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ESTIMATES OF NATURAL VULNERABILITY SET FOR AQUIFER CONTAMINATION AT MUNICIPAL SCALE: A CASE STUDY IN PANAMBI (RIO GRANDE DO SUL STATE/BRAZIL)

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Abstract

Vulnerability assessment applied to aquifers is an important tool to assess contamination in this environment. Inappropriate soil tillage techniques and population growth cause severe environmental complications and account for the need of adopting correct management for surface water and groundwater resources. The aim of the current research is to assess natural vulnerability to contamination in the Serra Geral Aquifer System through the GOD methodology in Panambi County, Northwest Rio Grande do Sul State – Brazil. Results have shown that the aquifer presented vulnerability classes ranging from insignificant to low. However, there are activities with polluting potential in the area, such as intensive agriculture, in addition to the mechanical metal industries hub; these activities, which can change the quality of the underground environment in case environmental standards are neglected.

Keywords: Groundwater; Territorial management; SASG.

ESTIMATIVA DA VULNERABILIDADE NATURAL À CONTAMINAÇÃO DO AQUÍFERO EM ESCALA MUNICIPAL: ESTUDO DE CASO EM PANAMBI/RS

Resumo

A avaliação da vulnerabilidade de aquíferos é uma ferramenta importante para avaliar a contaminação das águas subterrâneas. O emprego de técnicas inadequadas do preparo do solo e o crescimento populacional ocasionam severas complicações ambientais, indagando a correta gestão de recursos hídricos, sejam superficiais ou subterrâneos. Essa pesquisa teve como objetivo avaliar localmente a vulnerabilidade natural à contaminação do Sistema Aquífero Serra Geral em Panambi, localizado no noroeste do estado do Rio Grande do Sul. Os resultados demonstraram que o aquífero, em sua maior parte, apresentou classes de vulnerabilidade que variaram de insignificante à baixa. Entretanto, na área são realizadas atividades com potencial poluidor, como agricultura intensiva, além do polo metal mecânico, que podem alterar a qualidade do meio subterrâneo, caso ocorra negligência de normativas ambientais.

Palavras-chave: Água subterrânea; Gestão territorial; SASG.

ESTIMACIÓN DE VULNERABILIDAD NATURAL A LA CONTAMINACIÓN DEL ACUÍFERO A ESCALA MUNICIPAL: ESTUDIO DE CASO EN PANAMBI (RIO GRANDE DO SUL/BRAZIL)

Resumen

La evaluación de la vulnerabilidad de los acuíferos es una herramienta importante para evaluar la contaminación del agua subterránea. El uso de técnicas inadecuadas de preparación del suelo y el crecimiento poblacional provocan graves complicaciones ambientales, cuestionando la correcta gestión de los recursos hídricos, ya sean superficiales o subterráneos. Esta investigación tuvo como objetivo evaluar localmente la vulnerabilidad natural a la contaminación del Sistema Acuífero Serra Geral en Panambi, ubicado en el noroeste del estado de Rio Grande do Sul – Brazil. Los resultados mostraron que el acuífero, en su mayor parte, presenta clases de vulnerabilidad que varían de insignificante a baja. Sin embargo, en la zona se realizan actividades con potencial contaminante, como la agricultura intensiva, además del poste metálico mecánico, que pueden alterar la calidad del medio subterráneo, en caso de incumplimiento de la normativa ambiental.

Palabras-clave: Agua subterrânea; Gestión territorial; SASG.

1. INTRODUCTION

Contamination of surface water resources mainly caused by demographic growth and lack of adequate infrastructure (sewage collection and treatment systems, for example) is a serious issue affecting many Brazilian cities. Therefore, water supply from alternative sources is an attractive option to solve such a problem.

Groundwater is a water supply option for the population, mainly in regions hard to be accessed, where water supply is still not available. Groundwater use is currently very common in population centers in cities' rural zones; however, proper management of groundwater supply is required to avoid major environmental issues, mainly, those related to the availability of water resources. Freeze and Cherry (2017) reported that the quality of groundwater is deteriorating over time.

Geotechnologies provide broader knowledge of natural resources (water, soil and vegetation), which results in improved assessment on land use potential based on sustainable practices (FRANCISCO et al., 2018). Freeze and Cherry (2017) also stated that these technologies help planning regional development. Encina et al. (2018) have shown that data originated from geotechnologies can be indexed to georeferenced databases.

Estimating the natural vulnerability to aquifer contamination is a method to support water resource management practices. The GOD system (*Groundwater hydraulic confinement, Overlaying strata, Depth to groundwater table*), developed by Foster *et al*. (2002; 2006); the DRASTIC method (*Depth to the water, Net Recharge, Aquifer material, Soil Type, Topography, Impact of the unsaturated zone, Hydraulic Conductivity*), put forward by Aller et al. (1987) and the Susceptibility Index (Ribeiro, 2005) are some examples of such a method.

The GOD system reports good results under Brazilian and Caribbean conditions (Foster et al., 2002; 2006); moreover, it is widely used in volcanic and sedimentary rocks. Researches conducted by Reginato and Alhert (2013), Nanni et al. (2005), Cutrim and Campos (2010) have estimated the natural vulnerability index to contamination aquifer in Brazil.

Potentially polluting activities are performed on the surface of places presenting environmental features makes it easier for contaminants to percolate and put groundwater at risk of contamination. (Foster et al. 2002; 2006). The city of Panambi is located in the Rio Grande do Sul State plateau (Brazil), this region stands out as national and international site for steel and machine industries, given the several industries from this sector installed in this region.

Therefore, studies estimating the vulnerability of the aquifer are of paramount importance, since they list the areas mostly vulnerable to contamination due to activities with the potential to cause environmental impact. The aims of the current research were to estimate the natural vulnerability to contamination in Serra Geral Aquifer system (SASG), Panambi City, Rio Grande do Sul State - Brazil and to list the main activities presenting potential risk of contamination to this underground environment.

2. METHODOLOGY

2.1. Features of the assessed site

Panambi City is located in Northwest Rio Grande do Sul State (Figure 1). The city has 38,058 inhabitants divided into the rural area (3,496 inhabitants) and the urban area (34,562 inhabitants) (IBGE, 2010).

Panambi stands out in Rio Grande do Sul State industrial sector because of its relevant number of industries and high managerial and technological standards. The city is the third steel and machine industry hub in the state; it has hundreds of small, medium and large-sized industries in the metallurgical, metal-mechanics, electro-electronics, textile, wood, furniture, and food products sectors (GRACIOLI, 2012). There are 221 registered anthropic activities, of which 38 are manufacturing industries of specific products, 14 are gas stations and 2 are sanitary landfills (FEPAM, 2019a).

According to information from SEMA (2004), the studied site is in the Uruguay Hydrographic Region (U), in the Ijuí River Basin (U - 90). FEPAM (2019b) reports that economic activities in this watershed are overall linked to the primary sector, mainly with soybean crops. However, there are secondary and tertiary sector activities in some cities, such as Panambi.

Regarding local geology, according to CPRM (2006), Serra Geral Formation (FSG) shows the prevalence of Gramado Facies and Paranapanema Facies in a small portion of it. FSG comes from basaltic flood, so its soils come from basaltic rocks and its products come from weathering.

According to Machado and Freitas (2005), the city is inserted in SASG I due to its hydrogeological features, it shows high to medium groundwater yield with fracture porosity.

Therefore, the assessed aquifer is of the fissure crystalline type, it is covered by FSG basaltic rocks, and is mainly reloaded through fractures in the rocks (Freitas et al., 2012).

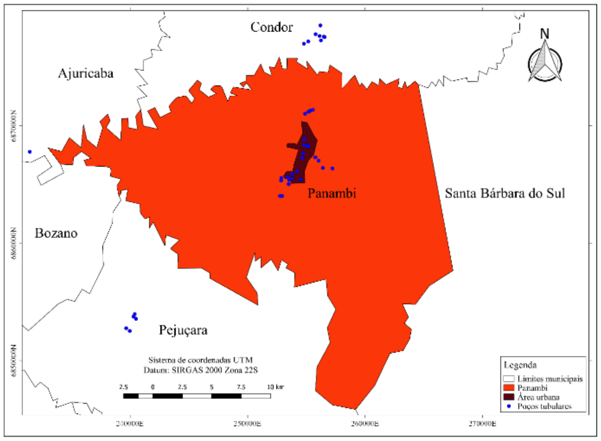

Figure 1 – Panambi City location. Source: IBGE (2005) and SIAGAS (2019).

2.2. Information collection to estimate the aquifer's natural vulnerability to contamination

The GOD system was used to estimate the natural vulnerability of the aquifer to contamination (Foster et al., 2002; 2006). The system uses variables G, O and D to find the vulnerability index, which classifies vulnerability as insignificant (values from 0 to 0.1), low (from 0.1 to 0.3), moderate (from 0.3 to 0.5), high (from 0.5 to 0.7) and extreme (from 0.7 to 1.0).

Figure 2 shows an example of GOD system used (Foster et al., 2002; 2006) in the assessed site.

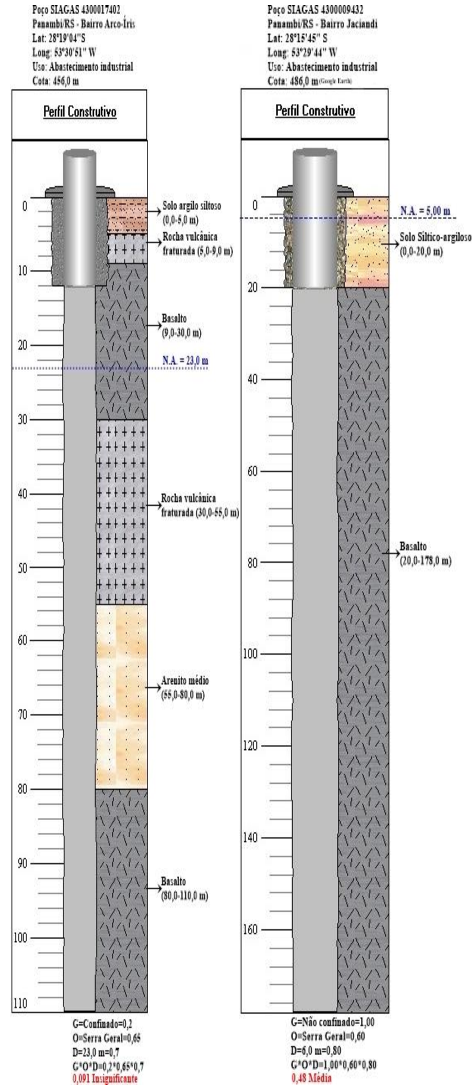

Figure 2 – Example of GOD system in use (Foster et al., 2002; 2006). Source: SIAGAS (2015).

Information of Groundwater Information System (SIAGAS), which is maintained by the Mineral Resources Research Company (CPRM) of the Brazilian Geologic System (available at http://siagasweb.cprm.gov.br/layout/pesquisa_complexa.php), was used to run the method. Information was collected from 68 underground sources in Condor, Cruz Alta, Panambi, and Pejuçara cities, as proposed by Costa et al. (2011). Information from the 21 wells registered in Panambi City was not enough to cover the total city area; therefore, further information was required in order to avoid data extrapolation, which could lead to result subjectivity.

Information was assessed inside SIG (Geographic Information System) by using data such as Universal Transverse Mercator (UTM) coordinates, static level of well drilling, geological profiles, well "mouth" dimension and other information of interest to estimate SASG vulnerability to contamination in Panambi City (Rio Grande do Sul State/Brazil).

South American Datum 1969 (SAD69) was used along with interpolator Inverse Distance Weighted (IDW).

2.3. Land use determination and identification of potential contamination sources

Potential contamination sources (graveyards, gas station and type 3 industries) were identified by using images of Panambi urban zone (Rio Grande do Sul State/Brazil) taken from Google Earth Pro (Google, 2014).

After potential contamination sources were identified, they were classified based on the POSH (Pollutant Origin and its Surcharge Hydraulically) method, by Foster et al. (2002; 2006), which classifies the degree of danger a given activity poses over the aquifer.

Images of land use determination classes were provided by the United States Geological Servey (USGS) (available at http://earthexplorer.usgs.gov/). Images come from Landsat 8 mission (USGS, 2016), February 2, 2016, without clouds. Based on this information, land use was classified into the following classes: water, urban zonea, agricultural zones and vegetation.

3. RESULTS AND DISCUSSION

Figure 3 shows the land use classes recorded for Panambi City; Table 1 shows their respective percentages. Vegetation was the greatest land use class (163.25 km²; 33.01% of the city area), which was followed by agricultural zones (162.37 km²; 32.83%). The exposed soil class covers 155.40 km² (31.44%), which has more potential for soil erosion. Urban zone (10.91 km²; 2.22%) and water (2.42 km²; 0.50%) were the smallest classes.

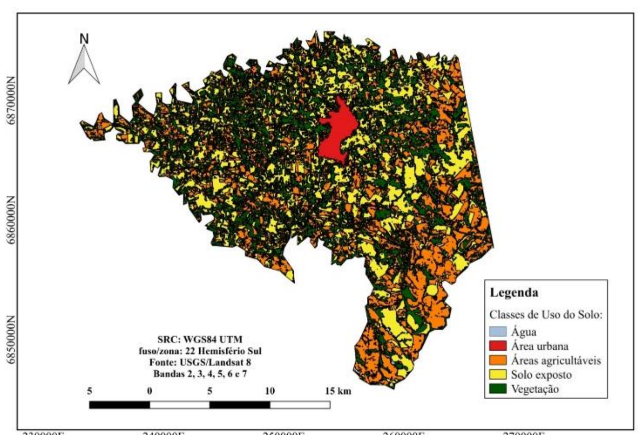

Figure 3 – Land use classes in Panambi City. Source: IBGE (2005) and USGS (2016).

Land use classes have different features regarding water infiltration in the soil and the consequent potential for aquifer reload (Löbler et al., 2014). According to Tucci and Clarke (1997), infiltration propensity depends on soil use and type. Forest soils often present good infiltration conditions, which make them important water supply sources for aquifers (LIMA, 2008). Soils without vegetation cover that suffer from compaction actions tend to reduce drastically their infiltration capacity, which results in greater runoff (TUCCI and CLARKE, 1997). Tucci and Clarke (1997) have reported that infiltration capacity varies depending on soil type and humidity condition, for example, clayey soils can have high infiltration capacity when they are dry; however, after getting moisture they can become almost impermeable.

Vegetation and agriculture were the prevailing land use classes in the assessed site. Agricultural areas can have problems related to the contamination of superficial and/or underground environments due to chemical fertilizers and pesticides, which, in their turn, can affect surface water resources or even infiltrate in the soil and reach the water table.

Hirata and Varnier (1998) have showed that issues related to agricultural activity include soil salinization and aquifer contamination by pesticides and nitrates.

Table 1 – Land use classes rate in Panambi City. Source: Authors.

Land use class	Area (km²)	Area (%)
Vegetation	163.25	33.01
Agricultural Area	162.37	32.83
Exposed Soil	155.40	31.44
Urban Area	10.91	2.22
Water	2.42	0.50
Total	494.35	100,00

Figure 4 shows the estimate of natural vulnerability to contamination in Panambi City based on the GOD method (Foster et al., 2002; 2006). Vulnerability classes ranged from insignificant (predominant class in the city area) to low. According to CPRM (2006), the prevalence of smaller vulnerability classes can be related to existing geologic formations, namely: volcanic rocks from the Serra Geral Formation and their weathering products. However, it is important noticing the fracturing of basaltic rocks, which can favor contaminant infiltration and allow it to reach the confined aquifer, since basalt rock fractures are the reload zones in this aquifer type (Freitas et al., 2012).

Several studies have assessed geology and hydrology types similar to those of those in the current research (Silvério da Silva et al., 2013; Reginatto and Alhert, 2013; Lobler and Silvério da Silva, 2015; Borba et al., 2016; Terra et al., 2016; Fernandes et al., 2016; Borges et al., 2017; Favaretto et al., 2020) and also found satisfactory results (Table 2). Lower vulnerability classes have prevailed in the research performed at SASG; therefore, results were similar to those recorded in the current study.

Table 2 – Vulnerability classes according to the GOD method applied to other SASG regions presenting the same hydrology and geology. Source: Authors.

Authors	Vulnerability class	Prevalent class
Silvério da Silva et al. (2013)	Insignificant to medium	Moderate (85.50%)
Reginato and Alhert (2013)	Low to medium	Low (79.00%)

Lobler and Silvério da Silva (2015)	Insignificant to extreme	Moderate (30.76%)
Borba et al. (2016)	Insignificant to high	Insignificant (73.15%)
Borges et al. (2017)	Low to extreme	Low (66.21%)
Favaretto et al. (2020)	Insignificant to low	Low (86.46%)

Figure 4 also shows the main sites with contaminating potential (graveyards, gas stations and type 3 industries) in the city area that can contaminate the aquifer based on the POSH method (Foster et al., 2002; 2006). These sources were classified based on their underground contamination potential: low (graveyards), moderate (gas stations) and high (type 3 industries: metal processing).

Graveyards that have low underground contamination potential and type 3 industries with high underground contamination potential (Foster et al. 2002; 2006) are in areas of low vulnerability located to the Northern part of the map (Figure 4). The remaining activities are set in areas classified as of insignificant vulnerability. Although graveyards have low underground contamination potential (Foster et al., 2002; 2006), they are located in a low vulnerability area, thus they risk contaminating the aquifer. Type 3 industries have high underground contamination potential and are located in regions presenting low natural vulnerability to aquifer contamination.

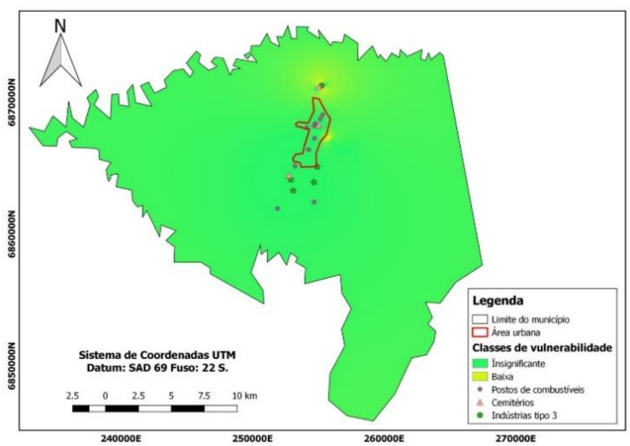

Figure 4 – Main sources with the potential to generate contaminant load. Source: Elaborated from IBGE (2005) and SIAGAS (2016), based on the GOD system.

4. FINAL CONSIDERATIONS

Panambi City (Rio Grande do Sul State - Brazil) in located in the volcanic rocks of Serra Geral Formation, which reported the following contamination vulnerability classes: insignificant and low. Such an outcome can be related to the presence of this rock type, which often results in features specific to this environment. In addition, activities presenting high underground contamination risk are located in low vulnerability areas.

Therefore, the current research shows the relative importance of the environment since it indicates the areas mostly vulnerable to contamination that can work as basis for the elaboration of municipal masterplans.

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