0	0
	tou	0	0	0	0
	env	1	0.783	1	1
A3	agr	1	1	1	1
	urb	0	0	0	0
A4	tou	0	0	0	0
	env	1	1	1	1
A5	tou	0	0	0	0
	env	1	1	1	1
A6	agr	0.359	0.169	0.634	0.241
	ind	0.519	0.611	0.286	0.499
	urb	0.120	0.219	0.078	0.259
A7	agr	0.294	0.428	0.123	0.503
	ind	0.348	0.271	0.579	0.251
	urb	0.356	0.299	0.297	0.244
ΔGDP (1000 €)		87	92	111	134
Δ Employment (N)		6417	6524	6403	5541
Δ urb land use (Km2)		1.208	1.208	1.208	1.208
Δ ind land use (Km2)		1.807	1.837	1.802	1.563
Δ groundwater use (MCM)		2.862	2.918	2.854	2.403
Δ surface water use (MCM)		-0.332	-0.332	-0.333	-0.339
Δ solid pollution (ton)		9407	9556	9386	8195
ΔBOD aquifer (ton)		17	17	17	17
ΔCOD aquifer (ton)		12	12	12	13
ΔBOD lake (ton)		11	11	11	11
ΔCOD lake (ton)		9	8	9	10
ΔBOD sea (ton)		14	14	14	14
ΔCOD sea (ton)		10	10	10	10
Variance economic parameters if	ρ=0.30	0.253	0.261	0.238	0.240
	ρ=0.60	0.442	0.457	0.417	0.420
	ρ=0.90	1.768	1.828	1.668	1.679

Two main differences with respect to insights obtained in sub-section 5.1 with no water policies are worthy noticed here. The suggested industry extension is almost double with water quality policies, when the value attached to the environment in very small or very large. Pollution indicators are slightly lower also in the aquifer and in the sea, where the depuration rate has not changed.

5.4.Optimal land uses in the average year with quantity and quality water policies

Table 8 presents the numerical simulations depicting all quantity water policies discussed in sub-section 5.2, together the quality water policy considered in with sub-section 5.3.

Table 8.Optimal land allocations in the average year with water **quantity and quality** policies.

Environment values		= agr	= urb	= tou	= ind
A1	agr	0.999	0.899	0.784	0.975
	urb	0	0.100	0.215	0.024
A2	agr	0	0	0	0
	urb	0	0	0	0
	tou	0.096	0	0	0
	env	0.903	1	1	1
A3	agr	1	0.672	0.672	0.672
	urb	0	0.327	0.327	0.327
A4	tou	0.487	0	0	0
	env	0.512	1	1	1
A5	tou	0.018	0	0	0
	env	0.981	1	1	1
A6	agr	0.065	0	0	0
	ind	0.735	1	0.854	0.759
	urb	0.198	0	0.145	0.240
A7	agr	0	0	0	0
	ind	1	0.797	1	1
	urb	0	0.202	0	0
ΔGDP (1000 €)		165	176	203	229
Δ Employment (N)		13089	13346	13775	13063
Δ urb land use (Km2)		0.413	1.208	1.208	1.208
Δ ind land use (Km2)		3.610	3.738	3.858	3.660
Δ groundwater use (MCM)		5.760	5.952	6.176	5.803
Δ surface water use (MCM)		-0.830	-0.821	-0.818	-0.823
Δ solid pollution (ton)		18167	18988	19581	18596
ΔBOD aquifer (ton)		11	17	17	17
ΔCOD aquifer (ton)		4	10	10	10
ΔBOD lake (ton)		8	12	12	12
ΔCOD lake (ton)		7	10	10	11
ΔBOD sea (ton)		9	14	14	14
ΔCOD sea (ton)		3	8	8	8
Variance economic parameters if	ρ=0.30	0.123	0.130	0.130	0.130
	ρ=0.60	0.215	0.228	0.228	0.228
	ρ=0.90	0.860	0.913	0.913	0.913

Three main differences with respect to insights obtained in sub-section 5.1 with no water policies are worthy noticed here. The suggested industry extension is almost seven times with water quality policies, although decreasing with the value attached to the environment. Pollution indicators are slightly lower everywhere. Tourism appears as a relevant activity (both around the lake and along the coast), provided the value attached to the environment is sufficiently low.

6.Main insights from numerical simulations

The main remarks presented in section 5 can be summarised in the following insights about **future** land management decisions:

- An optimal land use allows to achieve a remarkable increase in total GDP, even if economic and social dynamics, as well as social and environmental constraints are taken into account.
- Differences in increases in total GDP suggest that water policies affecting its quantity appear to be more urgent than those affecting its quality

- As far as resource sustainability, all quantity water policies combined allow to reach the sustainability of optimal land use in dry and very dry years, where groundwater shortages arise, while surface water is redundant
- The industry sector is held back by its groundwater demand rather than its environmental impacts, the urbanisation sector should be developed to meet the social dynamics, the agriculture sector is residual, and the tourism sector should be developed, provided both quantity and quality water policies are implemented.
- As far as pollution sustainability, a greater attention should be paid to BOD discharged in the aquifer and in the sea, while COD is a less pressing issue.

Next, the main remarks presented in section 5 can be summarised in the following observations about **past** land management decisions:

- The plan suggestion of no urbanisation in A1 seems to be optimal, whenever the value attached to the environment is sufficiently large
- Urbanisation is never suggested in A2, *consistently* with the plan
- The plan suggestion of 20% of A3 devoted to urbanisation seems to be optimal, provided (at least) water quantity policies are implemented
- The tourism development in A4, as prescribed by the plan, can be supported, provided both quantity and quality water policies are implemented
- Environment is always suggested in A5, *consistently* with the plans
- The plan suggestion of at least 25% of A6 devoted to urbanisation seems to be optimal, provided no water policies are implemented
- The plan suggestion of at least 20% of A7 devoted to urbanisation can be optimal, provided no water quantity policies are implemented

7.Conclusion

Results presented in section 5 and insights highlighted in section 6 seem to stress that the DSS for an ICM suggested in this paper show all features obtained in section 1 by combining potentials and inadequacies recognised in the literature. However, Westmacott (2001) identifies the essential characteristics that a DSS for an ICM should show, in terms of design and role.

In particular, as far as the **design**, Westmacott (2001) says that the DSS should incorporate multiple objectives and views. Our model considers all main sectors involved in the decision-making process. Moreover, the DSS should cover a multidisciplinary subject area. Our model relies on data based on analysis carried out by hydrologists and ecologists. Finally, the DSS should deal adequately with limited data and information. Our model combines data at municipal level, not always available, with data at regional and national level, by expressing the degree of accuracy of the obtained outcomes in terms of the largest average variance that micro-level parameters should show around the macro-level mean in order to achieve a suitable confidence level.

As far as the **role**, Westmacott (2001) states that the DSS should collate ICM data and information. Our model is suitable to a day-to-day management, since additional information on economic or environmental dimensions can be easily introduced, once the economic and ecological structure is set up. Moreover, it should facilitate discussion and play an educational role. Our model uses a straightforward maximisation approach, by applying clear assumptions and procedures, and by simplifying the decision making process into a comparison between the objective economic returns for stakeholders and the subjective value attached to environment (see Appendix for a GIS representation of results). Finally, it should be a support system, not a decision-maker. Our model has been used to stress relevant constraints and urgent priorities to be taken in to account in the planning process, by stressing the potential interactions between policies.

Therefore, the suggested DSS for an ICM meets all characteristics required by Westmacott (2001). Additional research efforts however will be required to further improve it.

In particular, it actually shows a quite rigid structure, although some degree of rigidity is unevoidable, if it must be tailored to local conditions. It presently disregards environmental and economic indirect impacts, but data availability of might allow to develop an Input-Output Model. It currently lacks an easy computer interface, even if it is already arranged for this application.

Appendix. A GIS representation of results

A.1. Optimal land uses without water policies

Figure 3. The environment evaluated as the industrial sector.
Environment is always suggested in A5, *while* at least 25% of A6 devoted to urbanization seems to be optimal, provided no water policies are implemented

A.2. Optimal land uses with quantity water policies

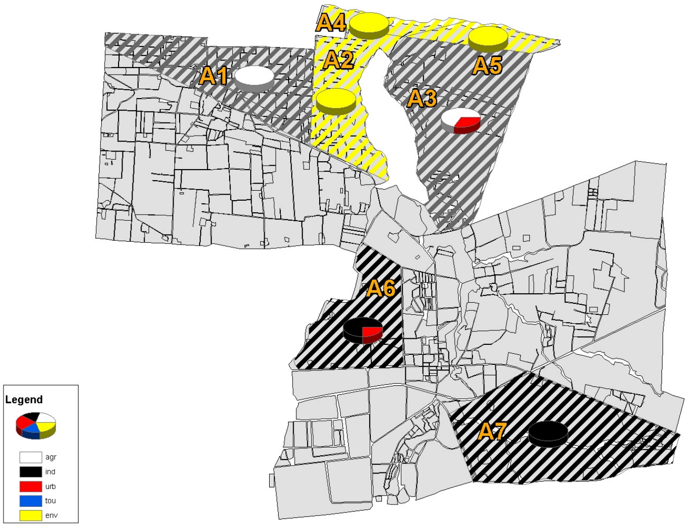

Figure 4. The environment evaluated as the tourism sector
No urbanization in A1, *and* 20% of A3 devoted to urbanization, seem to be optimal, provided (at least) water quantity policies are implemented.

A.3. Optimal land uses with quality water policies

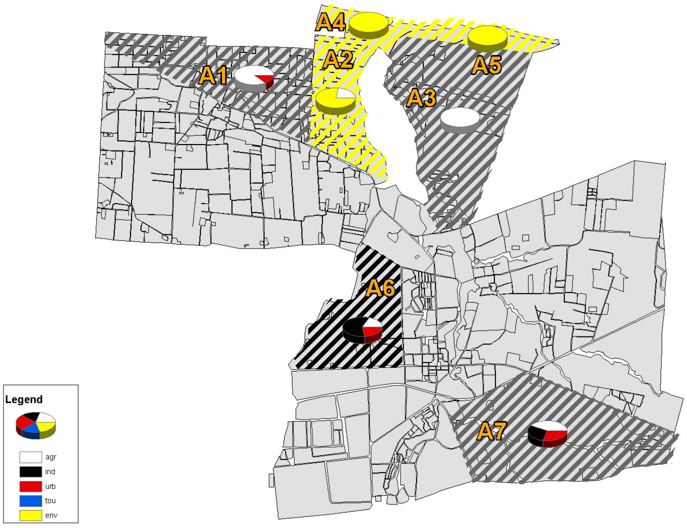

Figure 5. The environment evaluated as the urbanisation sector
Environment is always suggested in A5, while at least 20% of A7 devoted to urbanization can be optimal, provided no water quantity policies are implemented

A.4. Optimal land uses with quantity and quality water policies

Figure 6. The environment evaluated as the agricultural sector
Urbanisation is never suggested in A2, *and* the tourism development in A4 can be supported, provided both quantity and quality water policies are implemented

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