INTEGRATED GEOINFORMATION MODEL FOR ENVIRONMENTAL PLANNING IN RIO de JANEIRO, RJ, BRAZIL.

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KEY WORDS: GIS, Integrated Geoinformation, Image Analysis, Database Revision, GIS standards, Fusion

ABSTRACT

The design of an integrated geoinformation model was established to the environmental planning context, which is conduced by the Rio de Janeiro Municipal Secretariat for the Environment. Modelling boundaries were set from a semi-detailed soil survey executed by Embrapa Solos. This particular study aimed to evaluate the consistence of the GIS application as integrated part of the planning process. Therefore, the main objective was to identify weakness of existing procedures where the original data set could be revised by the proposed model. In addition, it was meant to explore object-oriented methodology applied to evaluate results from integrated spatial analysis according to existing products from survey methods. The methodological approach applies terrain object modelling standards in Molenaar (1996) and UML language for analysis and design (Rational, 1997). Yet, an integrated GIS environment supported by object-oriented technology (ILWIS 2.1 ®) was used to implement the conceptual model processes. Results are an updated semi-detailed soil map, at 1:75,000 scale, and derived information as land suitability for horticulture and reforestation, land vulnerability, and land environmental quality. Further spatial analysis were defined to support reclassification, aggregation, generalisation, and overlay processes for land suitability and land vulnerability interpretations. DTM analysis helped to review where the county area is classified either as highlands, due to erosion susceptibility, or as low lands, due to drainage conditions. Image analysis has considered supervised classification to extract update land cover information that helps to evaluate environmental quality of the lands.

1. INTRODUCTION

1.1 Information Modelling

Strong limitations are present during integration and interpretation of great amounts of data supporting environmental planning. Many times, the degree of detailed data collected does not correspond to degree of generalisation required for planning activities, or vice-versa. Therefore, meaningful relationship between different levels must be identified in order to establish a vertical communication flow, where groups of detailed data can be associated into a broad characteristic at higher level of abstraction. In addition, the current market competitiveness and resource limitations brought information technology as a strategic factor to improve life quality, supplying demands of precision and promptness in decision making and planning. In this context, GIS (Geographical Information System) becomes key environment to support scientific aspects of integrated studies, as well as to identify and to formulate new hypothesis. As result, we can observe an increasing demand of geoinformation systems that serves as tool to integrate different contexts in environmental planning. For all those reasons, the adoption of concepts, methods and tools from information technology already characterises primary actions of the research agenda driven to higher levels of food productivity and environmental quality of the lands.

The great potential of object oriented constructs are still not explored by thematic surveyors, although the methodology can express relationships of semantic representations of natural system components. This should be understood by specialists as a consistent tool that has abilities to deal with complex problems as identification and classification of biophysical terrain objects. Some of those constructs are abstraction, categorisation, inheritance, clustering, boundary delineation, aggregation, and generalisation. Object-oriented models can support descriptions of system structure properties and behaviour. Structural properties combine the static nature of the data organisation. The behaviour is the dynamic characteristic of the geo-object, which is related to possible changes in the information nature. In this context, environmental researchers can declare the nature of the phenomena by defining its attributes and the behaviour of its geometric representation.

In order to approximate concepts from thematic surveyors and system analysts, an integrated geoinformation modelling study was developed within a context of environmental planning aiming to identify critical phases of the existing process where the original data set could be revised or coupled by integrated spatial analysis. In addition, the model was meant to explore de object-oriented technology applied to evaluate model results and existing information from traditional survey. Since all existing products were only based upon field work attributes with satellite paper images and aerial photographs interpretations, expectations were that incorporated DTM procedures could aid land vulnerability interpretations where the county area was divided into highlands, due to erosion susceptibility, and low lands, due to drainage condition. The susceptibility for reforestation prioritised the rolling areas subject to land sliding, besides the suitability for horticulture at the low land areas of the west zone that are still under agricultural use. The vulnerability of the lands evaluated the environmental fragility for urban and agricultural growth. The map for environmental quality of the lands was obtained by overlaying vulnerability data with current land use from supervised classification of digital satellite images, stressing the level of urban pressure upon natural attributes and how the environment reacts under these conditions. Furthermore, it could be used to search for social-economic patterns, as proximity to urban slams, improving the interpretation method for environmental fragility according to urban and agricultural growth.

1.2 Environmental Planning Context

The Municipal Secretariat for the Environment (SMAC - Secretaria do Municipal do Meio Ambiente), executive organism created in 1994, has developed technical studies in order to protect new areas, and to accomplish areas already planed for preservation. The scheme also includes the Municipal Council for Environment and the Environmental Conservation Fund, both as part of the "Megacities Project Book", published by the United Nations, which in 1990, chose the 16 best projects in the field of environment in cities inhabited by more than 10 million people. The specific reforestation scheme, so called “Mutirão Reflorestamento”, is presently active in 56 hillside communities, located in different geographic areas of the Municipality of Rio de Janeiro, thus preventing landslides and rain caused erosion. Up to now, the scheme reforested 500 ha (5,000,000 m^2) and planted a million seedlings of native Atlantic Rainforest species, employing 580 local hillside villagers. In order to prevent new deforestation caused by the growth of hillside communities, a "non-growth" pact was settled between the Government and hillside village leaders, aiming to freeze the hillside communities at their present size. The annual cost of the project is around US$ 9 million. Protected Areas are areas of the Municipality that, due to their ecological value, have a special legal statute of use and occupation of the soil. Some of the most important protected areas are of Environmental Protection and Urban Recovery, Protection of the Cultural Environment, Relevant Biological Concern, Biological Reserves, Ecological Stations, National Parks, State Parks and Areas of Permanent Preservation, as in Figure 1 (SMAC, 1997).

Figure 1. Landscape pictures of some protected areas (from left to right: Grumari, Marapendi e Jequiá; © SMAC).

1.3 General Description of the Area

The municipal district of Rio de Janeiro is located from 43º 05' 54" to 43º 47' 32" Longitude West and from 22º 44' 44" to 23º 04' 51" Latitude South, having the official area of 125,530 ha. The relief is constituted basically by three great well-known crystalline massifs such as Tijuca, Pedra Branca and Gericinó and by the sedimentary coastal plain comprised by Jacarepaguá, Sepetiba and Guanabara bottomlands. At the massifs there is a predominance of precambrian gneiss rocks, of varied constitution, penetrated by intrusive granite and alkaline rocks. Those factors influence the characteristics and distribution of the soil, mainly considered by its strong influence on gully and sheet erosion, besides a close relationship to climate and vegetation cover. The climate characterisation for the working scale has considered the following Köpen classes: Cfa; Af; Am; Cwa; Aw. This climatic variation facilitated the correlation of soil units and higher humidity degree of east faced slopes, besides typical formation of latosol B horizon of west faced slopes with the mesothermal climate at massif tops. Regional vegetation was characterised as follows: five different groups of forest types (subperenial tropical forest, subcaducous tropical forest, caducous tropical forest, evergreen meadow forest, and subperenial meadow forest); grassland meadow; halophyte meadow, sandbanks, and the mangrove swamps. According to current land use map, the district maintains 19.549 ha of preserved forest vegetation with minor changes of native vegetation, which corresponds to 15.6% of the total area.

2. METHODOLOGY

2.1 Survey, Interpretation, and GIS Procedures

2.1.1 Soil Survey: This study was executed in partnership of Embrapa Solos (National Center for Soil Research) and SMAC in order to provide strategic information applied to "Mutirão Reflorestamento" and other specific planing actions. The existing soil survey information (Embrapa, 1980) had firstly minor legend revisions considering few updates on original criteria (Embrapa, 1999a), in order to accomplish new project goals. The revision was based on pedogenesis correlation of soil horizon notations and analytical results from old and new soil, besides a complete conversion of analytical units to international standards. Geometric representations of soil class boundaries were checked according to new soil types (Embrapa, 1999a), update information of urban areas, beach, dune, swamp and exposed rocky covering (Rio de Janeiro, 1997), and mangrove field survey, at 1:10,000 scale, conduced by SMAC. The final step was to input fieldwork and analytical information in SIGSOLOS database (Embrapa, 1997), providing a storage structure of thematic attributes that can be linked to the topology of geometric attributes structured in GIS.

2.1.2 Land Suitability for Reforestation and Horticulture: The disordered occupation of hilly areas in Rio de Janeiro has been source of serious environmental damages, in special by water erosion at steep slope areas and granite mining. In this way, reforestation of degraded hilly areas was considered as main focus of this study. Another strategic aspect considered was the evaluation of remaining horticulture observed in west zone low lands, providing flat areas of alluvial, gley, and organic soil types besides proximity to market. The methodology for this interpretation was adapted from Ramalho F. and Beek (1994), and it was further applied to the updated soil map. Two types of land utilisation systems were defined as basis of distinct evaluation criteria, thus considering different species for both reforestation and irrigated horticulture. The reforestation system was defined for areas with step declivity higher than 3%, focusing on erosional processes due to deforestation. For this purpose arboreal vegetation has been chosen for hilly areas because good results obtained by the "Mutirão Reflorestamento" project at slums' neighbourhoods, presenting fast vegetative growth and profuse rooting system. The level of management system also includes options for application of nutrients and fertilisers. Another aspect considered for reforestation was the remaining mangrove ecosystem, where two especial classes define either a preservation status or an identification of native species to restore the original coverage. The irrigated horticulture system was defined for areas with step declivity lower than 20%, mainly focused on the west portion of the district because gentile relief aspect and fertile soil types, although problems of tionic and salic properties. The remaining crop coverage is characterised by small and spread sites, so that being under pressure of urban expansion. Management systems considered nutrient and water deficits, soil drainage class and erosion susceptibility, and availability for irrigation or drainage systems. The final evaluation system considered five limiting factors according to basic environmental quality indicators. Expert rules to estimate degrees of limitation and to represent relationship of factors were implemented into spreadsheet functions described in Embrapa (1999).

2.1.3 Land Vulnerability: The ecosystem vulnerability evaluation was considered as cause of environmental inadequacy to deal with natural stress factors. In this sense, vulnerability was understood as being an association of essential qualities of the ecosystem, such as: stability, persistence and restoration potential (Batisdas, 1995). In this context, the term land vulnerability is related to the land fragility for purposes of agricultural exploration, highway and railroad construction, sanitary swelling and cemeteries, contamination risk assessment, ecological recreation, and urban

Table 1. Guidelines for land vulnerability classification on highlands.

Land Vulnerability Classes	Conditioning Factors					
	Effective Depth (cm) (k)	Horizon Transition [1] (t)	Swelling Clays (h)	Relief (g)	Rockiness (r)	Primary Vegetation [2] (c)
Low (B)	> 200	fuzzy and gradual	no	gentile ondulating	-	subcaducous tropical forest
Intermediate (M)	100-200	clear and abrupt	no	ondulating	-	subcaducous tropical forest
High (A)	50-100	-	yes	strongly ondulating	slight	caducous and subcaducous tropical forest
Very High (MA)	<50	-	yes	mountainous	moderate	subperenial tropical forest
Extremely High (EA)	-	-	no	steeped	abundant	rangeland

[1] - Considered as indicator of texture gradient variation between soil horizons.
[2] - Considered as reflection of soil hydrologic conditions.

and industrial expansion. Land fragility evaluation has straight relationship with susceptibility to natural phenomena. A high fragility class implies in a high probability of severe damages or even extinction of species from the ecosystem.

In a qualitative approach for land vulnerability assessment, it was related to erosion susceptibility of slope areas, drainage condition of low land areas, and climatic factors in especial precipitation. The interpretation of environmental vulnerability of the lands was elaborated upon analysis of updated soil profile information and new map units delineation. In this sense, the evaluation methodology is further detailed because its possibility of improvement by DTM analysis that was not considered in project phase. Which has divided the total area into highlands, due to erosion susceptibility, and low lands, due to drainage condition. A map was based in a two step procedure for thematic attribute generalisation. The first step was to establish a relationship of soil profile conditioning factors and adopted land vulnerability classes, as shown in tables 1 and 2. The following steps were soil class generalisation and geo-objects aggregation procedure of neighbour areas within the same vulnerability classification result.

Table 2. Guidelines for land vulnerability classification on low lands.

Land Vulnerability Classes	Conditioning Factors							
	Soil					Drainage		Primary Vegetation [1] (c)
	Swelling Clays (h)	Sand Texture (v)	Organic Layer (o)	Strong Structure Layer (b)	Salic and Tionic Property (s)	Flood Risk (f)	Water Table Depth (cm) (w)	
Low (B)	no	no	no	no	no	none	>200	-
Intermediate (M)	no	no	no	yes	no	once each 10 years	100-200	subcaducous tropical forest and grassland meadow
High (A)	yes	yes	no	yes	no	once each 5 years	50-100	sandbanks and halophyte meadow
Very High (MA)	yes	yes	yes	no	yes	once a year	<50	sandbanks and halophyte meadow
Extremely High (EA)	no	yes	no	no	yes	frequently	superficial	Sandbanks and mangrove

[1] - Considered as reflection of soil hydrologic conditions.

2.1.4 Land Environmental Quality: This was the project last product, generated from the relationship of land vulnerability and land cover for planning purposes. The abstracted integration of these thematic information were expressed into a two dimensional table (Embrapa, 1999a), giving an evaluation output class to each unique combination of both input domains. Following the same basic criteria defined for vulnerability evaluation, the total area was divided into two great geomorphologic domains, as erosional landforms of highlands and sedimentation basis of low lands having distinct considerations. After that, it was possible to perform the topological overlay of both geometric representations. Once more, the digital soil map topology (Figure 2) was a basic source of delineation of land environmental quality information by means of both GIS spatial analysis and its database linkage to SIGSOLOS (Embrapa, 1997).

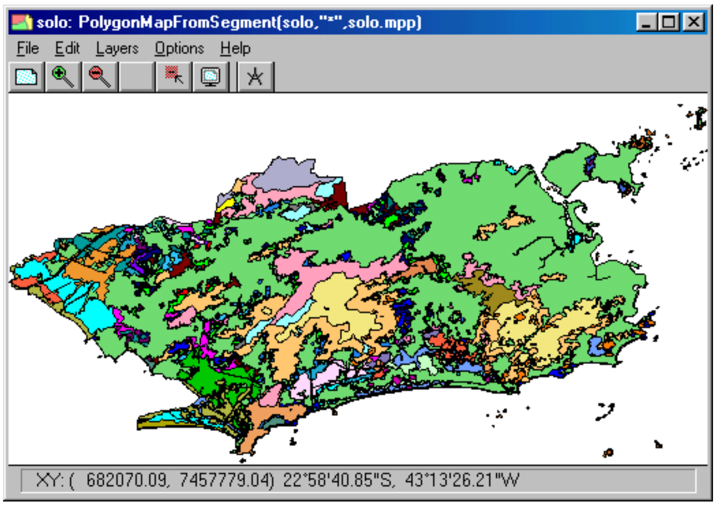

Figure 2. Overview of the digital soil map topology.

2.1.5 GIS Procedures: To accomplish the execution of main project phases, the ILWIS 2.1 (Integrated Land and Water Information System, 1997) environment was used in order to organise geometric attributes from thematic terrain objects. In this way, providing means to process basic spatial analysis as: statistical histograms, cumulative area calculation, two dimensional table definition for thematic overlays, and attribute tables for either correlation, class generalisation, or topology generalisation. For this purpose, most of basic digital information was supplied by SMAC: 1 - the topographic base map, georeferenced at 1:50,000 scale, in order to supply a common geometric data structure to both institutions; 2 - satellite images SPOT XS + PAN composition, scenes K722/J395 and K723/J395; 3 - the land use and vegetation coverage map (SMAC-RJ, 1997) in vector structure, at 1:50,000 scale, which was converted from raster format output of previously executed supervised classification; and 4 - remote sensed coverage information, on paper, of aerial photographs and SPOT satellite images for photo interpretation procedures.

After to import “dxf ” formatted files, the database structure organisation started with class domain analysis of the derived products, thus a revised soil map at 1:75,000 scale; a land suitability map; a land vulnerability map; and a land environmental quality map. The existing soil map of the of Rio de Janeiro district (Embrapa, 1980), at 1:50,000 scale, was georeferenced using the imported base map from SMAC. Further procedures involved the adjustment of vectored land cover information, which was extracted from digital image supervised classification in order to update urban expansion and specific vegetation with relevant biological concern. More over, the printout of the existing soil map served as basic material to fieldwork excursions. After the field data collection, laboratorial analysis and legend revision routines, new delineation of map units were digitised, as well as the point map for soil class identification. The final procedure of polygon generation requested some extra time for proper understanding of map domain definitions in ILWIS environment.

2.2 Integrated Geoinformation Modelling

The use of ILWIS 2.1, under an object-oriented approach, has required some substantial changes on previous operational processes and concepts for survey and mapping activities. The specific objective of this study was to evaluate suitable changes in traditional soil survey methods using elementary concepts of object-oriented methodology to execute conceptual system and data structure modelling. This choice aimed to facilitate information exchange, communication, by use case diagrams reflecting thematic abstractions, representations, and notations, according to UML analysis and design models (Rational, 1997). In addition, it was expected that this technology would be able to handle complex requirements of thematic integration. Furthermore, there is still necessary to show some surveyors the potential use of geographical analysis, because they usually can only see the automated cartography aspect of GIS. Therefore, they are still thinking in a manual process basis. For this reason, the idea was that the survey team should participate during modelling activities for both better guidance of thematic abstractions, and understanding of process driven models that can open new perspectives of spatial reasoning for land evaluation and zoning. Keeping away the perspective of pure technology just executing statistical analysis, automated functions, and geometric calculations.

Concepts for terrain objects modelling and formal data structure (FDS) in GIS environment are based on Molenaar (1996). In this sense, the conceptual model for environmental planning should also represent a multi-scale framework with different aggregation levels of information, besides to require inheritance, polymorphism, association, and generalisation constructs to be considered. Therefore, the integrated geoinformatiom model considered object classes and relationships from detailed field information up to district planing level. Still, SMAC has also contracted the previous described methodology to be applied in pilot watersheds at 1:20,000 scale. Consequently, the soil survey was done to generate more detailed planning information of critical areas around hillside slums (Embrapa, 1999b). Land suitability, land vulnerability, and land environmental quality were further generated in digital form, but still under traditional survey procedures. During the execution of SMAC projects, there was no concern to promote analysis considering distinct levels of information, appearing to have different survey purposes for two completely different areas. For this reason, the integrated model includes abstractions on how terrain object classes are related to terrain object superclasses. In final, the model predicts that future surveys at watershed level could be oriented by specialisation of upper level information, as they are already available at 1:75,000 aggregation level.

3. RESULTS

3.1 Environmental Planning Information

Project products for both survey levels were submitted to SMAC, having the quantitative information presented in Embrapa (1999a, 1999b), and the complementary GIS database. The soil survey could classify 41 different soil types and 7 special terrain types. One point to be observed is the difference of the total district area calculated in GIS, it shows a total area of 122,031.7 ha, against the official area of 125,250 ha given by the municipality statistical book.

However, there is no proper information on the book data reliability in terms of cartographic precision. Even more, there are minor islands inside the Guanabara Bay and other outer water bodies areas not include in the digital data set imported from SMAC. In the project framework, this difference was not considered of great importance, because the completeness of the continental cover.

Land suitability results included 40.384,9 ha of suitable areas for reforestation, being 33,1% of the total district area and 66,5% of the soil survey covering. From this result, the areas exclusively located at hilly slopes could be calculated as 35.333,8 ha, 28,9% of the total area and 96,6% of the total suitable for reforestation. Suitable areas for irrigated horticulture have an extension of 16.679,5 ha, 13,7% of the total district.

Primary criteria for land vulnerability, the sub-division of non-built areas into highlands and low lands resulted respectively in 36,850.0 ha and 23,885.3 ha. The areas considered of highest vulnerability for highlands (very high and extremely high vulnerability classes) are locate in the massifs of Tijuca, Pedra Branca, and Gericinó besides some isolated hills and mountains. Areas of lower vulnerability class for low lands are located at depositional slopes from Sepetiba, Pavuna, Jacarepaguá and Guanabara Bay. Highest vulnerability of low lands are presented close to Jacarepaguá, Tijuca, Camorim, and Marapendi lagoons; mainly close to dunes, mangroves, and sandbanks of Marambaia. Figure 3 gives an overall idea of land vulnerability class distribution for each one of the two main landscapes, as erosional environment of mountainous areas and depositional environment of piedmont areas.

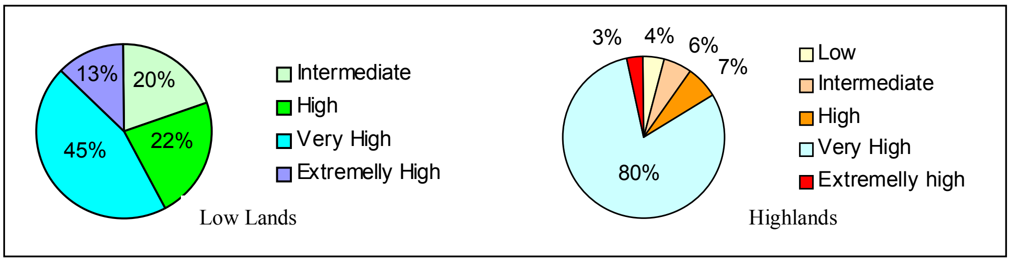

Figure 3. Percent distribution of vulnerability classes for depositional and erosional environments respectively low lands and highlands.

Areas with a better land environmental quality for highlands are those which are still covered with native Atlantic Forest species, mainly located in the massifs of Tijuca, Pedra, Branca, and Gericinó with 14,9% of the total district area. On the other hand, the worse environmental quality areas are close by mining activities, and mass sliding steps, which are in general spread all over the district at small sites representing 0,3%. At low lands, the best land environmental quality is the Marambaia sandbank, representing 0,4% of the total district area that is in a very good preservation state. In contrast, low lands have the worse environmental quality conditions at sand and sand stone mining that are mainly located in the west zone with total expansion of 0,3% of the total area of the municipal district. Mining activities also comprehends 1,7% of the total area, if considered exclusively at highlands.

3.2 Integrated Geoinformation Model

Although all the information and products that were generated in partnership with SMAC (Embrapa, 1999a; Embrapa, 1999b), the use of GIS procedures was static and limited to exchange hand made steps by automated functions. Therefore, the ability to use spatial analysis as integrated part of a process driven study, providing means of scenario generation to improve environmental elements recognition, was left behind. The specific results from the proposed modelling and procedural evaluation activities were related to surveyor's integration on systems approach methodology. The involvement of few researchers has clarified to system analysts certain details from data structure modelling constructs, as polymorphism and typing. On the order hand, researchers have been aware of the existence methods and software technology that can help them to abstract terrain object classes as thematic categorisation of biophysical actors under a process driven analysis and design models (see Figure 4).

Quantitative results form modelled processes were obtained by means of overlay procedures of previous generated land vulnerability and soil maps with the new slope map, which was calculated for each pixel from the generated DTM. Procedures were focus on land vulnerability information, because its evaluation has considered geomorphology as main criteria to define environmental limiting factors. Another procedure purposed as means of process optimisation was an image processing function, trying to refine previous executed supervised classification with detailed vegetation coverage and mining information from watershed level soil survey. Primary comparison of final area calculation results has shown that for highlands the DTM procedures can help with a more precise distinction between intermediate, high, and very high (M, A, and MA) land vulnerability classes, having up to 40% from previous A class total area as

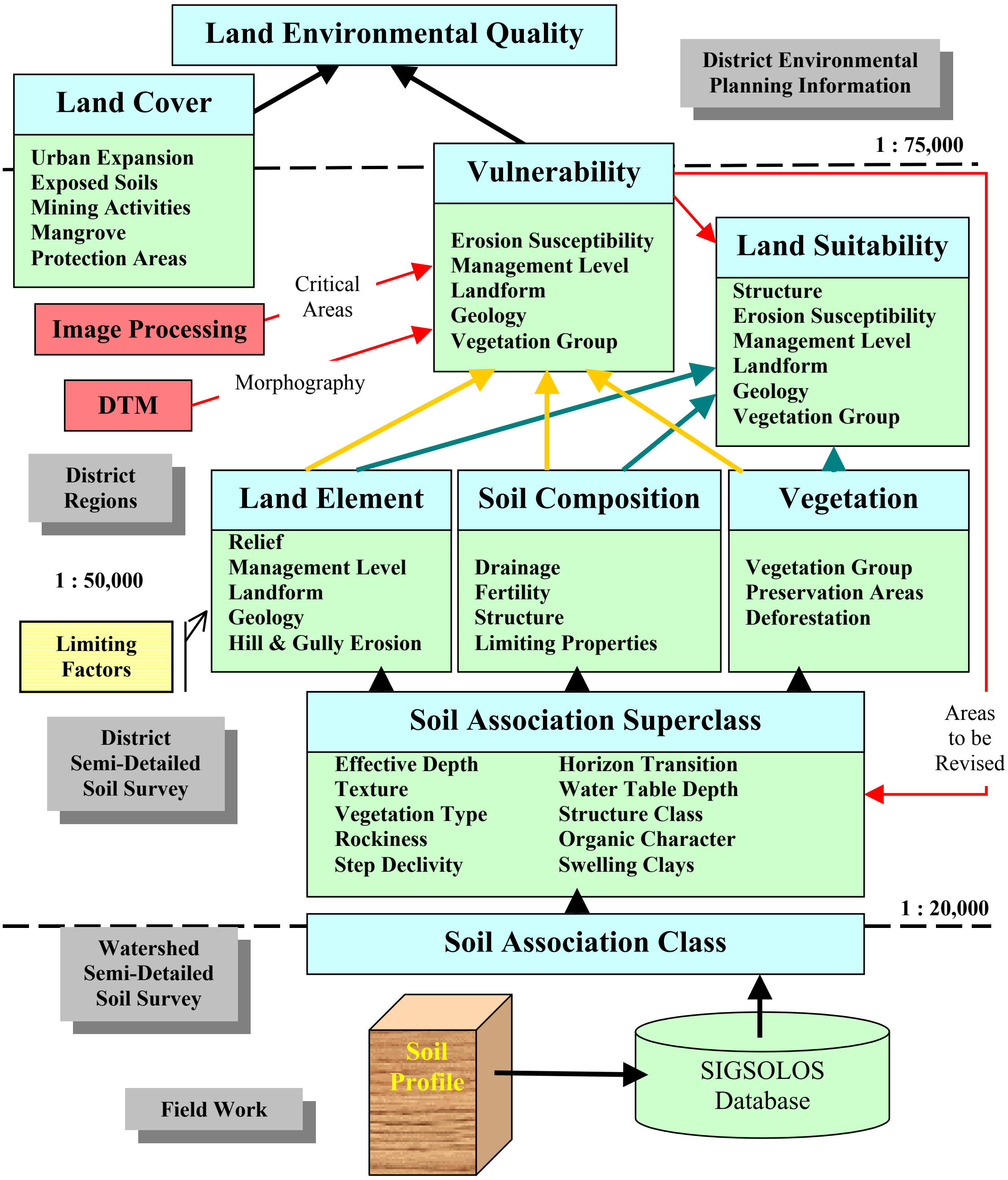

Figure 4. Conceptual model of terrain object classes integrating geoinformation to land environmental planning, including purposed spatial analysis (DTM and Image Processing) to be evaluated.

conflicting classification. Still, in extremely high (EA) vulnerability class for highland areas there was a very small difference around 0.1ha, showing that for those steeped slopes the DTM generation should be further refined. In low lands environment this procedure did not bring any significant difference, matching precisely previous calculated areas unless for areas with very high (MA) vulnerability class with a small difference of 0.4ha.

Further analysis has considered digital image processing functions for supervised classification, providing means to evaluate possible refinements for vulnerability assessment at low lands. Output results from final overlay phase were less significant than DTM analysis, having no classification improvement for highlands and most of low lands classes (0,2 ha for intermediate (M); 0.5 for very high (MA); and no differences for high (A)). For the depositional environment occurrences of extremely high (EA) vulnerability class differences were up to 17% from previous EA class total area as conflicting classification. This procedure could help to update land cover delineation of the old soil map (Embrapa, 1980), therefore from urban areas originally having 42,659.1 ha (34.9% of the total area) to 55,964.3 ha (45.9% of the total area) by vector digitalisation. Next step was supervised classification having 58,173.1ha (47,7% of the total area, $\Delta \approx$ 2,300 ha - 1.8%). In addition, a refined supervised classification to extract exposed soil areas giving 57,707.6 ha (47,3% of the total area, $\Delta \approx$ 550 ha - 0.4%). In closing, vegetation cover did not suffer any representative changes, since a detailed information from mining activities and mangrove vegetation, fieldwork at 1:10,000 scale, were incorporated on the land cover map.

4. CONCLUSIONS

- Using the project output information, the SMAC is already taking planning actions on preservation areas, in which mining activities have being pointed out as great impact on the land environmental quality.
- Although the importance and usefulness of numeric and cartographic products generated to the SMAC project, the most positive achievement was the full involvement of some surveyors whose have helped to make considerable changes on traditional survey methods.
- Considering the project execution, the ILWIS environment has proved to be easy and reliable to perform all the necessary spatial analysis, even if some extra time was required to fully understand the class domain management.
- In spite of the slow learning curve for proper application of object-oriented concepts, it has shown to be a consistent methodology to help surveyors during system abstractions by means of diagrams that reflect thematic processes, representations, and notations.
- The coupling of UML and geoinformation approaches offers a complementary environment for both the linguistic concepts for geometric representations, and the object-oriented constructs for development of graphic interfaces, distributed systems and dynamic management of data structure integrity.
- Environmental application researchers should be alert of the system approach potentiality for semantic representations of complex biophysical relationships.

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