VULNERABILITY ASSESSMENT IN COASTAL AQUIFERS OF RIO DE JANEIRO STATE, BRAZIL

Gerson Cardoso da SILVA JÚNIOR[1]
Tiago Carvalho PIZANI

ABSTRACT

The objective of this work is to present an aquifer vulnerability assessment carried out in coastal zones of Rio de Janeiro State, Brazil, between Niterói and Rio das Ostras municipalities, with the use of Geographical Information System (GIS) techniques. The area has suffered from salinization and anthropogenic contamination in the last decades, due to intense pumping and uncontrolled occupation. The GIS software was used in the acquisition, composition and elaboration of the DRASTIC method information layers. The DRASTIC (Environmental Protection Agency - USEPA) is widely used as a tool for aquifer vulnerability assessment. In this application, the information layers included: depth to water table or groundwater depth, aquifer recharge, lithology, soil type, topography and permeability, that were georreferenced with the software SPANS (PCI *Geomatics*), allowing the elaboration of a groundwater vulnerability map. Results show that the most vulnerable areas comprise the sand bar deposits, followed by the colluvial-alluvial sediments, moderately vulnerable. The crystalline rock domain and the corresponding regolith, as well as the organic clay deposits, are zones of relatively low vulnerability. The vulnerability assessment, coupled with a risk analysis-approach is a most effective instrument in subsidizing aquifer protection policies in the region. Continuing research will address this task.

Keywords: Coastal aquifers, Vulnerability Map, DRASTIC method, GIS.

RESUMEN

El objetivo de este trabajo es la presentación de una evaluación de la vulnerabilidad de acuíferos llevada a cabo en la zona costera este del estado de Rio de Janeiro, Brasil, entre las ciudades de Niterói y Río das Ostras, con el uso de técnicas de Geoprocesamiento. El área ha sufrido una salinización y contaminación de origen antrópica en las últimas décadas, por efecto de sobreexplotación y la ocupación descontrolada. El *software* de Geoprocesamiento ha sido empleado en la adquisición, composición y elaboración de las capas de información del modelo DRASTIC. El DRASTIC (Environmental Protection Agency - USEPA) es ampliamente empleado como una herramenta en la evaluación de la vulnerabilidad de los acuíferos. En la presente aplicación, las capas de información han incluido la profundidad al nivel freático, recarga al acuífero, litología, tipo de suelo, topografía y permeabilidad, que han sido georreferenciadas con el *software* SPANS (PCI *Geomatics*), permitiendo la elaboración de un mapa de vulnerabilidad del agua subterránea. Los resultados indican las áreas más vulnerables comprenden los depósitos de barras de arena, seguidos por los sedimentos colúvio-aluvionares, que son moderadamente vulnerables. El dominio de las rocas cristalinas y el regolito correspondiente, bien como los depósitos de arcilla orgánica, son zonas de relativamente baja vulnerabilidad. La evaluación de la vulnerabilidad, en conjunto con una aproximación de análisis de riesgo, constituye un instrumento muy efectivo para subsidiar políticas de protección de acuíferos en la región. La investigación sigue en busca de esta meta.

Palabras-clave: Acuíferos costeros, mapa de vulnerabilidad, método DRASTIC, Geoprocesamiento.

[1] Universidade Federal do Rio de Janeiro, Departamento de Geologia, Setor de Geologia de Engenharia e Ambiental, Av.Brig. Trompowski, s/n, Ed. CCMN, Sala J_0-05, Cidade Universitária, Rio de Janeiro - RJ Tel/Fax: (21) 2590-8091, e-mail: gerson@acd.ufrj.br ; pizani@acd.ufrj.br

INTRODUCTION

This work represents an approach on the natural vulnerability evaluation in coastal aquifers at Rio de Janeiro State Eastern coast, Brazil, between Niterói and Rio das Ostras municipalities.

The term *natural vulnerability* is applied to represent a group of essential characteristics that determine the degree of protection that natural environment provides to aquifer affected by a polluting load.

Vulnerability assessment to aquifer contamination has played a key role in territorial management and policies in many places of the world, and also in choosing sites potentially suitable for waste disposal (Hrkal, 2001).

The characterization of areas with unfavorable conditions of aquifer protection (high vulnerability), represents a powerful aid in elaboration of environmental projects, indicating the location and precautions to be taken in the phases of installation of the project and, later on, in the effluent manipulation, storage and discarding.

OBJECTIVE

The main objective of the present work is to produce a vulnerability map to evaluate possible contamination susceptibility of the coastal aquifers between Niterói and Rio das Ostras municipalities. It is intended also to subsidize public administrators in assessing the potential risk of groundwater contamination.

HIDROGEOLOGY

There are two main aquifer types in the area: the porous aquifer, constituted by recent sediments, like alluvial sands, colluvium, residual soils and sand bar deposits. The sand bars and the alluvial deposits are good aquifers. They comprise medium to coarse-grained sediments, both with good storage capacity and transmissivity. They constitute shallow aquifers, lying over crystalline rocks of relatively low permeability.

Colluvial and alluvial soil deposits are generally poor aquifers, due to their clayey nature and to human contamination.

The fractured gneissic rocks are widespread in the area, outcropping or as the bedrock. The presence of water is conditioned by the type, aperture, interconnections and persistence of fractures. In some cases, yields in these aquifers may reach as much as 16m^3/h in individual wells.

Overdraft in the region may be the cause of an observed saltwater intrusion, slowly advancing landwards. This phenomenon is more pronounced in the summer season, when a significant fluctuant population occupies the region. Besides, water salinity increases notably as a function of depth and sea proximity (Lowsby, 2000).

METHODOLOGY

Adoption of an interpretative model

The model used in the characterization of aquifer units' natural vulnerability in coastal aquifers at Rio de Janeiro was the DRASTIC, developed in the United States by NWWA (National Water Well Association) and the USEPA (United States Environmental Protection Agency) in a joint effort to define a standardized methodology that could be applied to the various regions of the United States (Merchant, 1994). Although there are a number of other methods available (Foster & Hirata, 1991) the DRASTIC is still a powerful and flexible tool that can easily be adapted to different environments and situations.

The database employed here resulted from surveys carried out by the authors. The data were processed with geographic information systems (GIS) techniques using the software SPANS-GIS.

The assigned weighting factors of the thematic maps were pre-established in the model in the following way, according to Table 1.

Table 1. Assigned Weights for DRASTIC Factors

Feature	Weight	%
Depth to Water Table (D)	5	21.739
Net Recharge (R)	4	17.391
Aquifer media (A)	3	13.043
Soil Media (S)	2	8.697
Topography (T)	1	4.348
Impact of Vadose Zone (I)	5	21.739
Hydraulic Conductivity (C)	3	13.043

Data entry

The database is composed of numerical data in tables (Tables 2 to 8) and basic maps in vectorial and raster formats (Figures 1 to 3).

The data processing carried out in SPANS included creation of layers and definition of the base map.

Weighting units in thematic maps

Relative scores were attributed varying from 1 to 10, which reflect the significance of each unit in the quantification of vulnerability. The highest values indicate the parameters that favour the aquifer contamination in case there is some polluting load in the area.

Table 2. Ranges and ratings for depth to water table

Depth to Water table (m)	
Depth (m)	Range
0-2	10
2-4	8
4-8	5
> 8	1

The scores attributed to the classes of each thematic map are represented in the tables 2 to 8 (adapted from Rosário, 1999).

Table 3. Ranges and ratings for recharge

Recharge (hm^3/yr)	
Recharge (hm^3/yr)	Range
< 20	1
20 - 80	5
80 - 140	8
> 140	10

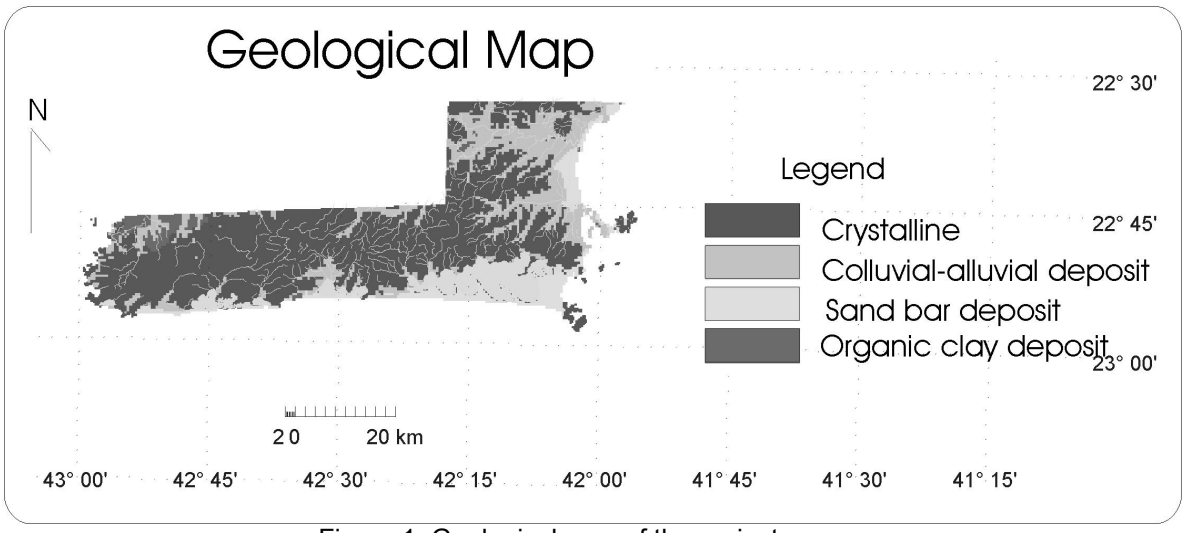

Figure 1: Geological map of the project area.

Table 4. Ranges and ratings for aquifer media

Aquifer Media	
Rock type	Range
Crystalline rock	5
Colluvial-alluvial deposit	8
Sand bar deposit	10
Organic clay deposit	1

Table 5. Ranges and ratings for soil media

Soil Media	
Rating	Range
A (alluvial deposits)	4
HP (hydromorphic soil)	5
Cd (cambissol)	5
Du (dune deposits)	10
G (gley humic)	1
LV (red latosol)	10
PA (yellow podzol)	3
PV (red podzol)	3
SI (indiscriminated soil)	5
Urban (urban areas)	1

Table 6. Ranges and ratings for topography

Topography (declivity %)	
Rating	Range
0 - 2	10
2 - 6	8
6 - 12	3
>12	1

Table 7. Ranges and ratings for impact of vadose zone

Impact of Vadose Zone	
Rock type	Range
Crystalline rocks	1
Colluvial-alluvial deposit	5
Sand bar deposit	10
Organic clay deposit	1

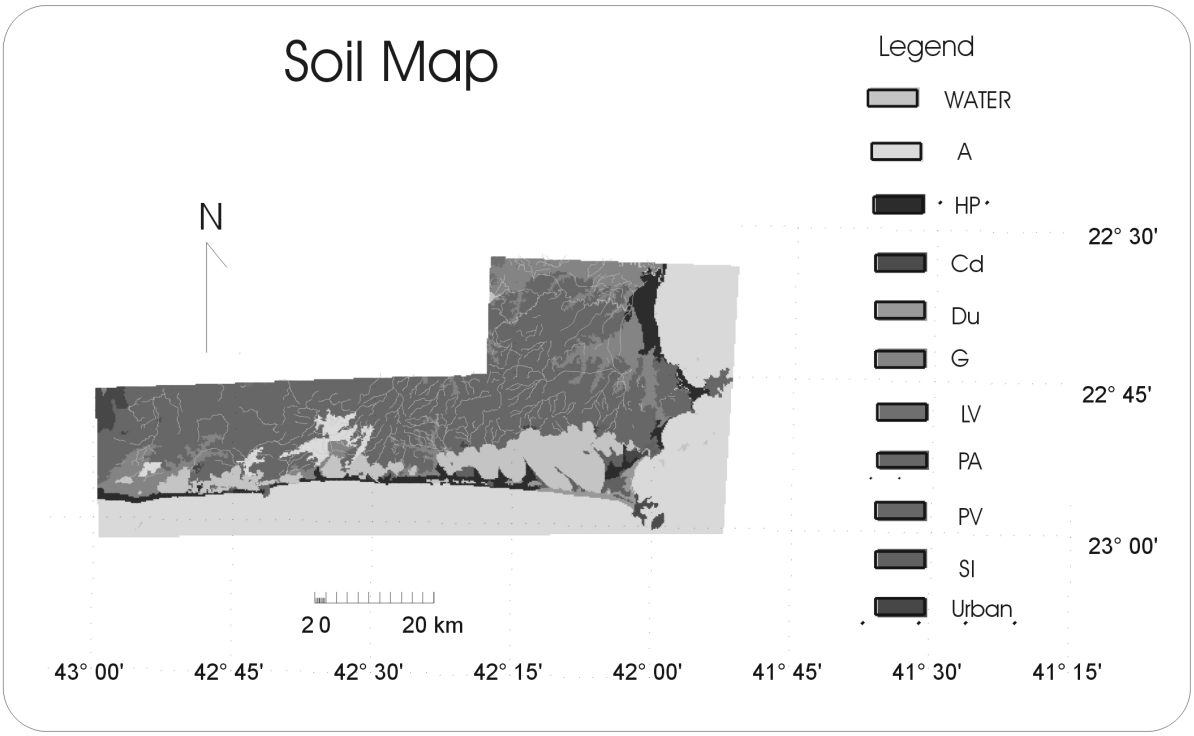

Figure 2: Soil map of the project area (A - alluvial deposits; HP - Hydromorphic; Cd - Cambisols; Du - dune deposits; G - Gley; LV - Red Latosol; PA - Podzol; PV - Red Podzol; PA - Yellow Podzol; SI - Indiscriminated soil; Urban - Urban areas).

Table 8. Ranges and Ratings for Hydraulic Conductivity

Hydraulic Conductivity (cm/s)	
Rating	Range
$< 10^{-6}$	1
10^{-6} - 10^{-3}	5
10^{-3} - 10^{-1}	8
$> 10^{-1}$	10

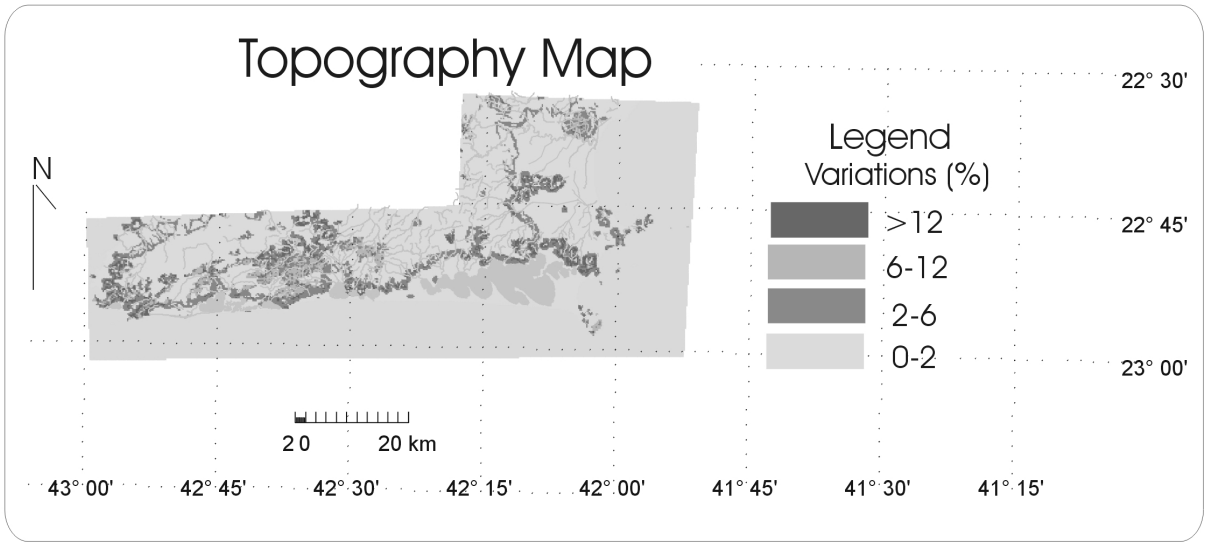

Figure 3: Topographic map of the project area, with declivity features.

Evaluation of contamination potential

Result of the DRASTIC application was determined by the following equation:

Contamination Potential = $D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_{w.}$, where, *r* is the rating and *w* is the weight for each factor and the capital letters are depicted in Table 1.

RESULTS

Units with values of potential pollution between 50 and 100 were considered as of low natural vulnerability to contamination. In the present case, only the organic clay deposits were inserted in this category.

The units with values between 100 and 139 were classified as of moderate vulnerability to the contamination. The crystalline rock outcrops belong to this category. Values of contamination potential between 140 and 179 were classified as of high vulnerability to contamination and are represented by the colluvial-alluvial deposits. Values of contamination potential between 180 and 226 were associated to a very high vulnerability and are represented by the sand bar deposits (Table 9 and figure 4).

Table 9. Ratings of contamination potential

Rating	Contamination Potential
Very high	180 - 226
High	140 - 179
Moderate	100 - 139
Low	23 - 99

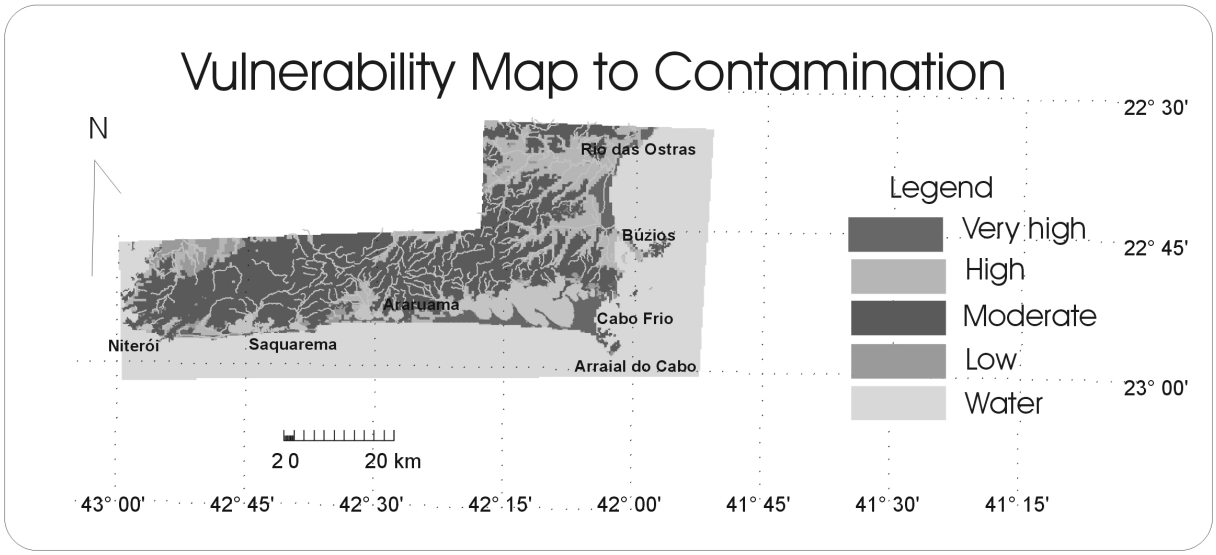

Figure 4: Vulnerability Map to contamination of the project area.

DISCUSSION

Considering the set of parameters in the vulnerability evaluation in coastal aquifers at eastern portion of Rio de Janeiro State, the highest values for contamination potential are attributed to the sand bar deposits and colluvial-alluvial deposits, due mainly to the high phreatic level, high hydraulic conductivity and smooth topography.

Characterization of areas with unfavorable environmental conditions (high vulnerability), assists the elaboration of projects, indicating location and precautions to be taken in the steps to implement an enterprise and later on, to manipulate, store and discard effluents in those areas.

Specific studies must be developed in order to assist land occupation planning to enhance aquifer protection, particularly in recharge areas.

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