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ENVIRONMENTAL MANAGEMENT OF SANTA MARIA DA SERRA WATERWAY SYSTEM – SP, BRAZIL

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Abstract

The risks of accidents in waterway systems have several reasons, being one of them the inadequate use of the soil, which intensifies the erosive process and causes the silting of the fluvial channel. The Project for the expansion of the Tietê-Paraná Waterway, named Santa Maria da Serra Hydric Enterprise, needs cartographic documents that aid in the orientation of the available resources in order to prevent adverse events generated by the silting process. Thus, this work aims at providing an auxiliary instrument for the management of hydric enterprises, which focuses on the establishment of restrictive criteria about the use of the soil on the margin of the waterway and in areas considered strategic for navigation safety. The adopted procedures are: generation of thematic maps; storage and manipulation of thematic data in a Georeferred Database; gathering of the data through a Geographic Information System, using Map Algebra, which results in the production of the Erosion Vulnerability Map; and, lastly, the ordainment of the territory through the Environmental Management Support Map of the Santa Maria da Serra Hydric Enterprise.

Keywords: Geoprocessing, map algebra, Images OLI/Landsat-8, hydric enterprise.

Introduction

Any type of work with a large extension, such as waterway systems, needs an Environmental Management System (EMS) in order to avoid environmental impacts and accidents risks in the waterway enterprise. Thus, the expansion of waterway systems must be harmonized with the sustainability of the terrestrial and aquatic environments, leading to preventive and corrective actions (Kraft and Penberthy, 2000). Also, it must conciliate the multiple uses of water and integrate its management with those of the soil. The essential procedures that give support to the waterway enterprise in relation to the environment are based on the guarantees of conservation of the local biodiversity and the adequate use of the natural resources, according to Wildenhahn (1994) and in the immediate updating of information from the environmental monitoring, according to Câmara et al. (2007). The preventive and controlling actions must be taken, in the areas near to the enterprise, as well as the distant ones, because the fluvial system not is isolated, but develops relationships with the whole river basin (Westen et al., 2000).

The main benefits of the Environmental Management System in waterway systems concentrate on the preservation of margins of the navigable bed, on the service life of the system, and on the quality of water for aquatic and human lives, according to Arnold (1998). Together with these factors, there are: the increase of international competitiveness, the work's cost minimization, and the security maximization, which are the more relevant economic advantages for the enterprise, according to Zemilynovski et al. (1985). Thus, the accomplishment of legal requirements, through the use of the Environmental Management System, makes it not only a preventive strategy but also a distinguishing factor in the market (Glasby, 2006).

Santa Maria da Serra Hydric Enterprise is a long term project for the extension of Tietê-Paraná waterway system, and it was designed on the Piracicaba River, which is a tributary of Tietê River (Botter et al., 2000). The studied area is the Low Piracicaba sub-watershed, delimitated by the parallels 22º15' to 22º45' South latitude and meridians 47º45' to 48º30' West longitude. Inserted in one of the main regions of greater occupational pressure in São Paulo state, it is the second industrial pole of the country and its geoeconomic system is the most dynamic of the state. Therefore, the expansion project for the Tietê-Paraná Waterway in this area demands attention in both state and national sceneries, since São Paulo is the state of greatest socio-economic development in Brazil. The primary hypothesis of the present work is that Erosion Vulnerability and Management Environmental Support maps in the given waterway are basic cartographic documents for initial decision-makings and that they can be generated and updated by semi-automatic and automatic computational processes and stored in data banks as a way to properly aid the enterprisers. Another hypothesis is that inadequate use of the soil intensifies the process of silting of the Piracicaba River, affecting the performance and security of the waterway.

Based on these considerations, the general objective of the present article is to present a methodological approach as an auxiliary tool in the environmental management of a waterway system. The emphasis falls on the analysis of the elements of the physical environment, with the objective of establishing restrictive criteria for soil usage surrounding the waterway and the areas considered strategic for navigation security. Some specific objectives were accomplished in order to reach the general one: to structure and implement a RGDB (Relational Georeferred Database); to generate thematic maps containing information about the components of the abiotic, biotic and anthropic environments; to integrate the data through a Geographic Information System (GIS), using map algebra and generating the Erosion Vulnerability Map; and, finally, to suggest the ordainment of the territory through the Environmental Management Support Map of the Santa Maria da Serra Hydric Enterprise.

Material and method

The materials necessary for the development of the present work were: Topographic maps of Dois Córregos, Brotas, Itirapina, Piracicaba, Capivari, Laras, São Pedro, Barra Bonita and Santa Maria da Serra, all of them in the scale of 1:50.000; Images OLI/Landsat-8; Geologic, Pedologic and Geomorphologic maps of São Paulo state, scale 1:50.000; and geoprocessing program SPRING (Georeferenced Information Processing System).

There are several methodological criteria for partitioning the erosive potential of a watershed, using as analysis tools, geotechnology (Berry, 2005). In short, the main steps of the technical procedures adopted in the present work were the compilation and operationalization of the data. The compilation gathered the acquisition and activities, selection, together with the prepared information and field work that complemented the data gathered and validated the obtained products. This phase includes the following steps: definition of a RGDB in the SPRING software; digitalization, analysis, correction and adjustment of the basic cartography and thematic maps (or importation of the ones that were in the digital format) and the conversion of formats and image geocorrection for the adopted system of cartographical projection. The cartographic basis was in the digital format, being therefore imported straight to the RGDB; the geologic, geomorphologic and pedologic maps (Almeida et al., 1981, Ross and Moroz, 1997, Oliveira et al., 1999) were digitalized as they were in the analog format. The maps of slope classes and vegetal coverage and soil use were generated in SPRING by automatic processing and by visual interpretation of images, respectively.

The operationalization of the data involved the generation of erosion vulnerability and environmental management support maps. The method used to generate the erosion vulnerability map was based on Morphodynamic Analysis of the Landscape, by the delimiting Basic Territorial Units (BTUs) from the satellite images and integrating this maps using algebra mapping. BTUs are formed by units of natural landscape and polygons of anthropic action, and they were generated by the crossing of geologic, geomorphologic, pedologic, slope and vegetal coverage and soil use maps, having the satellite images as support for the analysis. Algebraic Mapping operations were used to accomplish the automatic integration of the data and to classify the degree of stability or instability to erosion (scale 1 to 3), through the morphodynamic analysis of the landscape, considering the relationship between morphogenetic and pedogenetic processes (Table 1). The distribution of weights to the elements related to erosive processes was based on field work and analysis of drainage networks conducted by the author and colleagues (Nascimento and Garcia, 2005 Nascimento et al., 2008) by visual interpretation of satellite images by systematic method (Soares and Fiori, 1976, Veneziani and Anjos, 1982) and geostatistician method of ordinary kriging (Landim, 2006).

In computational terms, these procedures were developed by the authors of the present work as computational programming routines, using language adequate for the software SPRING, explained in Tables 1 to 5. The model that is applied to each theme individually receives a final value, which results in the average of individual values, in the pre-established scale of erosion vulnerability. At first, each class is analyzed, attributing a corresponding value for the behaviour concerning the erosive processes. The rock’s high resistance to erosion is therefore a consequence of the greater degree of cohesion among minerals, while greater soil development indicates that the pedogenic process prevailed along with the smallest slope values and greater coverage capacity to protect the landscape. In the context of RGBD, the attribution of those values was done through the pondered-transformation operation applied on thematic maps, changing them into numeric maps, Tables 2, 3 and 4.

Table 1: Synthesis of the model of generation of map of vulnerability to erosion.

<table>
<tr><th>Unit of Landscape</th><th colspan="3">Value of the Morphodynamic Analysis</th><th colspan="3">Pedogenetic-Morphogenetic Relationship</th><th>Degree of Vulnerability</th></tr>
<tr><td>BTU 1</td><td rowspan="11">Instability</td><td>3,0</td><td rowspan="11">Stability</td><td rowspan="11">Morphogenesis Prevails</td><td rowspan="11">Balance</td><td rowspan="11">Pedogenesis Prevails</td><td rowspan="4">Vulnerable</td></tr>
<tr><td>BTU 2</td><td>2,9</td></tr>
<tr><td>BTU 3</td><td>2,8</td></tr>
<tr><td>BTU 4</td><td>2,7</td></tr>
<tr><td>BTU 5</td><td>2,6</td><td rowspan="4">Moderately Vulnerable</td></tr>
<tr><td>BTU 6</td><td>2,5</td></tr>
<tr><td>BTU 7</td><td>2,4</td></tr>
<tr><td>BTU 8</td><td>2,3</td></tr>
<tr><td>BTU 9</td><td>2,2</td><td rowspan="3">Moderately Vulnerable-Stable</td></tr>
<tr><td>BTU 10</td><td>2,1</td></tr>
<tr><td>BTU 11</td><td>2,0</td></tr>
</table>

BTU 12		1,9					
BTU 13		1,8					
BTU 14		1,7					Moderately Stable
BTU 15		1,6					
BTU 16		1,5					
BTU 17		1,4					
BTU 18		1,3					Stable
BTU19		1,2					
BTU 20		1,1					
BTU 21		1,0					

Table 2: Morphodynamic analysis and punctual pondered-transformation operation of the rock formations and slope classes.

Recover the thematic variable **Geo**		Recover the thematic variable **Dec**	
Create the ponderation table **GeoT:**		Create the ponderation table **DecT:**	
Aluvionar Formation = **3,0**	Botucatu Formation = **2,4**	<2% = **1,0**	10-20% = **2,0**
Itaqueri Formation = **2,6**	Pirambóia Formation = **2,5**	2-5% = **1,3**	20-30% = **2,3**
Serra Geral Formation = **1,5**	Corumbataí Formation = **2,8**	5-10% = **1,7**	30-50% = **2,7**
		>50% = **3,0**	
Create the exit numeric variable **GeoN**		Create the exit numeric variable **DecN**	
Execute the operation of ponderation:		Execute the operation of ponderation:	
GeoN = Ponder (Geo, GeoT)		**DecN = Ponder (Dec, DecT)**	

Table 3: Morphodynamic analysis and punctual operation of ponderation of types of soil.

Recover the thematic variable **Soil**
Create the ponderation table **SoilT:**
Lithosol = **3,0**
Humic Gley = **3,0**
Red Yellow Podzolic Eutrophic = **2,4**
Red Yellow Podzolic Aluminic = **2,2**
Red Yellow Podzolic Alic= **2,0**
Red Yellow Latosol Distrophic = **1,1**
Create the exit numeric variable **SoilN**
Execute the operation of ponderation:
SoilN = Ponder (Soil, SoilT)

Table 4: Morphodynamic analysis and punctual operation of ponderation of types of relief, vegetal coverage and soil use.

Recover the thematic variable **Rel**	Recover the thematic variable **Use**	
Create the ponderation table **RelT:**	Create the ponderation table **UseT:**	
Plain fluvial = **3,0**	Riparian Forest = 20	Pasture = **2,6**
Convex types of low dissection = **2,2**	Primary Forest = **1,6**	Permanent culture = **2,7**
Convex types of average dissection = **2,6**	Savannah = **2,1**	Annual culture = **2,9**
Convex types of low dissection = **3,0**	Secondary Forest = **1,9**	Soil exposed = **3,0**

Tabular types of average dissection = **1,0**	Sugar cane = **2,8**	Urban area = **3,0**
Tabular types of low dissection = **1,2**		
Create the exit numeric variable **RelN**	Create the exit numeric variable **SoilN**	
Execute the operation of ponderation:	Execute the operation of ponderation:	
RelN = Ponder (Rel, RelT)	**UseN = Ponder (Use, UseT)**	

Afterwards, through the operation of arithmetic average with the operator "Update", a numeric object was generated that represents the average vulnerability value of the BTUs after each numeric field resulting from the operation of ponderation, Table 5. The following step was the generation of the arithmetic average for the erosion vulnerability of each BTU of all numeric fields used, through the operator "Attribute" according to the following expression: Average **Obj.= (Obj.Geo + Obj.Dec + Obj.Soil + Obj.Rel + Obj.Use)/5**. After these operations, RGDB starts to contain, more than thematic maps, their respective numeric fields of erosion vulnerability and the numeric field with the average vulnerability value in BTUs. The last operations that were developed to finish the Erosion Vulnerability Map were the spatialization and slicing ones, Table 6, generating a numeric map, which defines the interval of erosion vulnerability and a thematic map.

Table 5: Operation of updating rock formations, slope classes, soil types, relief, vegetal coverage and soil usage.

Recover the registering variable **BTU**
Recover the numeric variables **GeoN**, **DecN**, **SoilN**, **RelN** and **UseN**
Execute the numeric variables of Updating:
Obj.Geo = Update (GeoN, BTU, MedZ)
Obj.Dec = Update (DecN, BTU, MedZ)
Obj.Soil = Update (SoilN, BTU, MedZ)
Obj.Rel = Update (RelN, BTU, MedZ)
Obj.Use = Update (UseN, BTU, MedZ)

Table 6: Operations for the spatialization of the numeric variable arithmetic average and slicing of the spatialized map.

Recover the registering map **BTU**
Recover the numeric variable Average **Obj.**
Create the table of slicing **Tab**: [1.0, 1.3]: "Stable"; [1.3, 1.7]: "Moderately Stable"; [1.7, 2.2]: "Moderately-Stable-Vulnerable"; [2.2, 2.6]: "Moderately Vulnerable"; [2.6, 3.0]: "Vulnerable".
Create a Numeric Informational Plan to be spatialized **Num**
Create a Thematic Informational Plan to be visualized **Tem**
Execute the operation of Spatialization: **Num = Spatialize (Average Obj.)**
Execute the slicing on the spatialized map: **Tem = Slice (Num, Tab)**

To create the Environmental Management Support Map, points for sediment collection were defined, as well as the ideal areas for the culture of sugar cane and pastures, the restauration of natural vegetation along the Piracicaba River and the reforesting of hillside of Itaqueri and São Pedro mountains, based on the Forestal Code. Definition the sediment collection points for the quantification of volume of transported material by the tributaries and deposited in Piracicaba River and in Barra Bonita Dam was done initially after drainage connections were considered. In order to have the equidistribution of these points, a quadricular net of 4.000 meters was used with a distance between the points of 500 meters, according to the work scale (1:50.000). When this step was completed, these points were refined with the objective of decreasing the number of collection points for optimization and therefore decrease the costs of excess sampling. In this phase, the places surrounding the waterway enterprise and the drainages that discharge in Piracicaba River were most relevant regarding those that discharge in Barra Bonita Dam. The Erosion Vulnerability Map was also used to reject and to conserve the points of collection, where the classes of greater erosive potential were decisive in the final choice of the points.

Another procedure was to define the ideal areas for the culture of sugar cane, which would be restricted to the classes of erosion vulnerability classified as moderately stable and stable and the culture of pasture, classified as moderately stable-vulnerable. Between the two classes of soil use, two classes of vegetal coverage were established: Riparian Forest and Rain Forest, with the aim of restauring the Riparian Forest by reforesting it with native species. The first one comprehends the area surrounding Barra Bonita Dam and Santa Maria da Serra Hydric Enterprise and it was defined between the altimetric quotas of 460 and 480 meters. The second one is extended all along the steep hillside, whose altimetric quotas vary according to the mountain in question: São Pedro mountain was between 580 and 900 meters and Itaqueri mountain, between 560 and 1200 meters. In addition to this set of information, the Environmental Management Support Map contains a zone between the quotas 450 and 460 meters, which is the simulation of the enterprise of interest.

Results and discussion

The conceptual and technological bases developed a computational environment that provided the operationalization of all the steps of technical procedure. Through algebraic mapping of the integrated landscape, a morphodynamic analysis of the physic-biotic-anthropic data generated a profile of the environmental framework of the region, defining the areas that could cause potential damages to the waterway due to the erosive processes and consequential silting of Piracicaba River. It is important to highlight that the silting of a waterway causes risks of boat stranding and decreases the service life of the own enterprise, which provokes not only financial damages but also the mortality of aquatic biota.

The delimitation of the BTUs is a way of approaching the geographical reality, and the geographical information is related to the existence of objects with particular properties and topologic relationships with other objects. It has a dual nature expressed by its place in the geographical space and the descriptive attributes of non-spatial nature, which can be stored in a RGDB, and made it possible to develop procedures for the geographical analysis. The availability of the algebraic operations, through the computational programming, in an environment of manipulation and geographic analysis revealed to be efficient and fast because it facilitated the integration of environmental variables used in the cartographical modeling. This overlapping of technological and methodological resource allows the constant updating of data and the respective dynamic vision of the natural and anthropic processes of the sub-watershed. Thus, the waterway can be monitored constantly to prevent accidents and incidents as well as to avoid environmental impacts and/or mitigate those that can happen, considering that any enterprise of this extent may always cause some environmental damage.

The Erosion Vulnerability Map constitutes one of the intermediate products, Figure 1, and represents the contribution offered by the physic-biotic-anthropic environment to the rational occupation of the territory. This map, associated with legislation and suggestion of preventive and mitigating actions, was responsible for the creation of the Environmental Waterway Management Support Map for the Santa Maria da Serra Hydric Enterprise, Figure 2.

The adoption of conservationist practices, as long as being effectively employed, will propitiate greater rural activity efficiency, which is the productive structure of the region. Besides, it will represent a fundamental role for the preservation of the natural resources and, consequently, avoid risks for the waterway enterprise. It is in this context that the recommendations present in the letter environmental management support were proposed. It is evident that, for the restauration of the Riparian vegetation and reforesting with native species a collective action of politicians and enterprisers is necesssary. In this case, it is also important that those in charge of the Santa Maria da Serra Hydric Enterprise realize the importance of the preservation of areas of native vegetation (that protects the soil), so as to monitor and invest in the mitigation of the possible environmental risks and areas that are vulnerable to erosion.

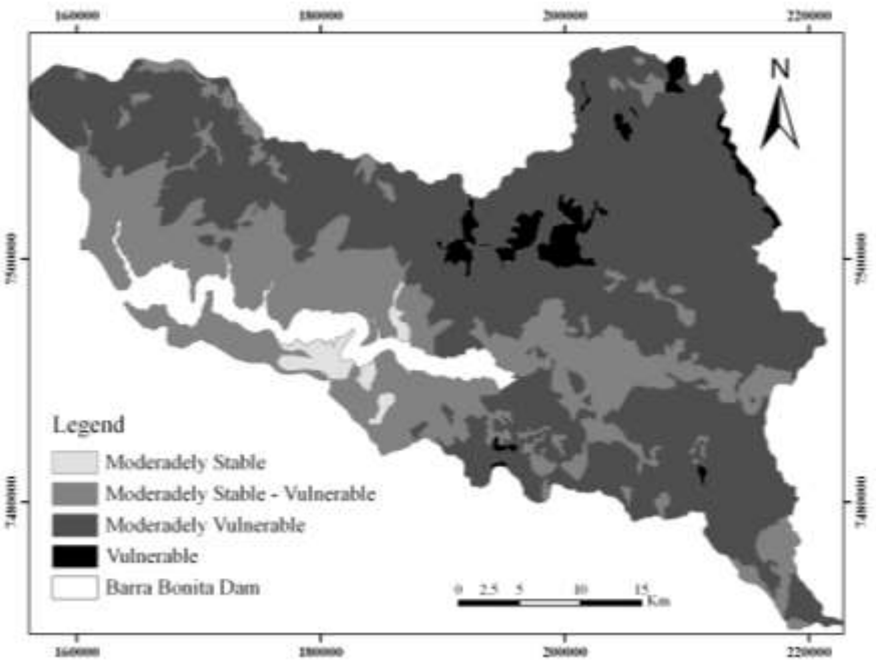

Figure 1: Erosion Vulnerability Map for the Lower Piracicaba Sub-watershed.

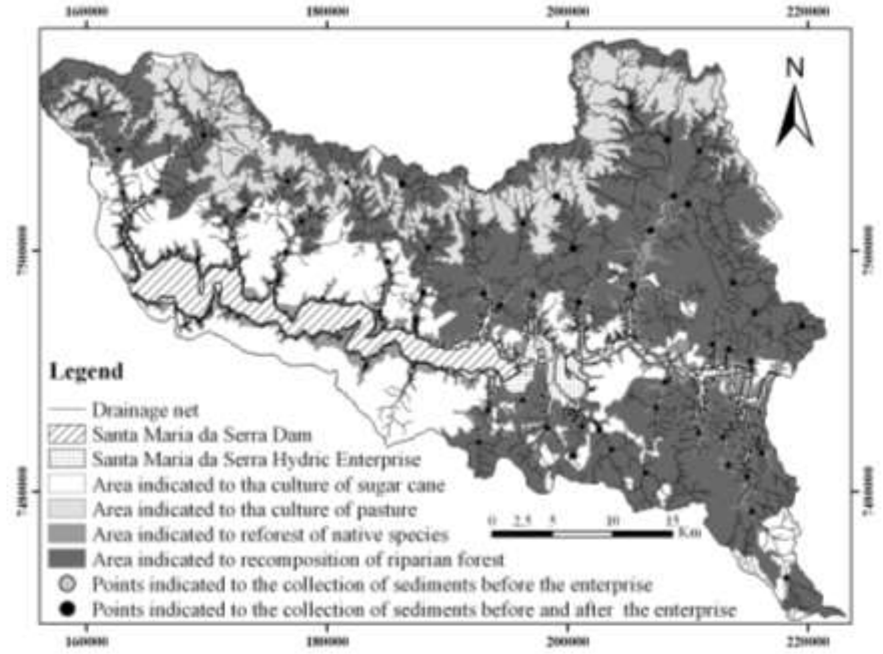

Figure 2: Environmental Management Support Map for the Santa Maria da Serra Hydric Enterprise.

The propose of the suggestions in the Environmental Management Support Map is to decrease the erosive process by reforestation of the hillsides and adequately define areas for the cultivation of sugar cane or pasture, creating protection zones in the area surrounding the waterway by the restauration of the Riparian Forest and definition the sampling points for quantifying the volume of sediments that may affect the enterprise, aiming at controlling the process of silting and hinder any type of risk associated to such processes.

Conclusions

Based on the development of the present research, the results attest that the general objective was fulfilled; that is, a methodological contribution to aid the environmental management of the Santa Maria da Serra Hydric Enterprise, aiming at establishing restrictive criteria for the soil use along the margins of the waterway and the areas considered strategic for navigational security. Regarding the specific objectives, all of the essential data was generated for the development of the present study, namely: defining the BTUs, and integrating the information by algebraic mapping in order to generate the Erosion Vulnerability Map. This map represented a contribution offered by the physic-biotic-anthropic environment for the occupation of territory which, in association wich legislation and suggestions of preventive and mitigating actions, generated the Environmental Management Support Map for the Santa Maria da Serra Hydric Enterprise, procedures that are carried out when structuring a RGDB. This one, by chance, may be updated whenever necessary for the adequate operationalization and constant monitoring of the waterway.

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