Geoecological Mapping to Identify Groundwater Ecosystem Services Conflicts in a Brazilian Municipality

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Abstract

This study applies geoecological-based mapping techniques to identify the natural potential of the landscape to promote groundwater ecosystem services. In addition, this diagnosis analyzed its relationship with land use to identify groundwater geoethical conflicts in Brotas municipality, Brazil, which is completely included in the Guarani aquifer system, one of the largest world natural groundwater reservoirs. In the analysis, we used spatial data of geology, soils, land use, terrain forms, DEM and lineament density. The results of land use analysis indicate that the main economical drive force for the study area is the sugarcane production. On the other hand, the analysis shows that local geoenvironmental conditions of this region are favorable to the groundwater production. Finally, the geoethical conflicts chart, produced from the interaction between land use and the potential to provide groundwater ES's chart, showed that 59% of the study area has geoethics groundwater conflicts, i.e., places where anthropic activities endanger the quality and availability of groundwater ecosystem services. The results obtained can support decision making in Guarani aquifer areas for several countries as Brazil, Argentina, Uruguay and Paraguay.

Keywords

Geoethics • Ecosystem services • Groundwater management • Guarani aquifer system

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1 Introduction

In Brazil, since the 1970s, land use changes, mainly promoted by the expansion of agriculture and urbanization (Lollo et al. 2019), have been the main driving force that induces the degradation of ecosystem services balance, considering the benefits that natural areas and resources provide to humans (MEA 2005; Lollo et al. 2019).

Among the main services provided by ecosystems in Brazil, there is the provision of drinking water by the Guarani aquifer system (GAS), one of the largest groundwater reservoirs on the planet (Hirata et al. 2007).

Despite the large availability of water provided by the GAS, the ES's delivered by this natural resource are increasing the vulnerability due to intensive use of the physical environment without any planning and the slackening of environmental laws in favor to increased profits from agricultural activities (Covre et al. 2017; Guerrero et al. 2019) and situation that reveal the existence of potential geoethical conflicts.

Geoethical conflicts can be defined as reflections about the negative results of the interaction of anthropic activities with the geosphere (Peppoloni and Capua 2015).

Cartography based on landscape geoecology like Rodriguez et al. (2007) is defined as a set of research methods, techniques and procedures that consist of obtaining knowledge about the natural environment and establishing operational diagnoses which emerges as a tool to provide support for geoecological planning of landscapes and ecosystem services to mitigate geoethical conflicts, including those related to groundwater exploration and vulnerability.

Thus, the objective of this work was to use geoecological techniques using GIS to identify the potential of the landscape to produce groundwater ecosystem services and identify geoethical conflicts that occur in Brotas, Brazil. The results obtained are expected to aid decision making in Guarani aquifer areas of Brazil.

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2 Materials and Methods

2.1 Study Area

The municipality of Brotas is located in the central region of São Paulo state, southeastern Brazil (Fig. 1), with an area of 1103 km^2 and an estimated population of 24,160 inhabitants. The municipality is located over the sedimentary basin of Paraná, and the local morphostructure refers to the western plateau of São Paulo. The geologic–geomorphological framework reflects the lithological units and aquifer units described at Fig. 1.

2.2 Methods

In order to map the landscape potential to promote ecosystem services of groundwater production, geoecological-based mapping techniques were used based on the adaptation of the methodology proposed by Andualem and Demeke (2019).

The production of the Groundwater Ecosystem Services Potential Chart (GESPC) first required the weights assignment representing the ability of each attribute of the parameters (e.g., geology, soils) to assist in groundwater production. In addition, values of relative importance were also attributed between the parameters themselves, indicating which ones have the greatest influence on the production of groundwater ES's. All the values assigned are shown in Fig. 2a.

Parameters' overlap was performed using the analytic hierarchy process (AHP), a mathematical theory that allows to organize and evaluate the relative importance between criteria and to measure the consistency of judgments (Saaty 1990; Moreira et al. 2001).

In order to understand how human appropriation of local territory occurs, we used land use data from the MAPBIOMAS project (https://mapbiomas.org/).

Finally, we produced a geoethical conflict chart following the lines proposed by Brown and Reymond (2014), which illustrates the results from the paired comparison between the landscape potential of providing groundwater supply

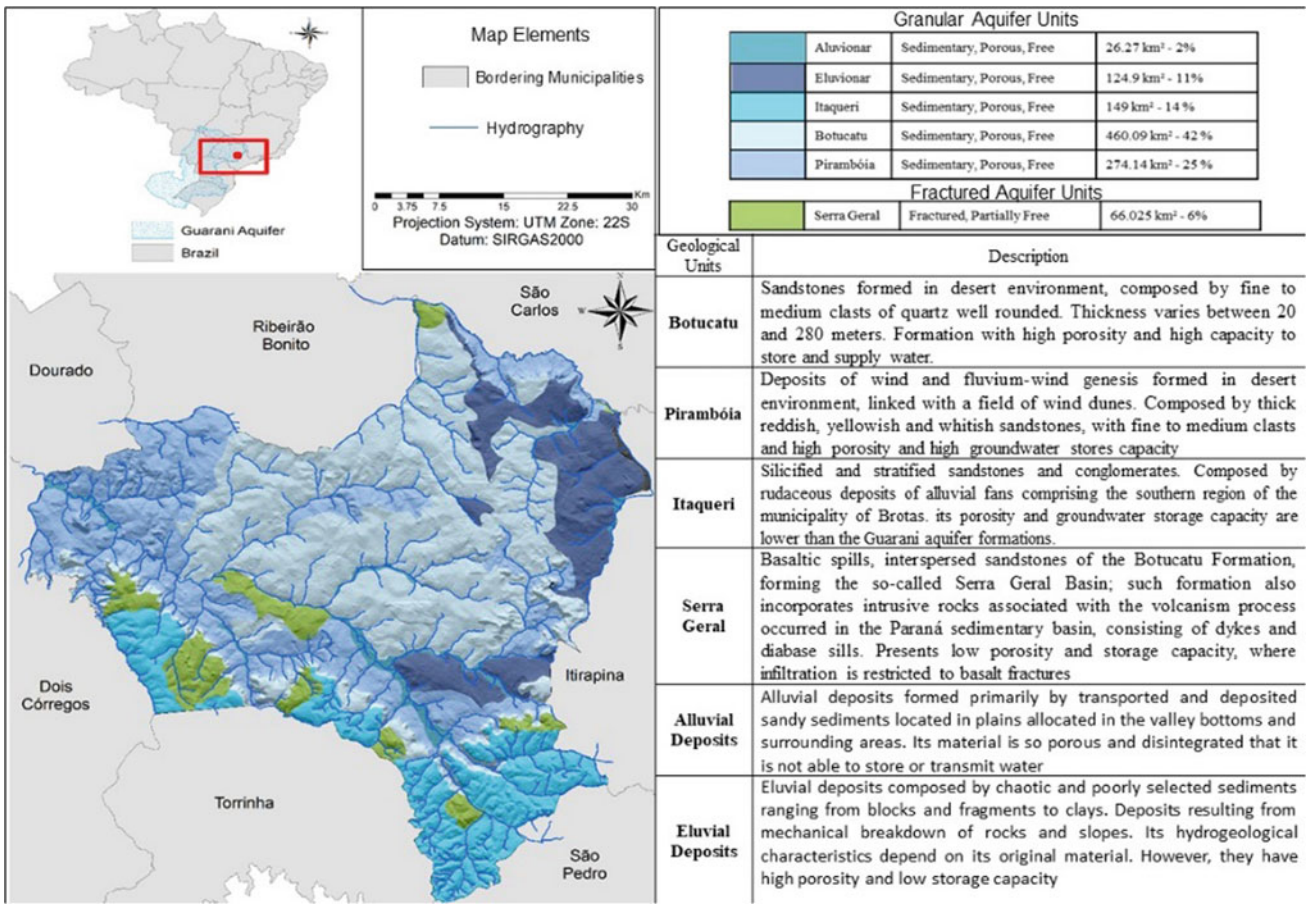

Fig. 1 Study area corresponding to Brotas municipality, Brazil

a

Atributes	*Groundwater ES's Potential*		
	Low	**Medium**	**High**
Rock Units	Elluvial and Alluvial Deposits	Serra Geral, Itaqueri	Botucatu , Piramboia
Soil Types	Lithic Entisols; Quartzipsamments Entisols; Histosols	Red Oxisoils Sandy Oxisoils; Inceptisols (Glei)	Ultisols Red-Yellow Oxisoils Médium Oxisoils
Slope	>20 %	5 – 20 %	0 – 5 %
Drainage Density	0.63 – 0.75	0.57 – 0.63	0 – 0.57
Terrain Forms	Convergent-Concave; Rectilinear-Convergent; Convergent-Convex	Rectilinear planar; Convex-Planar; Concave-Planar	Divergent-Concave; Divergent-rectilinear; Divergent-Convex
Linement Density (km²)	0 – 0.1	0.1 – 0.2	0.2 – 0.25

b

Land Use Type	Value
Forests	1
Savanna	2
Water	3
Grassland	4
Pasture	5
Forestry	6
Non Vegetaded	7
Urban	8
Agriculture	9

+

ES Potential	Value
Low	10
Medium	100
High	1000

=

Result Value	Conflict	Result Value	Conflict	Result Value	Conflict
11	*	101	*	1001	*
12	*	102	*	1002	*
13	*	103	*	1003	*
14	*	104	**	1004	**
15	*	105	**	1005	***
16	*	106	**	1006	****
17	*	107	***	1007	****
18	*	108	***	1008	****
19	*	109	***	1009	****

Where :

*	No Conflict	***	High Conflict
***	Low Conflict	****	Highest Conflict

Fig. 2 Groundwater potential table (**a**) and geoethical conflict workflow (**b**)

ES's and the current pattern of land use. For this, we assign dummy values to the attributes of each map and analyze the result of the sum between them from the perspective of what kind of conflict it represents (Fig. 2b).

The geoethical conflict chart produced analyzes spatially the resultant relationships between the interaction of anthropic activities (land use) with the geosphere (groundwater ES's potential), considering negative results as potential conflicts.

3 Results and Discussion

From the analysis of the study area physical environment dynamics, we conclude that 50% of the territory as high potential to provide significant groundwater ecosystem services (Fig. 3b), meaning that in these areas, the combination of landscape elements results in maximum groundwater potential. This result is compatible with those published by Guerrero et al. (2019) and Hirata et al. (2007), which can be explained by the predominant presence of the Botucatu and Pirambóia formations (units that makes up the Guarani aquifer system), terrain slopes and shapes that facilitate infiltration rather than runoff (Costa et al. 2019; Wendland et al. 2015).

The areas mapped as medium potential indicate that landscape can produce groundwater; however, the elements analyzed show that the capacity is lower than those previously presented. These sites represent 44% of the total and occur mainly for two conditions: (1) presence of the geological formations Itaqueri and Serra Geral (forming the Serra Geral aquifer), which, due to their porosity regulated by discontinuities as the main hydrodynamic feature, the recharge is slower than in the Botucatu and Pirambóia sandstones (Giampá and Souza 1982); (2) where despite favorable slopes and terrain, extremely sandy rock units such as alluvial and eluvial deposits occur, which have very low water retention capacity (IAC 2015).

Finally, we have areas where there is little or no groundwater storage capacity which is classified as low potential, making up 6% of the territory and occurring by the combination of low water retention capacity of soils and rock units, high slopes and terrain forms that increase runoff.

From the land use chart (Fig. 3a), we identified main driving force of the municipality which is farming activity, considering that 78% of the territory is occupied by agriculture (mainly sugar cane), pasture and forestry (Eucalyptus). Natural formations such as forests, savannah and grasslands cover only 22% of the area, indicating the high degree of anthropization of the municipality toward unsustainable activities.

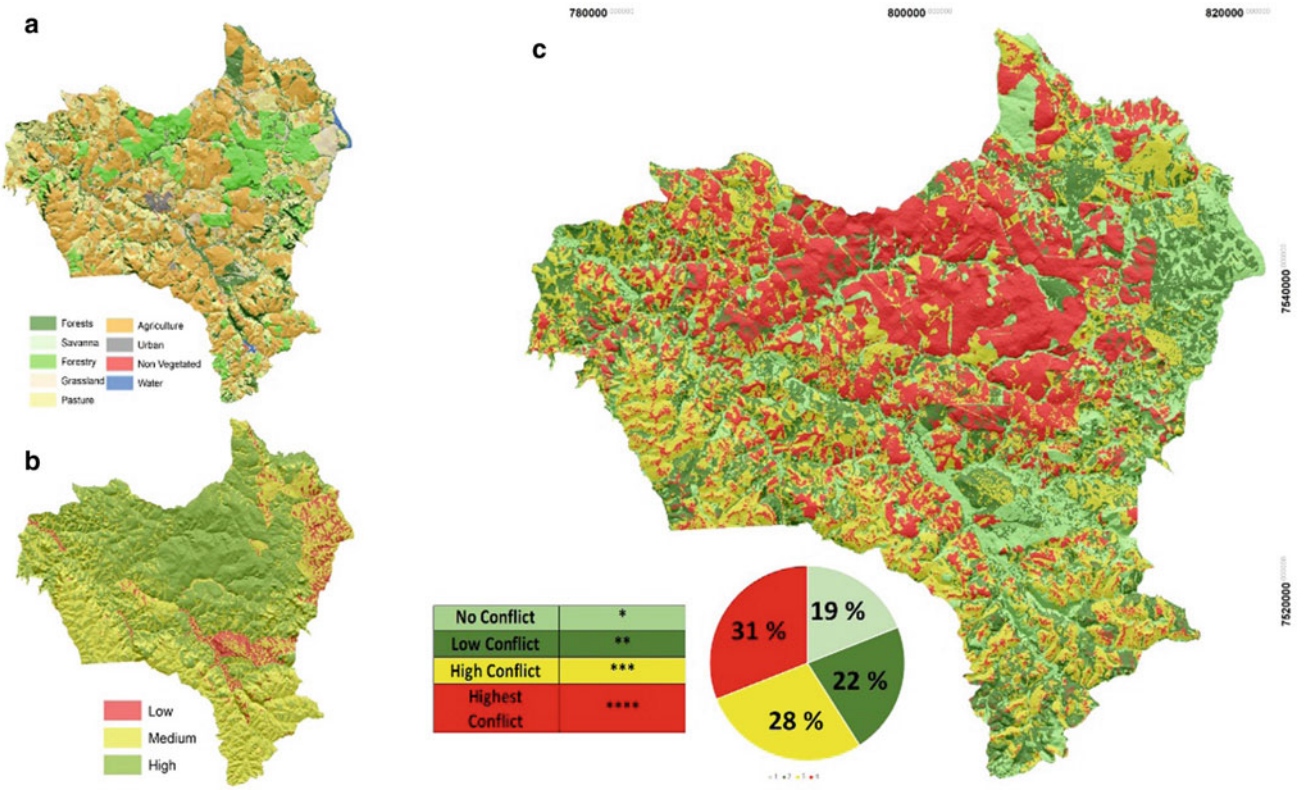

Fig. 3 Results: charts of land use (**a**) and potential to provide groundwater ES's (**b**) and geoethical conflicts (**c**)

Our analysis shows that 59% of the territory consists of areas with high and higher geoethical conflict. These geoethical conflicts essentially occur in areas where the potential for landscape to promote ecosystem groundwater services is maximum and land use is comprised of sugarcane, urban, exposed soil and forestry.

Sugarcane (which covers 42% of the Brotas municipality) is one of the largest commodities produced in the state of São Paulo (Carvalho et al. 2013), not only responsible for sugar production, but also for the production of ethanol, one of Brazil's main fuels (Kohlhepp 2010).

Despite the strategic importance of sugarcane to the local economy, its production becomes the main geoethical conflict in the area from the unrestricted use of pesticides (Acayaba 2017; Fialho et al. 2018), overexploitation of groundwater for irrigation and the flexibility of environmental legislation in favor of higher productivity (Covre et al. 2017), which puts great pressure on surface and underground water resources (Acayaba 2017).

Areas with low (22%) or no conflict (19%) generally occur in locations where the potential for ecosystem service provision is medium or low and/or where land use is composed of natural formations, like forests, savanna and grasslands.

4 Concluding Remarks

The municipality of Brotas has natural conditions that favor the availability of ecosystem services related to groundwater supply, especially related to the presence of rock units of the Botucatu and Pirambóia formations, part of the GAS. However, we identified agricultural activity as the major driving force that governs the local economic dynamics, especially large areas of sugarcane production.

Our study identified that sugarcane cultivation without adequate territorial planning, combined with the lack of a conservationist policy in the municipality of Brotas, generated geoethical conflicts related to groundwater, jeopardizing the availability of this essential resource, including for agriculture itself.

Spatial identification of geoethical conflicts is an important process in the management of groundwater ecosystem services, making it possible to direct territorial planning actions to areas where conflicts endanger the quality of this essential resource for human well-being.

The results obtained here are expected to assist decision making in municipalities with conflicts between land use, groundwater dynamics and ES's provided by groundwater, especially for the multinational Guarani aquifer system.

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