A Decision Support Method to Generate Interactive Maps of Suggestion for Land Use, by Soft Decision Tree. The Case of Island of Sao Francisco, Brazil

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Abstract

This work presents a decision support method for planning and administration of land use, with the concept of soft decision tree. The results are interactive maps of suggestion for land use. The source data are obtained from field survey and from thematic maps, combined in geographical information system environment. The data are stored in geodatabase, and operated by fuzzy logic. The information contained in the geodatabase is managed by a developed interface software (ALDA) that aggregates and analyzes the variables by a soft decision tree, using the fuzzyTech® and MS Access® software. The resulting data are then processed in ArcGis®, generating the interactive map of suggestion for land use. The application and validation of the proposed method is accomplished with the elaboration of the interactive map of suggestion for land use on the Island of São Francisco do Sul, Southern Brazil.

Keywords: decision support system; fuzzy logic; soft decision trees; geographic information system; territory management.

1 Introduction

Improper use of space and deforestation are responsible for erosion, silting, landslides, floods, droughts and other natural disasters around the world. The month of November of 2008 is marked in the history of the middle and lower valley of the River Itajai, Santa Catarina State, Brazil, as a month of tragedies, which left over 100 dead. In January of 2011, in the mountain region of the State of Rio de Janeiro, 916 deaths were accounted and around 345 persons missing. The high rate of rainfall caused by unusual meteorological situation in regions formed by valleys, hills and mountains, caused flooding and landslides, with losses in human lives and material that reached millions of dollars. The search, rescue and shelters cost another millions dollars.

The lack of planning and managing the use of space is compounded by the failure of the government not to intervene in the occupation of unsafe areas and the release of so many without a prior study.

According to Santos (1997), "the use of inappropriate techniques and lack of understanding of the interdependence of processes that act on a particular area, are the main causes of environmental degradation (...). To reach a diagnosis of physical preservation or deterioration conditions of an area, you should first analyze the environment, which includes soil component as the most important (...). With the combined knowledge of geology, of Pedology and Soil Mechanics, it is possible to advance the knowledge of the physical and geotechnical parameters for civil works". Effective land management requires good planning and this can only be done with technology and the knowledge of the area you want to use.

The diagnosis of the physical environment, which was developed in the past with the overlapping of overlays or thematic transparencies, today is done with the aid of Geographic Information Systems through the creation and linking of information plans. In these systems, the information plans are previously digitalized, stored, and the final synthesis maps are obtained by the intersection of these plans,

two by two to obtain the desired final map. This analytical process involves the evaluation of the weight information plans that, in turn, depends heavily on the experience and filling of the researcher.

This diagnosis depends intrinsically on the experience, sensitivity and knowledge of the analyst, and as a very subjective analysis, due to the characteristics and peculiarities of each of the components of the physical environment and its multiple relationships, may lead to inaccurate and unstable results.

This work presents a decision support method for planning and managing the use of space, which seeks to overcome the exclusive dependence on the analyst's tacit knowledge, to an extent and integrated explicit knowledge base. The aggregation method of all the variables is supported by fuzzy logic, based on analysis of the main aspects that constitute and define the behaviour of the physical environment, which are: rocks, relief, soil and the effect of rainfall. This method makes the operation of integration and data analysis independent of the analyst's personal feeling, based only on their technical knowledge in thematic maps and data in data field mappings.

The variables aggregation method of soft decision-tree are the same as presented by Son (2002) and Wehenkel Olaru (2003), using fuzzy sets originally defined by Zadeh (1965). The information analysis are based on fuzzy rules with the structure If – Then and membership functions, where the influence among variables are defined by analysts. The soft top-down decision tree shows efficiency when dealing with fuzzy variables, in an environment of incomplete information and heavily dependent variables.

2 Model development

The steps of method development are according to the flowchart of Figure 1 below.

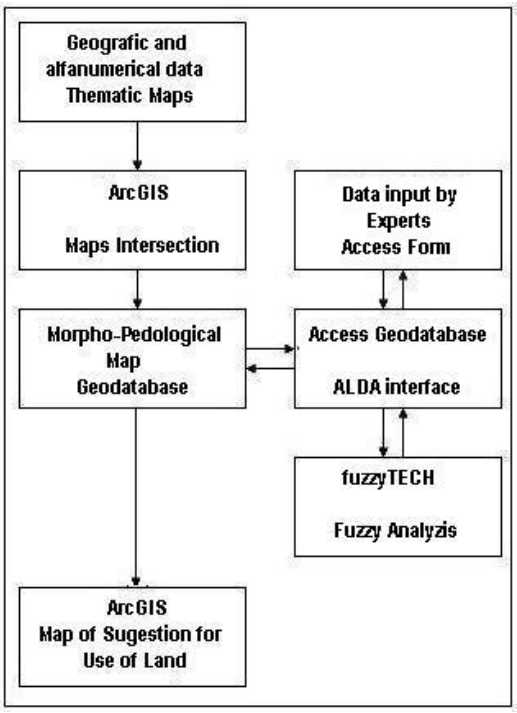

Figure 1 – Flowchart of system process. Source: FERNANDES, 2009.

The proposed method was applied in a study of the island of Sao Francisco do Sul, northern coast of Santa Catarina province, Brazil (Figure2), with the original maps data from the National Coastal Management Project (GERCO 3, 2002) – Brazil performed by the Instituto Brasileiro de Geografia e Estatistica - IBGE / SC The sheets are SG-22-ZB-II-2 and SG-ZB-22-II-4, part of the "Mapeamento Sistemático do Brasil", edited by IBGE scale 1:50.000 (1981).

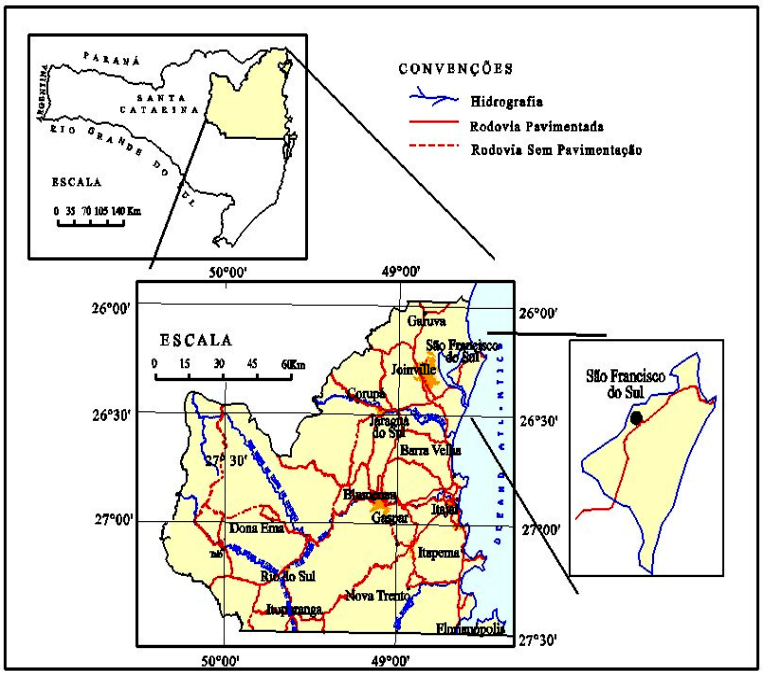

Figure 2 – Location of Sao Francisco do Sul Island. Source: FERNANDES, 2009.

Geologically, the island is inserted in the context of Paranagua Mobile Belt, which extends east from the southern Parana province to south of Sao Paulo province, and is constituted by a set of igneous rocks, formed by a variety of granitites, generally deformed (foliated), restricted portions of gneisses, schist, quartzite and amphibolites from Upper Proterozoic, embedded in marine sediments resulting from the deposition, wind and flood of to the Quaternary.

The geomorphology of the area are of sharp and rounded hills, belonging to the Geomorphologic Domain of Pre Serra do Mar, with marine terraces, dunes, marine plains, alluvial depositional environments and mangrove morph structural domains of Quaternary sediments (Fernandes, 1999).

The soils are mainly of ultisols, quartzipsamments and marine sands classes, and depositional environments of mangrove and dune field that occurs in the eastern portion of the island.

2.1 Method presentation

The process of analysis starts by the modelling of the decision tree scheme, developed in the top-down direction, as shown by Boclin and Mello (2005), where the final systemic variable – the objective answer, occupies the top of the tree. The branches are formed by thematic variables and the leaves are formed by direct indicators (or primary variables), which are linked to rule blocks, as shows the tree drawing in Figure 3.

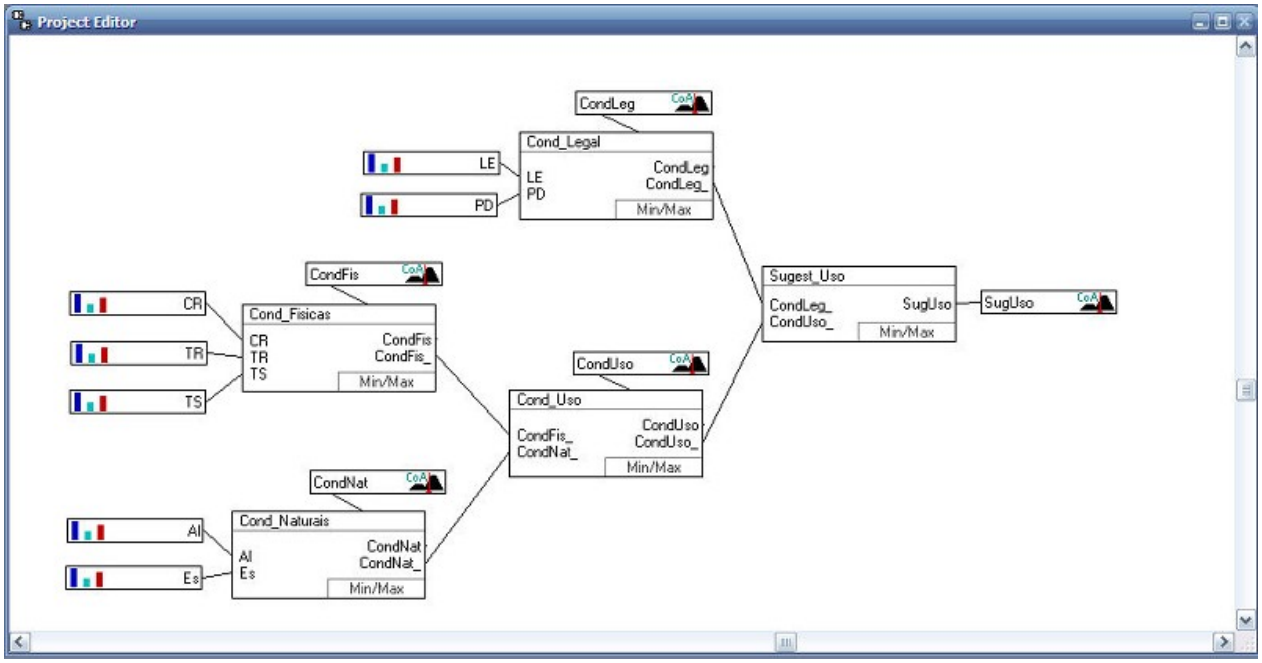

Figure 3 – Decision tree. Source: FERNANDES, 2009.

The next step is the data input. The thematic information of geology, geomorphology and soils were originally obtained from IBGE maps in a 1:50,000 scale (IBGE, 2002), scanned and converted to closed polygons "shape files" by ArcGIS ®, as shown in Figure 4.

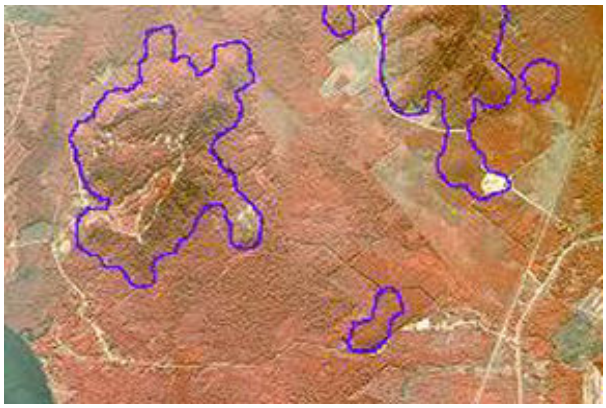

Figure 4 – Interpretation of false-color infrared aerial photography, showing the contour (polygon) of masses of granite embedded in Quaternary sediments. Source: FERNANDES, 1999.

The morpho-structural map, which stores the alphanumeric and graphical information of the early maps, was generated using the software ArcGIS® by the intersection of the topological features of the Geological and Geomorphological polygons maps, as shows the Figure 5 below.

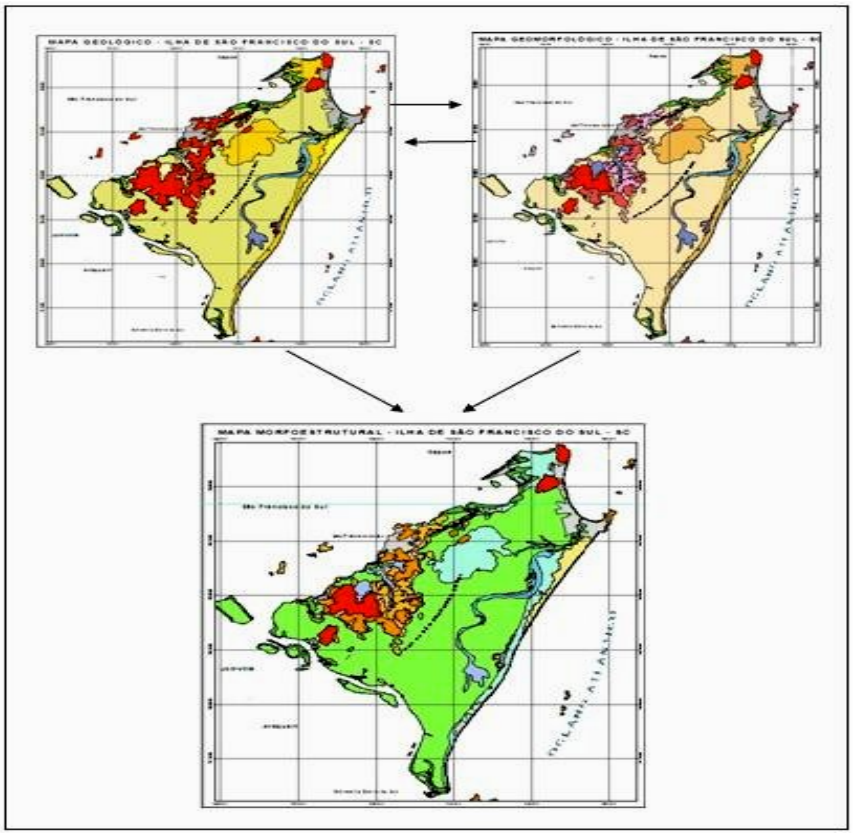

Figure 5. Intersect operation of Geological and Geomorphological maps. Source: FERNANDES, 2009.

A second useful intersection generates a morpho-pedological map, according to Fernandes (1999), from the soil and morpho-structural maps. In this map, the polygons are identified by similar characteristics in terms of rock, terrain and soil classes. The morpho-pedological map was the base for the suggestion of Space Use.

A data base was then generated from graphical information contained in the morpho-structural maps and the alphanumeric information of each of the polygon. This data base contains the primary indicators and the resulting systemic variables generated by the soft decision tree aggregations.

2.2 The primary and thematic variables

The two main themes that compound the final decision (suggestion of space use) are defined as the natural use constrains (CondUso) of and legal constrains (CondLeg).

The Use Constrain (CondUso) was compounded by physical constrains (CondFis), which express the characteristics of rocks, soil and topography, and by natural constraints (CondNat), which express the periodicity of the effects of climatic events on the physical environment. For the definition of the primary variables that constitute the class of physical constraints, the prevailing aspect was the resistance to erosion.

For the rock, which conforms of natural landscape unit, the erosion resistance is a consequence of the degree of cohesion. Since a degree of cohesion of the rock means the intensity of the bond between the mineral particles or the constituent (CREPANI et al., 1996). As the degree of cohesion is a characteristic of the formation mineralogy and arrangement of the original rock minerals, and this formation mineralogy and arrangement depend on the origin of the rock, was defined the type of rock (TR) and its origin, as one of the conditioning characteristics the use of space. Thus, the rock type (TR) is a primary variable, and the values that this variable can assume, from least to most constraint condition are: igneous rock; high-grade metamorphic rock; metamorphic rock low degree; sedimentary rock and sediments.

The preponderant aspect in soil erosion resistance is the structure of the horizon B, the subsoil, and therefore adopted as the principal conditioning. The possible values for the variable soil type (TS), from least to most constraint condition, are: strong structure; moderate structure; weak structure and no structure.

With respect to relief, the prevailing aspect was the slope. The possible values for this variable are: **plain terrain**; **plain terrain with smooth wavy**; **wavy**; **strongly wavy**; **mountainous** and **steep** topography, as shown in Figure 6.

Relief Classes	Slope (%)	Slope (°)
Plan	0 – 3	2
Smooth Wavy	3 – 8	2 - 5
Wavy	8 - 20	5 – 11
Strongly Wavy	20 – 45	11 - 24
Mountainous	45 – 75	24 – 37
Steep	75 ->	37 ->

Figure 6 – Relief classes adopted in fieldworks. Source: Authors

The natural constraints that express the effects of climatic events in the regional context are represented by the landslides (ES) or flooding (AL). The occurrence order of the primary variables (AL) and (ES, from less to more inhibitive, are the following possibilities: **rare or null** if not occur; **occasionally**, when they occur only in abnormal conditions of rainfall, and **constant**, when they frequently occur.

The legal constraints are divided into two classes: laws (CL), which covers federal and state laws, and master plan (PD), which deals with municipal laws. It is possible that the master plan can be more restrictive then other laws.

The primary variables (CL) and (PD) were defined from least to most conditioning factor, and can assume the following values: **free** - when there are no restrictions on use; **restrictive** - when there are restrictions but not prohibitions, like the case of parks, squares and public use areas, and **prohibitive** - when there are prohibitions to the use, reserving the area for permanent preservation.

Thus the primary variables, or indicators, of this method are: class relief (CR), type of rock (TR), soil type (TS), flooding (AL), slipping (ES), law (LE) and Master Plan (PD), and represent the input data, occupying the space left at the base of the tree.

The thematic variables express the results of the interactions occurring within the rules blocks and result in a systemic output variable, named (SugUso). The possible values that this variable can assume for each polygon in the maps are defined as: **Free** - when none of the restrictive conditions are present; **Shotly restricted** -when some of the physical, natural or legal constraints variables need more accurate studies for its use; **Supervised** - when more than one of the of physical, natural or legal constituents constraints need to have more accurate studies, and use of that space must be monitored; **Very restricted** - when one or more of the variables constraints have strong impediments to their use, and **Preservation** - when the legal conditions so requires, regardless of other constraints results.

2.3 Structure of input data for the analysis in the Decision Tree

The primary variables input data form of the morpho-pedological map was developed in the MS Access® software. The values of these variables vary from 0 to 1. The values relate the degree of the variable input data to the designed membership functions. The value 1 when the relevance is total, and 0, when there is no relevance. For example: When the soil distribution in a polygon presents a wavy slope, the value for this variable is 1. If the soil presents a smooth wavy relief distribution to wavy, the expert can assign different values according to their knowledge, such as values 0.8 to smooth wavy and 0.2 to wavy (Figure 7).

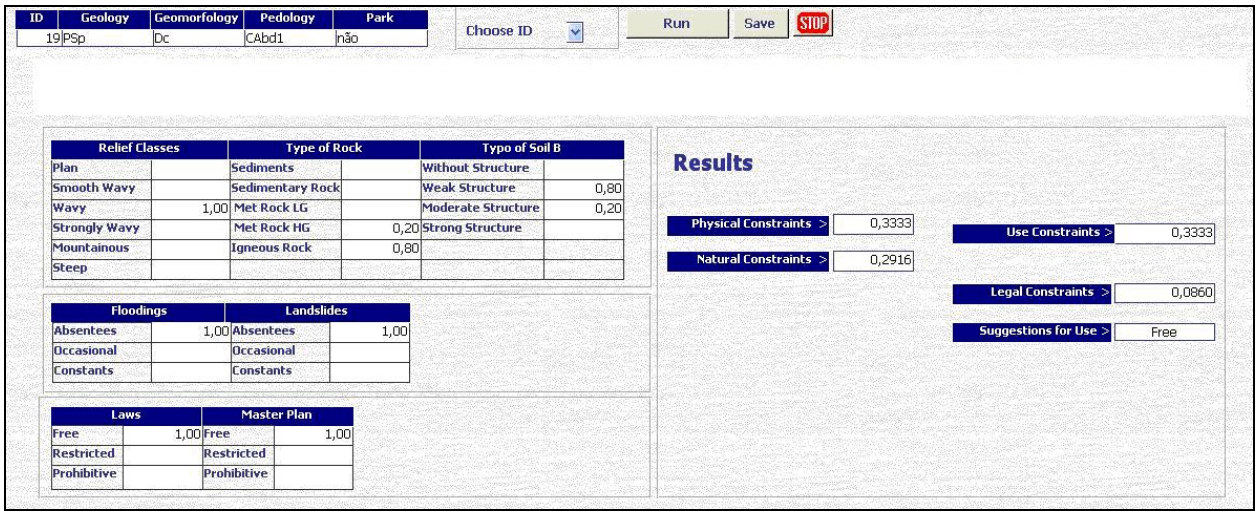

Figure 7 – Input/output data form example. Source: FERNANDES, 2009.

2.4 Decision Tree Processing

The authors developed an interface application called ALDA (**A**rcGis® - Fuzzy **L**ogic - **A**ccess®) that manages and integrates data from GIS and Fuzzy Logic and also generates the final maps. The ALDA application is interactive, allowing the analyst to enter or change data in the MS Access® interface form of, aggregate the variables by the soft decision tree and verify the answer before writing it to the georeferenced database and then letting it available to use by GIS. It also allows that changes or corrections after the map preparation can be interactively appended to the geodatabase and consequently the map itself.

The developed application works in an MS Access® environment. It is the server that controls the soft decision tree in the fuzzyTech® program. The results are the thematic variables and the systemic "Suggested land use (SugUso)". Figure 8 below shows the application screen and the results of a study.

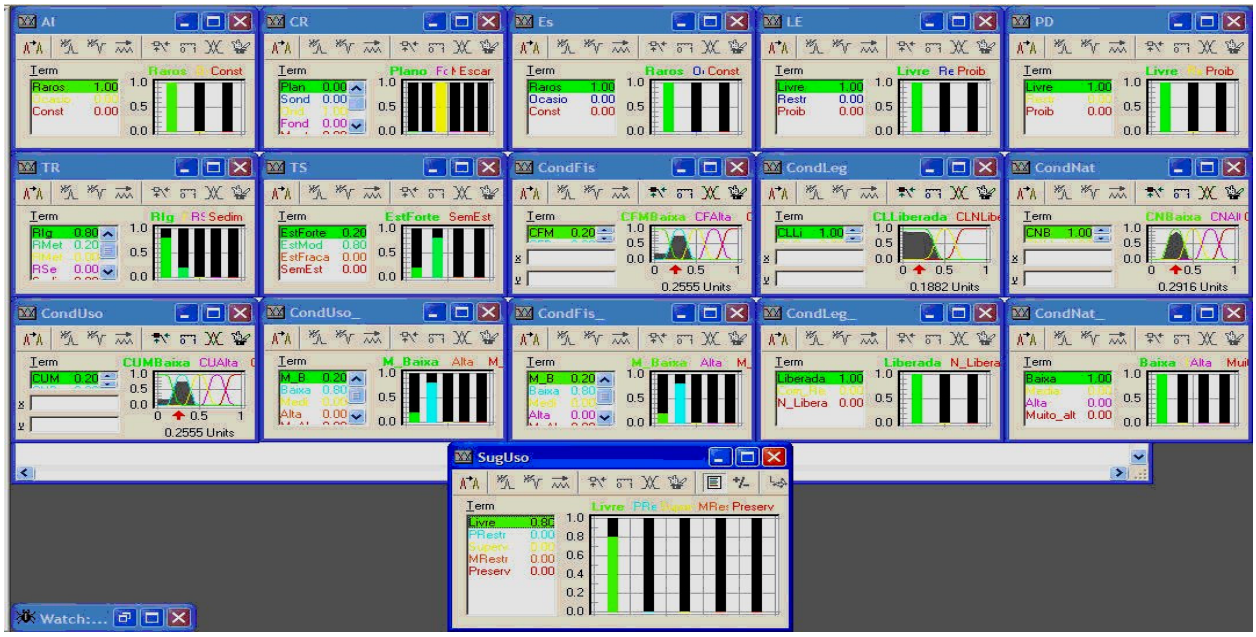

Figure 8 – Soft decision tree study data. Source: FERNANDES, 2009.

3 The Map of Suggestion of Land Use

The developed application is able to receive the resulting data from the soft decision tree and to generate the maps by the Geographic Information System. Figure 9 below shows the suggestion of land use map "SugUso" of a practical study. The generated map is result information according to the knowledge of experts that define membership functions for each variable. These functions can be modified, based on new information or from others knowledge sources. Thus, if membership functions change, a new map will be produced.

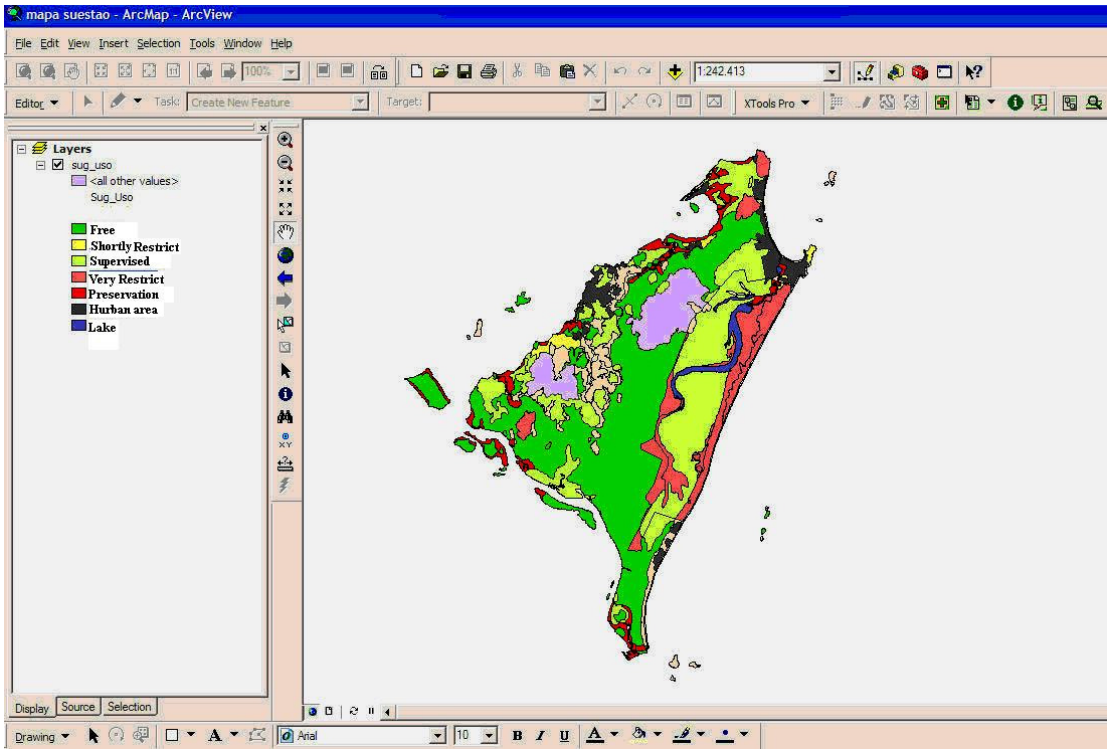

Figure 9 – Map of suggestion of land use. Island of Sao Francisco. Source: FERNANDES, 2009.

The method also allows an alphanumeric information consult in the database, to the details of each generated polygon. This query may be performed on the same form shown in Figure 8. For example, the map shown in Figure 10 contains 211 polygons. The Figure 10 below shows a partial detail of polygons example.

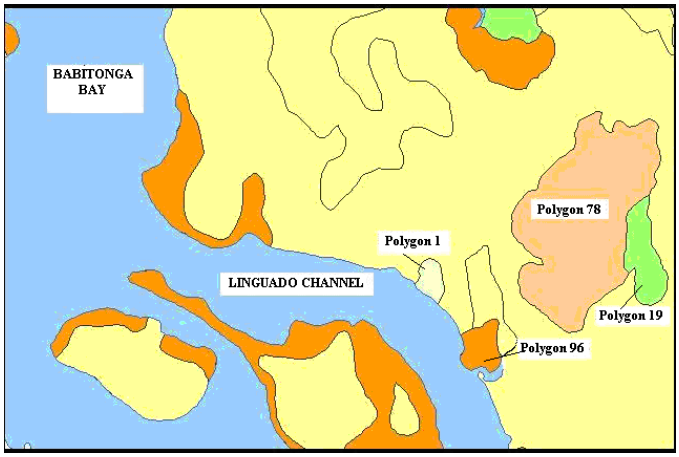

Figure 10 - Partial detail of polygons example. Source: FERNANDES, 2009.

In this example, the polygon number 1 consists of Paranagua complex rocks; Cambisol altered soil, and has wavy topography. The area has no information of landslides and flooding, and there is no legislation

restricts for its use. The Figure 11 shows the area form. The soft decision tree analysis results show a suggestion of "Shortly Restricted" area. This means that the polygon area has few restrictions on its use, and that the restrictions are related to the relief slope.

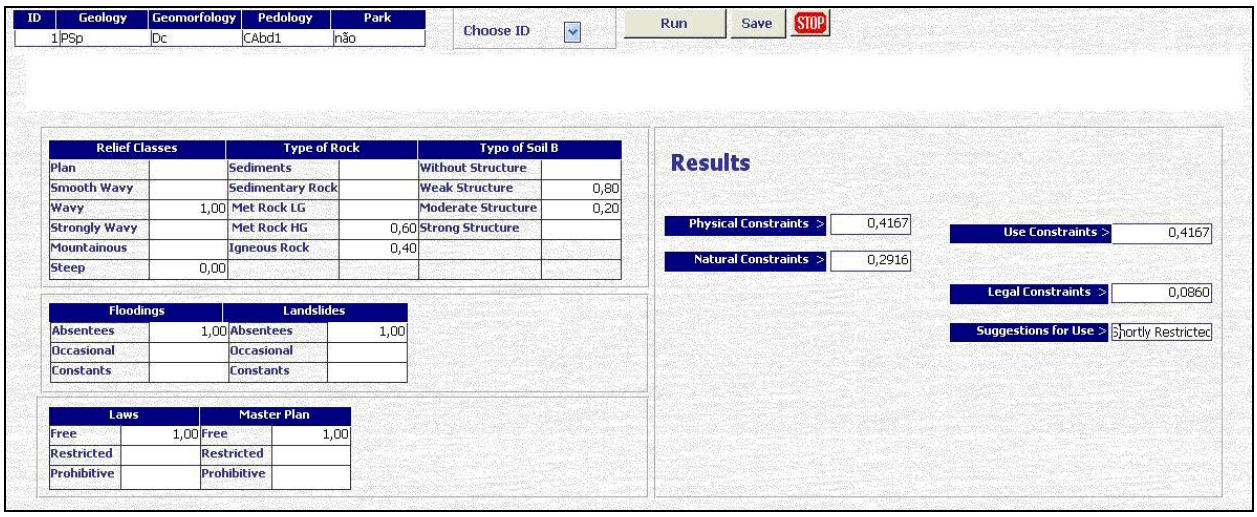

Figure 11 - Input/output form to polygon 1- (ID 1). Source: FERNANDES, 2009.

In another example, the polygon 78 shows rocks from Paranagua Complex with igneous and metamorphic formations, Cambisol soil with weak to moderated structure and a relief with mountainous to strongly classes. Those natural characteristics, associated to a legal restriction, strongly influences the results to a very restrict suggestion for use, as shown in Figure 12.

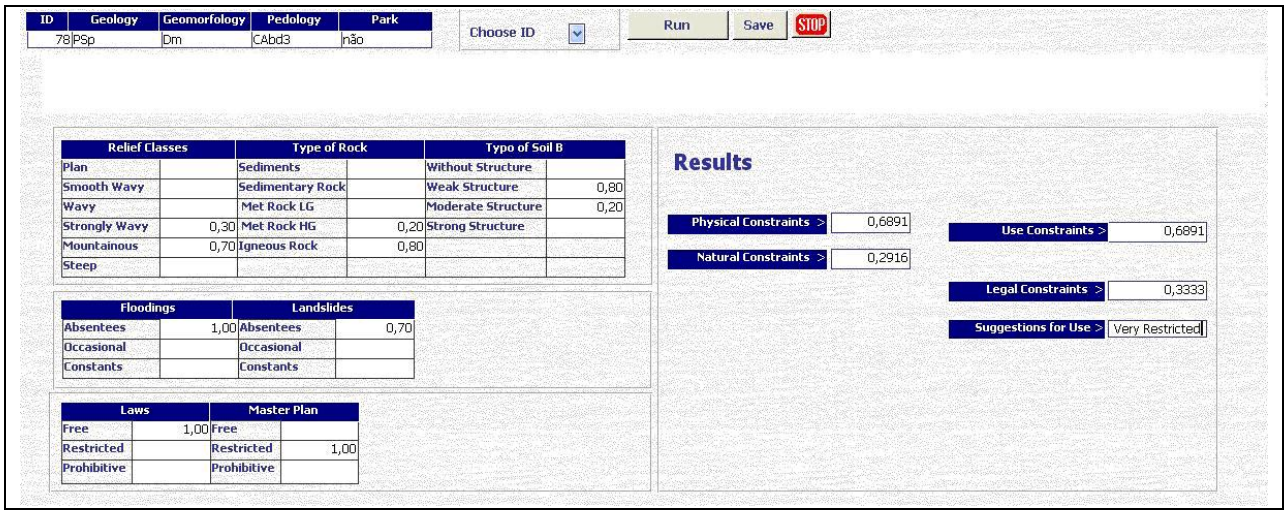

Figure 12 – Input/output form to polygon 78- (ID 78). Source: FERNANDES, 2009.

4 Conclusion

The developed model and application is based on a well known method of soft decision trees, associated to an also well known geographic information system. The contribution of our model and application is to integrate those methods and to turn the operations easy and understandable to experts and stakeholders.

The expert's knowledge is dynamically incorporated by the membership functions definitions and by field assessments. The model allows comparisons among diverse opinions of experts and stakeholders.

The model is sensitive and robust. All the 211 polygons were analyzed by the model and in the field. The results show that there are consistencies among both results. The island area is a mosaic natural systems ranging from mountains to beaches. The model is able to classify all of them.

The model is sufficiently robust to be used in any scale, preserving the fact that the larger the scale, the greater will be the need of detail of the data mapping and field work. The decision tree can also be altered to contain any other necessary variables for more detailed studies on larger scales of work, with a change in the input/output.

The generated information must be used simultaneously. The form provides technical information of values of the variables, and the map provides the locations of the final results in different colors. A new knowledge can be obtained, providing indications to the space use to public managers, stakeholders and dwellers, providing a responsible use of space.

References

Boclin, A. S. C.; Mello, R. de (2006). A decision support method in environmental impact assessment using the Fuzzy logic approach. *Ecological Economics*, Elsevier, v. 58, n. 1, p. 170-181.

Crepani, E. et al (1996). *Sensoriamento remoto e geoprocessamento aplicados ao zoneamento ecológico-econômico e ao ordenamento territorial*. São José dos Campos: Instituto Nacional de Pesquisas Espaciais. (INPE-8454-RPQ/722).

Fernandes, E. (1999). *Uso de Sistema de Informações Geográficas (SIG), na integração de mapas temáticos no Município de São Francisco do Sul – SC.* 121 p. Dissertação (Mestrado em Engenharia Civil)-Universidade Federal de Santa Catarina, Florianópolis.

_____. (2009). *Método de elaboração de mapa interativo de sugestão de uso do espaço com apoio da lógica difusa.* 139 p.: il., mapas. Tese (Doutorado em Engenharia Civil)-Universidade Federal de Santa Catarina, Centro Tecnológico, Progama em Pós-Graduação em Engenharia Civil.

IBGE - Instituto Brasileiro de Geografia e Estatística (1981). Mapeamento Sistemático do Brasil. Rio de Janeiro, s.d. Vários mapas. 1981.

____ (2002). Projeto Gerenciamento Costeiro - GERCO (3ª FASE). morrodobau.ufsc.br/files/2011/03/Geologia_final.pdf. morrodobau.ufsc.br/files/2011/03/Solos_final.pdf.

morrodobau.ufsc.br/files/2011/03/Geomorfologia.pdf.

Olaru, C.; Wehenkel, L. (2003). A complete Fuzzy tree decision technique. Fuzzy Sets and Systems, Elsevier, v. 138, p. 221-254.

Santos, G. T. (1997). Integração de informações pedológicas, geológicas e geotécnicas aplicadas ao uso do solo urbano em obras de engenharia. Tese (Doutorado em Engenharia)- Escola de Engenharia, Universidade Federal do Rio Grande do Sul, Porto Alegre.

Son, N. H. A soft decision tree. In: SYMPOSIUM ON INTELLIGENT INFORMATION SYSTEMS, 2., 2002. Proceedings. p. 57-66.

Zadeh, L.A. Fuzzy Sets, Information and Control, vol. 8, 1965, pp. 338-353.