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Multi-criteria analysis in the strategic environmental assessment of the sugar and alcohol sector

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ABSTRACT. The Strategic Environmental Assessment (SEA) of the sugar and alcohol sector guides a territorial and sectoral planning that benefits most of the local society and supports this economic activity in all its stages. In this way, the present work aims to determine an index of aggregation of the indicators generated in the baseline of the SEA process, called Index of Sustainability of Expansion of the Sugar and Alcohol Sector (IScana). For this, it was used the normalization of the indicators of each city by the fuzzy logic and attribution of weights by the Analytic Hierarchy Process (AHP). Then, the IScana values had been spatialized in the region of 'Grande Dourados'– Mato Grosso do Sul State. The northern portion concentrated the highest values of IScana, 0.48 and 0.55, referring to the cities of Nova Alvorada do Sul and Rio Brilhante, while, in the central portion, the city of Dourados presented the lowest value, 0.10. The selection of the set of indicators forming the IScana, and their relative importance, was satisfactory for the application of fuzzy logic and AHP techniques. The IScana index supplies objective information regarding the diagnosis of the region for the application of SEA.

Keywords: sectoral planning, fuzzy logic, AHP method.

Análise multicritério no contexto da avaliação ambiental estratégica do setor sucroalcooleiro

RESUMO. O processo de Avaliação Ambiental Estratégica (AAE) do setor sucroalcooleiro orienta o planejamento territorial e setorial que beneficia maior parte da sociedade local e conduz a sustentabilidade desta atividade econômica em todas as suas etapas. Deste modo, o presente trabalho busca determinar o índice de agregação dos indicadores gerados na etapa de baseline do processo de AAE, denominado Índice de Sustentabilidade de Expansão do Setor Sucroalcooleiro (IScana). Utilizando, para tanto, normalização dos indicadores de cada município, por meio de lógica fuzzy, e atribuição de pesos, através de Analytic Hierarchy Process (AHP). Em seguida, o IScana foi espacializado na região da Grande Dourados, Estado do Mato Grosso do Sul. A porção norte concentrou os maiores valores de IScana, 0,48 e 0,55, referentes aos municípios de Nova Alvorada do Sul e Rio Brilhante, respectivamente, enquanto, na parte central, o município de Dourados apresentou o menor valor de sustentabilidade, 0,10. A seleção do conjunto de indicadores que formam o IScana, bem como a importância relativa definida para os quais se apresentaram satisfatórias na aplicação da técnica que incorpora lógica Fuzzy e o método AHP. O índice IScana, aplicado na escala de municípios e associado a utilização de SIG, fornece informações objetivas sobre o diagnóstico da região de aplicação da AAE.

Palavras-chave: planejamento setorial, lógica fuzzy, método AHP.

Introduction

The increasing energy demand over the world has led to remarkable agricultural and industrial expansion of the sugar and alcohol sector in various locations of Brazil (CAMPOS et al., 2008; MORAES, 2007). There is an expressive concentration of sugarcane cultivation around these industries, besides the orientation of political, economical and social actions of the municipalities involved in the support and development of this activity.

Due to the high demand for labor, for raw material and infrastructure by the sugar and alcohol activity, it is indispensable a planning that benefits most of the population, in other words, which aims the sustainability of the activity in all its stages. For this, the Strategic Environmental Assessment (SEA) may be a tool for assessing environmental, social and economical impacts in the planning phase of Policies, Plans and Programs (PPP) referent to the sugar and alcohol sector and its expansion. Strapasson and Job (2006) commented that the SEA can be one of the mechanisms for the development of sustainability in the sugar and alcohol industry in social, economical and environmental scopes.

The SEA process encompasses the following stages: identifying PPP objectives (*screening*); setting goals (*scoping*); selecting indicators (*baseline*); predicting impacts (scenarios); public consultation and monitoring (ARCE; GULLON, 2000; FINNVEDEN et al., 2003). In the SEA context, Dalkmann et al. (2004) recommend the inclusion of techniques of multi-criteria analysis (MCA) to favor the applicability of SEA results in the decision-making process. This allows the aggregation of variables of influence, of quantitative and qualitative order, of different units, in order to support the identification of priorities and viable alternatives in decision process.

The MCA techniques are objective tools to analyze multiple factors simultaneously. In this way, the *Analytic Hierarchy Process* (AHP), originally developed by Saaty (1980), is flexible and of easy implementation of MCA, and it has been widely used in literature, with several examples in the localization of better areas for installation (DEY; RAMCHARAN, 2008; WANG et al., 2009), analysis of land suitability (BARROS et al., 2007; YANG et al., 2008) and vulnerabilities (WANG et al., 2008; OLIVEIRA et al., 2009).

The advantages of the AHP method are: the lower subjectivity in determining relative weights of incorporated variables and the analysis of the coherence degree employed by the user, based on the ratio of consistency obtained (OLIVEIRA et al., 2009). Moreover, the AHP method has gained increasing acceptance worldwide, as one of the most powerful methods of decision making (RAHARJO et al., 2009; VAIDYA; KUMAR, 2006).

Lee and Lin (2008) have integrated the methods of fuzzy logic and AHP in environmental analyses, achieving good results. According to Kahraman et al. (2004), the fuzzy logic provides a systematic basis that operates ambiguous and subjective situations. Liou et al. (2006), evaluating the SEA methodological procedures in Taiwan, recommend changes in the hierarchy of indicators and the introduction of fuzzy functions in the quantification of local sustainability.

The use of Geographic Information System (GIS) also contributes to the generation of objective information and systematization of the SEA process, allowing the spatial representation of several aspects covered in the process, the identification facilitated of possible conflicts of land use, and provides a basis that integrates the assessments developed during the SEA process (GONZÁLEZ et al., 2008).

In this way, the present study aimed at determining an Index of Sustainability of Expansion of the Sugar and Alcohol Sector (IScana), employing the fuzzy logic and AHP to aggregate the indicators generated in the baseline step of the SEA process, in order to consolidate a sector monitoring tool.

Material and methods

Study area

The study was conducted using as a basis the region of 'Grande Dourados', composed of 12 municipalities with considerable economic expression in the state of Mato Grosso do Sul (Figure 1).

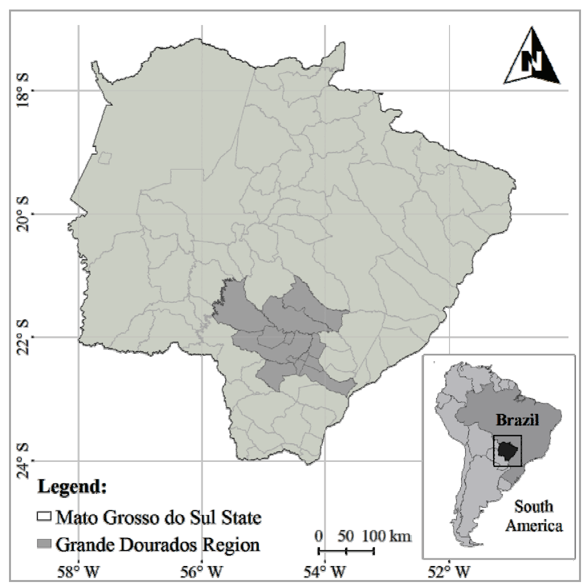

Figure 1. Location of the region of 'Grande Dourados'.

The territorial extension of the region of 'Grande Dourados' is 26,642.40 km² equivalent to 6.92% of the state area. This region has relative homogeneity of the productive sectors, routes of production and access, infrastructure and environmental characteristics. The process of occupation in the region followed the economic cycles of the country and state, with the expansion of agriculture and livestock (OLIVEIRA et al., 2011). Currently the urban perimeter of Dourados municipality may be classified as a regional hub, centralizing the development and commercialization of products, and the rest of the municipalities in the region are predominantly suppliers of basic inputs.

Recently, the sugar and alcohol activity is under a striking expansion in the region of 'Grande Dourados', with eight industries and an area of 120,500 ha of sugarcane crops (CANASAT, 2009) (Table 1).

Table 1. Obtaining selected indicators.

Municipality	Population	Planted area (ha)	Number of industries in the sector
Jateí	3,913	788	1
Douradina	5,047	0	
Vicentina	5,787	1,618	
Glória de Dourados	9,915	31	
Deodápolis	11,586	745	
Nova Alvorada do Sul	12,430	22,332	2
Itaporã	19,187	4,420	
Fátima do Sul	19,327	79	
Caarapó	23,437	890	
Rio Brilhante	27,435	59,453	1
Maracaju	31,933	25,092	3
Dourados	18, 7601	5,051	1

Selection of indicators

The indicators selected to compose the IScana are based on three dimensions of sustainability: social, environmental and economic. For this, the indicators considered relevant refer to sugarcane cultivation, environmental protection, educational structure, Human Development Index of the municipality (IDH-M), industrial energy consumption, and percentage of formal jobs. The Table 2 lists the ways of obtaining each indicator during the baseline of the SEA process.

At the step of indicators selection, it was weighed the representativeness degree of the dimensions of sustainability and the feasibility of constant obtaining of these variables by the actors involved in SEA process. Thus, most variables used were obtained from data made available free by government agencies in the World Wide Web.

The values of the indicators used to generate the IScana for each municipality are shown in Table 3.

Interpretation and integration of indicators

The sequence of steps aiming the interpretation and integration of indicators were developed in a spreadsheet (*Microsofit Office Excel*), making operations of indicators normalization, assigning relative weights, aggregation and generation of the IScana (index of sustainability of expansion of the sugar and alcohol sector) for each municipality of the region of 'Grande Dourados'. Then the values of the IScana index were spatialized in a GIS environment, in the software ArcGIS 9.2© (ESRI, 2006), analyzing their distribution pattern in the study area.

Normalization of the indicators by Fuzzy inference

The values presented in the Table 2 were transformed to the same unit of measure, using fuzzy inference, where it was used the sigmoid function for the normalization of values to a scale from zero to one, making them comparable. The sigmoid function, in its various forms: increasing, decreasing, and symmetric is presented in Figure 2.

The fuzzy functions include control points, which are independent variables that define the upper and lower limits for the normalization of the indicators values. The Figure 3 shows the equations involving the control points for each specific fuzzy function.

Table 2. Process of obtaining the selected indicators.

Indicator	Operation	Unit	Source
Sugarcane cultivation	Sugarcane cultivation Area (2005-2009)/ Municipal area	(% of municipal area)	CANASAT (2009) SEMAC (2008)
Environmental protection	Conservation Units Area / Municipal area	(% of municipal area)	IMASUL (2008); SEMAC (2008)
Educational structure	Municipality population/ number of teachers	(inhhabitants/ teacher)	SEMAC (2008); MTE (2008)
IDH-M	Observed values	dimensionless	PNUD (2000)
Industrial electric power	Industrial consumption of electric power	(Mwh)	SEMAC (2008)
Formal jobs	Number of formal jobs / Municipal population	(% of municipal population)	MTE (2008) SEMAC (2008)

Table 3. Values of selected indicators per municipality.

Municipality	Environmental		Economic		Social	
	Sugarcane cultivation (%)	Environmental protection (%)	Formal jobs (%)	Industrial electric power (Mwh)	Educational structure (inhabitants/teacher)	IDH-M
Jateí	0.00	0.00	0.10	3.0	78.26	0.72
Douradina	0.00	0.11	0.03	11.0	72.10	0.71
Vicentina	0.00	0.00	0.04	291.0	81.51	0.73
Glória de Dourados	0.00	0.00	0.05	3090.0	75.11	0.75
Deodápolis	0.00	60.46	0.05	3152.0	80.46	0.74
Nova Alvorada do Sul	0.04	30.80	0.22	6196.0	77.20	0.75
Itaporã	0.00	1.78	0.08	6989.0	102.60	0.71
Fátima do Sul	0.00	97.63	0.06	6196.0	90.31	0.75
Caarapó	0.00	7.19	0.11	3251.0	94.50	0.72
Rio Brilhante	0.06	0.00	0.25	5381.0	118.25	0.75
Maracaju	0.03	0.22	0.17	6546.0	82.51	0.78
Dourados	0.00	0.59	0.16	31522.0	99.00	0.79

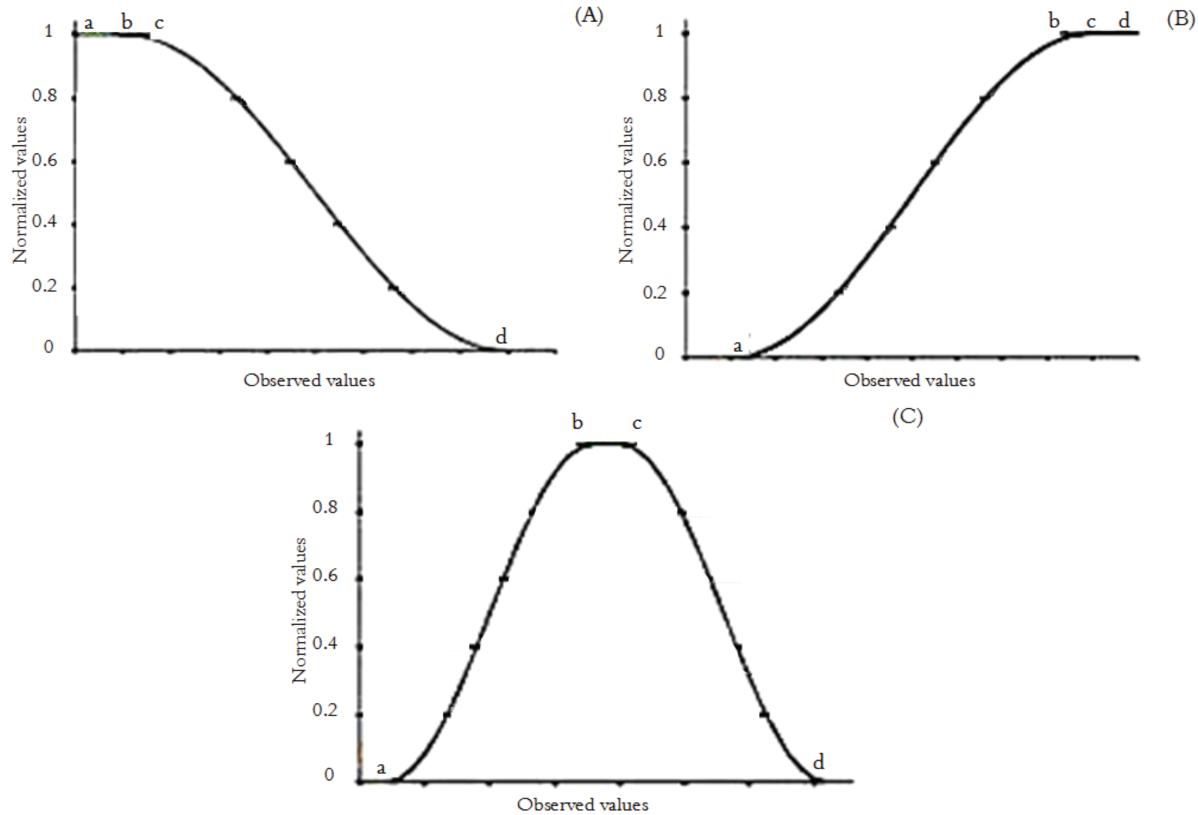

Figure 2. Sigmoid fuzzy functions: (A) decreasing; (B) increasing; and (C) symmetric, with optimal range. Legend: a, b, c and d are control points.

When the function is increasing, the variables b, c, and d are equal:

$\mu(x) = 0 \text{ se } x < a$

$\mu(x) = \cos^2\alpha \text{ e } \alpha = (1 - (x - a)/(b - a)) \cdot \pi / 2 \text{ se } x \geq a \text{ e } x \leq b$

$\mu(x) = 1 \text{ se } x > b$

When the function is decreasing, the variables a, b and c are equal:

$\mu(x) = 1 \text{ se } x < c$

$\mu(x) = \cos^2\alpha \text{ e } \alpha = (x - c)/(d - c) \cdot \pi / 2 \text{ se } x \geq c \text{ e } x \leq d$

$\mu(x) = 0 \text{ se } x > d$

When the function is symmetric:

$\mu(x) = 0 \text{ se } x < a$

$\mu(x) = \cos^2\alpha \text{ e } \alpha = (1 - (x - a)/(b - a)) \cdot \pi / 2 \text{ se } x \geq a \text{ e } x \leq b$

$\mu(x) = 1 \text{ se } x > b \text{ e } x < c$

$\mu(x) = \cos^2\alpha \text{ e } \alpha = (x - c)/(d - c) \cdot \pi / 2 \text{ se } x \geq c \text{ e } x \leq d$

$\mu(x) = 0 \text{ se } x > d$

Figure 3. Scheme of sigmoid fuzzy functions applied to conditions of decreasing increasing and symmetric.

The values of each variable were normalized using the sigmoid fuzzy function suitable to the peculiarities of each variable, i.e., whether favor or not the sustainability. For the indicators 'sugarcane cultivation' we adopted a symmetric function, due to the limits on the municipal percentage with planted area, preventing the establishment of a monoculture. The indicators 'environmental protection', 'formal jobs' and 'IDH-M' have values directly proportional to the encouragement of sustainability, while the indicators 'education' and 'energy' have values that are inversely proportional, hence the application of increasing and decreasing functions, respectively (Table 4).

Table 4. Values of the selected indicators.

Indicator	Function	Control points			
		a	b	c	d
Sugarcane cultivation (% of municipal area)	Symmetric sigmoid	0	10	15	20
Environmental protection (% of municipal area)	Increasing sigmoid	0	20	20	20
Educational structure (inhabitants/teachers)	Decreasing sigmoid	79	79	79	42
IDH-M	Increasing sigmoid	0	1	1	1
Industrial electric power (Mwh)	Decreasing sigmoid	0	0	0	31,522
Formal jobs (% of municipal population)	Increasing sigmoid	0	45	45	45

The lower and upper control points that limit the scale from 0 to 1, applied for the normalization of each indicator, were set arbitrarily based on the references of order national, international, and local, as follows:

- The proportion of sugarcane cultivation was set as ideal in the range between 10 and 15% of municipal area, in order to prevent the harmful condition of the monoculture and, at the same time, stimulate the production within acceptable limits. These limits were determined from a law project recently subjected in Dourados municipality, which limits the sugarcane cultivation to 15% of municipal area.

- The proportion of Conservation Units was considered as ideal when exceeding the level of 20%, since, taking the entire municipality as a rural area, this would be the portion of legal reserve, pursuant to the Law 4771/65 (BRASIL, 1965).

- Regarding the education, we took as reference the current condition of Brazil of 79 inhabitants/teacher and of Cuba, with 42 inhabitants/teacher (LÓPEZ, 2000), as the worst and the best condition, respectively.

- The IDH-M was used directly, since its values are already on a scale from 0 to 1.

- In relation to the energy, it was assumed that the sugar and alcohol industries are mostly self-sufficient and even suppliers of electric power, so that the current levels of industrial consumption tend to decrease from the level of 31,522 Mwh (SEMAC, 2008).

- The percentage of formal jobs was defined as ideal starting at 45%, since this is the average for the Middle-West region and for Brazil (IBGE, 2000), thus, from this level the municipality is already in acceptable condition within the regional and national context.

Assignment of weights and aggregation of indicators

The first step of the AHP method is the structure of the decision problem in a hierarchy. A typical hierarchy of this method represents an overall objective of the decision-making process (objective) at the upper level, the criteria that affect the decision at an intermediate level, and the decision options (alternatives) on the lower level. The second step is the comparison between pairs of criteria (TEGOU et al., 2010). So, along with the indicators normalization, we measured the relative importance of them by means of the AHP method, in which the indicators were compared two by two, in the context of the decision-making process or during the SEA.

The AHP method is based on a square matrix (n x n), where the rows and columns correspond to the n analyzed criteria for this issue. Thus, the value aij is the relative importance of the indicator at the row i, given the indicator at column j. Considering that this matrix is reciprocal, only the lower triangular half needs to be evaluated, since the other half comes from this, and the main diagonal assumes values equal to 1 (ZAMBON et al., 2005). The indicators are compared arbitrarily from a scale of values from 1 to 9, defined by Saaty (1980) (Table 5).

Table 5. Scale of AHP values for pairwise comparison.

Degree of importance	Definition and Explanation
1	Equal importance. The two factors contribute equally.
3	Moderate importance. One factor is slightly more important than the other.
5	Essential importance. One factor is much more important than the other.
7	Demonstrated importance. One factor is strongly favored, and its greater relevance is shown in practice.
9	Utmost importance. The evidence that differ the factors is of the highest order possible.
2; 4; 6; 8	Intermediate values between the trials.

Source: Modified from Saaty (1980).

From the choice of criteria for comparison and the establishment of the relative importance of each information plan, the AHP model informs a Consistency Ratio (CR). This is used to determine the degree of coherence when comparing the variables (ALPHONCE, 1997; DAI et al., 2001). The consistency ratio should be lower than 0.1, for a 6-elements matrix, and when there are higher values, it is needed revisions of the comparisons performed (SAATY, 1977).

Through trials arbitrated by experts involved in the SEA process, the pairwise comparison of the indicators has prioritized, at higher levels of importance, the diversity of cultivations in the region, and the lower consumption of electric energy, at similar level, it was considered the job and education, while the IDH-M and the environmental protection, by means of conservation units, were defined as less important. To this end, we used the matrix in the Table 6, in which was obtained the CR value equal to 0.1.

Then the Index of Sustainability of Expansion of the Sugar and Alcohol Sector, so-called IScana, was generated through the *Weighted Linear Combination* (WLC) (Equation 1).

$$IScana = \sum_{i=1}^{n} X_i W_i \quad (1)$$

where:

IScana: Index of Sustainability of Expansion of the Sugar and Alcohol Sector;

Xi: normalized value of each indicator i (with $i=1,\ldots, n$);

n: number of indicators;

Wi: relative weight of each indicator i (with $i=1,\ldots, n$).

Results and discussion

The application of the AHP method, given the pré-established trials, promoted the following importance order of the indicators compounding the IScana: environmental protection, IDH-M, educational structure, formal jobs, industrial energy, sugarcane cultivation. The normalized values of the social, economic and environmental indicators relative to each municipality of the region of 'Grande Dourados', the relative weight of the indicators, and the IScana index obtained, are listed in Table 7, with the population range, area with sugarcane cultivation, and number of industries.

The IScana values had little variation for the municipalities with population up to 20,000 inhabitants (0.32-0.33), and greater variation for the municipalities with population over 20,000 inhabitants (0.10-0.55). The spatial distribution of the IScana values in the region of 'Grande Dourados' (Figure 4) evidenced that the southern region have similar values, in the range from 0.32 to 0.33, corresponding to the municipalities of Jateí, Vicentina, and Glória de Dourados, Mato Grosso do Sul State, while the northern region concentrates higher values of IScana, 0.41, 0.48 and 0.55, relating to the municipalities of Maracaju, Nova Alvorada do Sul and Rio Brilhante, Mato Grosso do Sul State, respectively. In the central part, the municipality of Dourados had the lowest sustainability value, 0.10.

The municipality of Rio Brilhante achieved the highest index of sustainability in the region of 'Grande Dourados'. This is because of the suitable percentage of area with sugarcane cultivation, and high proportion of formal jobs in relation to the total population, however, there should be greater efforts to implement conservation units in the municipality (Table 3). On the other hand, Nova Alvorada do Sul, Mato Grosso do Sul State, presented the second highest values of IScana, due to the significant degree of environmental protection.

Table 6. Relative importance of each indicator*.

	Sugarcane cultivation	Environmental protection	Formal jobs	Industrial electric power	Educational structure	IDH-M
Sugarcane cultivation	1					
Environmental protection	1/4	1				
Formal Jobs	1/2	3	1			
Industrial electric Power	1	3	2	1		
Educational structure	1/2	3	1	1/2	1	
IDH-M	1/4	1	1/2	1/3	1/3	1

*CR = 0.1

Table 7. Normalized values and relative weights of the indicators, and the IScana obtained.

Population range (ha)	Variable	Sugarcane cultivation	Environmental protection	Formal jobs	Industrial energy	Educational structure	IDH-M	IScana
	Relative weights	0.28	0.07	0.15	0.26	0.16	0.07	
Lower than 10,000	Jateí	0.00	0.00	0.12	1.00	0.00	0.72	0.33
	Douradina	0.00	0.00	0.01	1.00	0.08	0.71	0.33
	Vicentina	0.00	0.00	0.02	1.00	0.00	0.73	0.32
	Glória de Dourados	0.00	0.00	0.03	0.98	0.03	0.75	0.32
10 to 20,000	Deodápolis	0.00	1.00	0.03	0.98	0.00	0.74	0.38
	Nova Alvorada do Sul	0.31	0.44	0.50	0.91	0.01	0.75	0.48
	Itaporã	0.00	0.02	0.07	0.88	0.00	0.71	0.29
	Fátima do Sul	0.00	0.96	0.05	0.91	0.00	0.75	0.36
20 to 30,000	Caarapó	0.00	0.29	0.14	0.97	0.00	0.72	0.34
	Rio Brilhante	0.59	0.00	0.59	0.93	0.00	0.75	0.55
Higher than 30,000	Maracaju	0.25	0.00	0.31	0.90	0.00	0.78	0.41
	Dourados	0.00	0.00	0.28	0.00	0.00	0.79	0.10
Arithmetic mean								0.35

*CANASAT (2009).

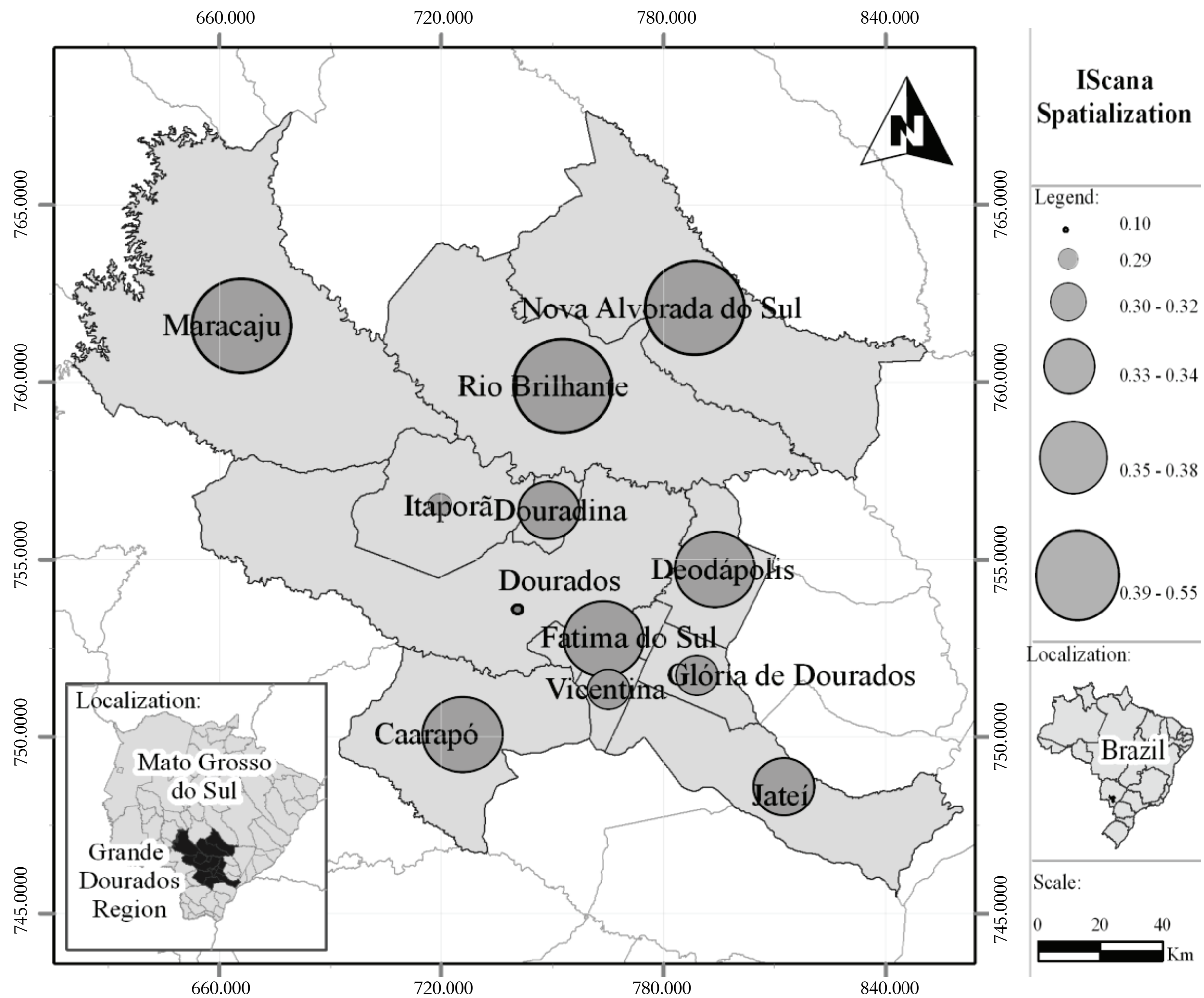

Figure 4. Spatialization of the IScana in the region of 'Grande Dourados'.

The lowest IScana values was found in the municipality of Dourados, mainly due to the high consumption of energy, the low educational levels (low concentration of teachers per capita), and the low percentage of sugarcane cultivation. These characteristics, partly, match the condition of regional hub given to this municipality.

The technique that incorporates the fuzzy logic and the AHP method (Fuzzy-AHP) applied to the aggregation of indicators referent to the sustainability dimensions is appropriate, because the proposed IScana index obeys a pattern of spatial distribution coherent to the development conditions of the region. Employing similar methods, Pereira et al. (2008) defined the best locational alternative for an industrial area, taking into account the aggregation of environmental, social and economic factors of the study region.

The application of the methodology (Fuzzy-AHP) enables the joint analysis of several kinds of variables in an objective way. In this way, Dalkman et al. (2004) proposed the evolution of the Strategic Environmental Assessment (SEA) for the Analytical Strategic Environmental Assessment (ANSEA), by using multi-criteria analysis techniques, aiming lower subjectivity during the SEA process. In accordance with Pischke and Cashmore (2006), this analysis should be adopted, since the traditional methods of assessing environmental impact do not guide, clearly, the SEA process.

In this way, the IScana index associated with the use of GIS is presented as a tool for data integration at baseline of the SEA process, by providing objective information about the diagnosis of the region of application of the SEA, and subsidy for further decision-making in the process of development of the region.

The methodology (Fuzzy-AHP) can also be applied temporally, in the step of SEA monitoring, thus contributing to a greater systematization of this process, during its several stages. The continued implementation of the methodology to obtain the IScana index, in different locations and times, allows to identify patterns and a possible inference of a rating sustainability scale of the sugar and alcohol sector.

Conclusion

The technique that incorporates the fuzzy logic and the AHP method enables the joint analysis of several aspects of a given productive sector, and other applications with the goal of measuring the sustainability.

The selection of the set of indicators to form the sustainability degree of the sugar and alcohol activity is satisfactory, because it shows that the quality of the expansion of the sugar and alcohol sector in a municipality depends of the achievement of several features or dimensions.

The IScana index, applied at the municipality scale, and associated with the use of GIS is a tool for data integration at baseline of the SEA process, by providing objective information about the diagnosis of the region of application of the SEA. In a regional context, a greater attention should be given to the locations with lower values of IScana, since they present some weaknesses that must be addressed.

References

ALPHONCE, C. B. Application of the analytic hierarchy process in agriculture in developing countries. **Agricultural Systems**, v. 53, n. 1, p. 97-112, 1997.

ARCE, R.; GULLON, N. The application of strategic environmental assessment to sustainability assessment of infrastructure development. **Environmental Impact Assessment Review**, v. 20, n. 3, p. 393-402, 2000.

BARROS, M. A.; MOREIRA, M. A.; RUDORFF, B. F. T. Processo analítico hierárquico na identificação de áreas favoráveis ao agroecossistema cafeeiro em escala municipal. **Pesquisa Agropecuária Brasileira**, v. 42, n. 12, p. 1769-1777, 2007.

BRASIL. **Lei nº 4.771**. Institui o novo Código Florestal. Brasília: 1965. Diário Oficial da União, 15 de dezembro de 1965.

CAMPOS, C. M.; MILAN, M.; SIQUEIRA, L. F. F. Identificação e avaliação de variáveis críticas no processo de produção da cana-de-açúcar. **Engenharia Agrícola**, v. 28, n. 3, p. 554-564, 2008.

CANASAT. **Mapeamento da cana via imagens de satélite de observação da Terra**. Available from: <http://www.dsr.inpe.br/mapdsr>. Accessed on: July 22, 2009.

DAI, F. C.; LEE, C. F.; ZHANG, X. H. GIS-based geo-environmental evaluation for urban land-use planning: a case study. **Engineering Geology**, v. 61, n. 4, p. 257-271, 2001.

DALKMANN, H.; HERRERA, R. J.; BONGARDT, D. Analytical strategic environmental assessment (ANSEA) developing a new approach to SEA. **Environmental Impact Assessment Review**, v. 24, n. 4, p. 385-402, 2004.

DEY, P. K.; RAMCHARAN, E. K. Analytic hierarchy process helps select site for limestone quarry expansion in Barbados. **Journal of Environmental Management**, v. 88, n. 4, p. 1384-1395, 2008.

ESRI-Environmental Systems Research Institute, Inc. **ArcGIS Professional GIS for the desktop, version 9.2**. Redlands, Esri, 2006. (Software).

FINNVEDEN, G.; NILSON, M.; JOHANSSON, J.; PERSSON, A.; MOBERG, A.; CARLSSON, T. Strategic environmental assessment methodologies – application within the energy sector. **Environmental Impact Assessment Review**, v. 23, n. 1, p. 91-123, 2003.

GONZÁLEZ, A.; GILMER, A.; FOLEY, R.; SWEENEY, J.; FRY, J. Technology-aided participative methods in environmental assessment: An international perspective. **Computers, Environment and Urban Systems**, v. 32, n. 4, p. 303-316, 2008.

IBGE-Instituto Brasileiro de Geografia e Estatística. **Pesquisa nacional por amostra de domicílios 1999**. Rio de Janeiro: IBGE, 2000. [CD-ROM] (Micro-dados).

IMASUL-Instituto do Meio Ambiente do Mato Grosso do Sul. **Sistema Interativo de Suporte ao Licenciamento Ambiental**. Available from: <http://sisla.imasul.ms.gov.br/sislaconsultor/aplicmap/sisla.htm?00bf7eb5bff542b9e3141da6dad2654d>. Accessed on: May 29, 2008.

KAHRAMAN, C.; CEBECI, U.; RUAN, D. Multi-attribute compaison of catering service companies using fuzzy AHP: the case of Turkey. **International Journal of Production Economics**, v. 87, n. 2, p. 171-184, 2004.

LEE, K-L.; LIN, S-C. A fuzzy quantified SWOT procedure for environmental evaluation of an international distribution center. **Information Sciences**, v. 178, n. 2, p. 531-549, 2008.

LIOU, M.; YEH, S.; YU, Y. Reconstruction and systemization of the methodologies for strategic environmental assessment in Taiwan. **Environmental Impact Assessment Review**, v. 26, n. 2, p. 170-184, 2006.

LÓPEZ, P. M. **Cuba**: um mestre para cada 42 habitantes. Havana: pedagogia em foco, 2000. Available from: <http://www.pedagogiaemfoco.pro.br/cub03.htm.>. Accessed on: July 20, 2009.

MORAES, M. A. F. D. As profundas mudanças institucionais ao longo da história da agroindústria canavieira e os desafios atuais. **Economia Aplicada**, v. 11, n. 4, p. 555-557, 2007.

MTE-Ministério do Trabalho e Emprego. Available from: <http://perfildomunicipio.caged.gov.br/seleciona_uf_consulta.asp?uf=ms>. Accessed on: July 20, 2008.

OLIVEIRA, P. T. S.; ALVES SOBRINHO, T.; RODRIGUES, D. B. B.; PANACHUKI, E. Erosion risk mapping applied to environmental zoning. **Water Resources Management**, v. 25, n. 3, p. 1021-1036, 2011.

OLIVEIRA, P. T. S.; RODRIGUES, D. B. B.; ALVES SOBRINHO, T.; PANACHUKI, E. Processo analítico hierárquico aplicado a vulnerabilidade natural a erosão. **Geociências**, v. 28, n. 4, p. 417-424, 2009.

PEREIRA, S. H. F.; CALIJURI, M. L.; PEREIRA, S. C. M.; BEZERRO, N. R. A multicriteria-based location of an industrial park in a defined area in ipatinga, Minas Gerais State, Brazil. **Sociedade and Natureza**, v. 1, n. 20, p. 139-159, 2008.

PISCHKE, F.; CASHMORE, M. Decision-oriented environmental assessment: an empirical study of its theory and methods. **Environmental Impact Assessment Review**, v. 26, n. 7, p. 643-662, 2006.

PNUD-Programa das Nações Unidas para o Desenvolvimento. **Atlas do desenvolvimento humano no Brasil**. 2000. Available from: <http://www. pnud.org.br/atlas/tabelas/index.php. Accessed on: July 20, 2009.

RAHARJO, H.; XIE, M.; BROMBACHER, A. C. On modeling dynamic priorities in the analytic hierarchy process using compositional data analysis. **European Journal of Operational Research**, v. 194, n. 3, p. 834-846, 2009.

SAATY, T. L. A scaling method for priorities in hierarchical structures. **Journal of Mathematical Psychology**, v. 15, n. 3, p. 234-281, 1977.

SAATY, T. L. **The analytical hierarchy process**: planning, priority setting, resource allocation. New York: McGraw-Hill, 1980.

SEMAC-Secretaria de Estado do Meio Ambiente, das Cidades, do Planejamento, da Ciência e Tecnologia. **Dados estatísticos dos municípios de Mato Grosso do Sul**. Campo Grande: Semac, 2008.

STRAPASSON, A. B.; JOB, L. C. M. Etanol, meio ambiente e tecnologia: reflexões sobre a experiência brasileira. **Revista de Política Agrícola**, v. 15, n. 3, p. 51-63, 2006.

TEGOU, L.-L.; POLATIDIS, H.; HARALAMBOPOULOS, D. A. Environmental management framework for wind farm siting: Methodology and case study. **Journal of Environmental Management**, v. 91, n. 11, p. 2134-2147, 2010.

VAIDYA, O. S.; KUMAR, S. Analytic hierarchy process: An overview of applications. **European Journal of Operational Research**, v. 169, n. 1, p. 1-29, 2006.

WANG, G.; QIN, L.; LI, G.; CHEN, L. Land fill site selection using spatial information technologies and AHP: a case study in Beijing, China. **Journal of Environmental Management**, v. 90, n. 8, p. 2414-2421, 2009.

WANG, X. D.; ZHONG, X. H.; LIU, S. Z.; LIU, J. G.; WANG, Z. Y.; LI, M. H. Regional assessment of environmental vulnerability in the Tibetan Plateau: Development and application of a new method. **Journal of Arid Environments**, v. 72, n. 10, p. 1929-1939, 2008.

YANG, F.; ZENG, G.; DU, C.; TANG, L.; ZHOU, J.; LI, Z. Spatial analyzing system for urban land-use management based on GIS and multi-criteria assessment modelling. **Progress in Natural Science**, v. 18, n. 10, p. 1279-1284, 2008.

ZAMBON, K. L.; CARNEIRO, A. A. F. M.; SILVA, A. N. R.; NEGRI, J. C. Análise de decisão multicritério na localização de usinas termoelétricas utilizando SIG. **Pesquisa Operacional**, v. 25, n. 2, p. 183-199, 2005.

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