Vulnerability of groundwater in the semiarid region of Bahia, municipality of Tucano, by GOD method

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Abstract

Human activities can promote contamination of aquifers, compromising the quality of groundwater. Therefore, it is important to map the risks of vulnerability of natural environments, and one of the most used methods is the GOD (Groundwater occurrence; Overall aquifer class; Depth to groundwater). The present study has the objective of analyzing the vulnerability of aquifers to contamination in the municipality of Tucano, using GOD method. For the study, geological and hydrogeological data from 449 tubular wells obtained from the SIAGAS database (CPRM) were analyzed. G parameter was defined for the majority of the area as an unconfined aquifer, O parameter received values between 0.4 and 0.8 (due to variation of the lithological composition along the area) and D parameter, corresponding to the depth of the static level, was between 0.6 and 0.9, indicating a superficial water table. The GOD method indicated the occurrence of four classes of vulnerability: insignificant (1.28 %), low (71.99 %), average (23.79 %) and high (2.94 %). It was verified a low to medium vulnerability in most of Tucano territory, indicating low risk of contamination for the aquifer; an index pointing out high vulnerability was found only in the portion of Itapicuru River.

Keywords: Aquifer. Contamination. Geoprocessing.

Introduction

Near 97% of fresh water available for human use can be found in the underground layers (MEIRA et al., 2014); however, natural quality of these water reserves may be at risk due to their excessive exploitation, uneven soil occupation and non-compliance to legislation (RIBEIRO et al., 2011). That may be due to eventual releases of pollutants on soil surface, they can reach aquifers if met with favorable infiltration and percolation environment (BATISTA et al., 2016).

Groundwater is usually of good quality; therefore, 39% of Brazilian municipalities collect them through tubular wells. In the state of Bahia, 78 cities are supplied solely by this water source, and 32 use groundwater as a complement to their supply (ANA, 2010).

In the municipality of Tucano, northeast Bahia, the tubular wells are registered in the Underground Water Information System (SIAGAS, 2016), at the Geological Service of Brazil (Mineral Resources Company - CPRM). These wells are intended for domestic industrial and commercial use, providing water for animals, among other uses (VIEIRA et al., 2005). In addition, groundwater is of great touristic importance for the semi-arid region because of thermal waters that attract visitors,

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generating income and development for the locality. Therefore, it is important to supervise the qualitative and quantitative standard of these waters, since wells that are not monitored can become contamination routes for groundwater, affecting water quality in the aquifer (FERON; REGINATO, 2014).

According to Feron and Reginato (2014), there are distinct factors that must be not only integrated but analyzed in order to assess the vulnerability of aquifers. These factors may be natural (soil cover, existence of confined layers, structure and composition of rocks, among others) or through human intervention, according to Marquezan (2008). Thus, agricultural, industrial, urban and mining activities pollute by emission and leachate, excessing the soil natural attenuation capacity on cover layers (FOSTER et al., 2002).

The ideal is to maintain groundwater quality by analyzing the vulnerability and risk of contamination in order to identify regions that present different risks of impurities (REGINATO; AHLERT, 2013). One of the most used methods in those analyzes is the GOD method, an acronym of each phase: Groundwater occurrence, Overall aquifer class and Depth to groundwater. The methodology proposed by this method, besides being very useful, serves to guide soil occupation, avoiding areas that may have greater potential for aquifers contamination, assisting, thus, in the management of water resources (SANTOS et al., 2013).

The GOD method for assessing the vulnerability of the aquifer to contamination is of simple application and it was widely tested in the Caribbean and Latin America in the 1990s (FOSTER et al., 2002), nowadays, it is widely used in Brazil (SOUZA et al. , 2004, MONTEIRO; PEIXOTO, 2013, TERRA et al., 2013, DUARTE et al., 2016, SABADINI et al., 2017).

Therefore, when considering the potential risk of contamination of aquifers and anthropogenic exploration activity, the present study was carried out with the goal of analyzing the vulnerability of groundwater to contamination, using the GOD method, in the municipality of Tucano, state of Bahia.

Material and methods

Area of study and data collection

The study was carried out in the municipality of Tucano, Bahia, with a total area of 2,817.74 km^2, located between the UTM (X/Y) coordinates: 552151,32 / 8740373,09 and 482422,268 / 8817963,622, in northeast Bahia, in the central portion of Itapicuru River Basin, located in the semi-arid climatic region, with annual rainfall lower than 700 mm, vegetation cover with pastures interspersed with areas of Caatinga vegetation (INEMA, 2017) and this type of soils: Latosols, Planosol and Vertisol, these are the predominant soils in the municipality (EMBRAPA SOLOS, 2016).

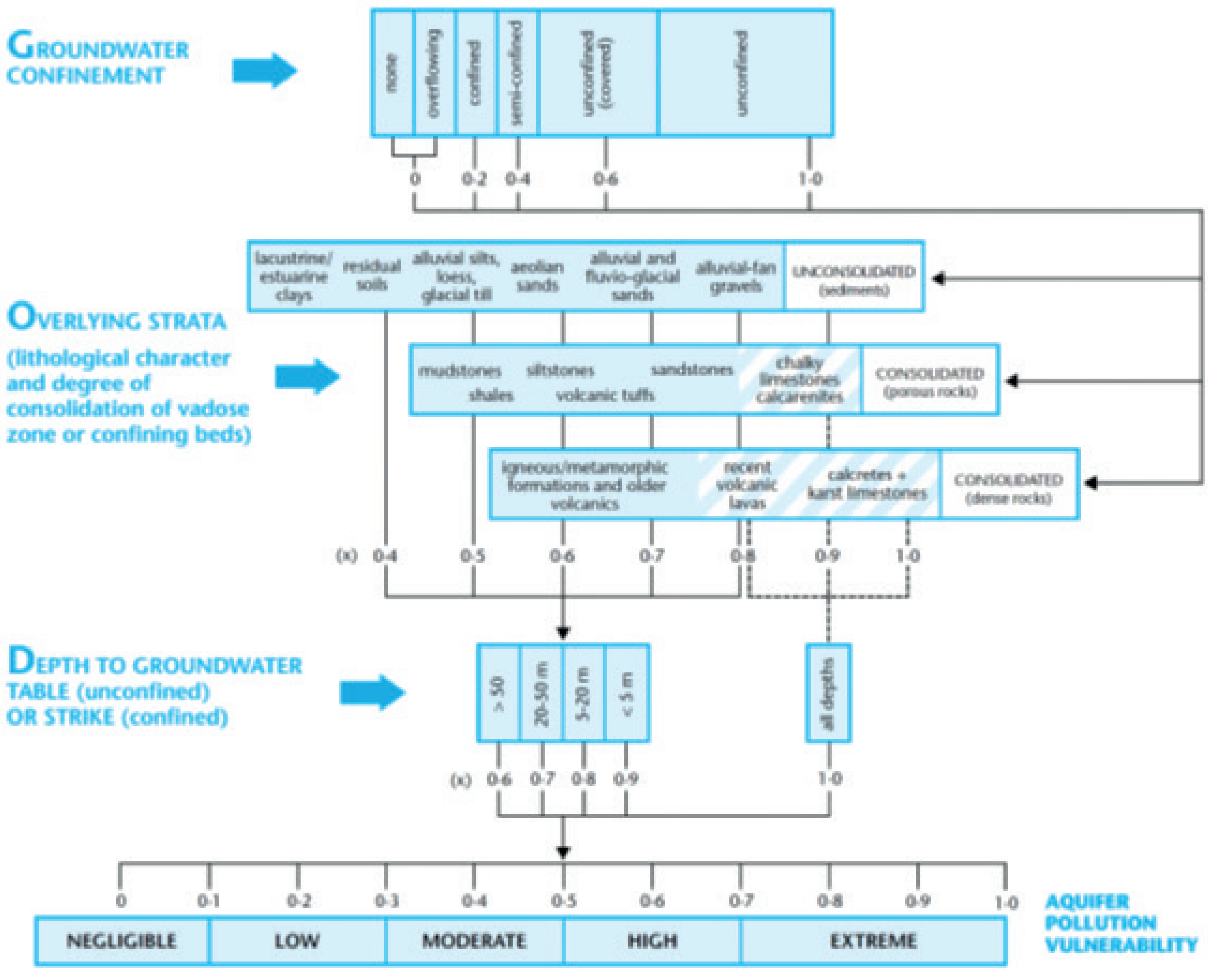
The depth (static water table level) and lithological composition of each well, of a total of 449, as well as lithology of the study area were acquired from Geological Survey of Brazil website (CPRM, 2017), through Groundwater Information System (SIAGAS) and from Data, which in turn provides data on the wells in Brazil, which were used for the present study of a time series of 01/01/1938 to 10/08/2013.

GOD Method

The GOD method is divided into three phases (groundwater confinement rate, characteristic of the stratum of the aquifer and depth of the water table), it considers different conditions and establish a greater or lower potential of vulnerability of the aquifer (FIGURE 1) based on the characteristics of each aquifer; for each characteristic, it was attributed a specific "weight" according to their composition, associated to the one verified in the municipality of Tucano.

The lithotype and lithology data were used to define the degree of confinement and the coverage strata, they were converted into a Raster matrix file and the values were assigned to each characteristic. In Phase 3, from the static groundwater vector data of each well, the Inverse Distance Weighting (IDW) method was performed, grouping the values according to the five depth classes of the method and exporting to a new Raster.

Figure 1. GOD method to classify aquifer contamination vulnerability.



Source: Foster et al. (2002).

All data were worked on ArcGIS 10.2.2, each Phase of the GOD method was performed independently in order to subsequently cross (multiply) the information of each pixel with its respective assigned value and generate the final map vulnerability of the aquifer.

Results and discussion

The geological strata from the analyzed wells, which involve the lithologic characteristics that influenced the formation of the soil and the degree of consolidation of the vadose zone, presented two defined units: Supracrustal Coverage and Crystalline Basement (TABLE 1), which have a correlation with their ligotype associated with the substrate characteristic and, consequently, the degree of vulnerability.

Table 1. Classification of existing geological formations in the municipality of Tucano (BA).

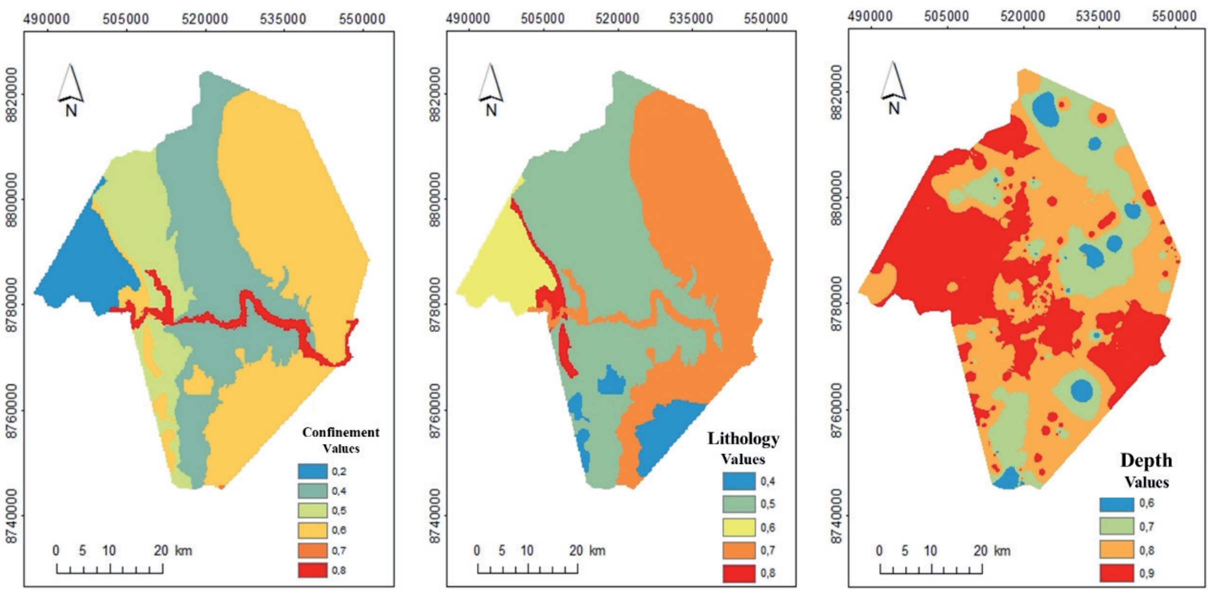
Geological Unit	Ligotypes	Characteristics
Supracrustal Coverage	Subarkoses sandstone, Coal, Shale, Siltstone	Sedimentary - Intergranular / Unconfined
Supracrustal Coverage	Sandy argilite, Conglomerate sandstone	Sedimentary - Intergranular / Unconfined
Supracrustal Coverage	Calcilutite, Sandstone, Conglomerate Sandstone, Conglomerate	Essentially Intergranular with influence Cárstica / -
Supracrustal Coverage	Conglomerate, Shale, Sandstone, Siltstone, Silexite	Sedimentary - Intergranular / Unconfined
Supracrustal Coverage	Sand deposits, Gravel deposits	Half porous behavior / Unconfined
Supracrustal Coverage	Clay deposits, Gravel deposits	Half porous behavior/ Unconfined
Crystalline Basement	Granodiorite and Granite	Fissural / –
Crystalline Basement	Metabasalt, Iron flock formation (BIFs)	Fissural / –
Supracrustal Coverage	Metasandstone, Metaconglomerate, Metachert	Fissural / –
Contact between Crystalline Basement and Supracrustal Coverage	Metadacite, Metatuff	Fissural / –
Contact between Crystalline Basement and Supracrustal Coverage	Migmatite, Kinzigite, Calcissilicatica rock, Quartzite	Fissural / –
Supracrustal Coverage	Siltstone, Carbonaceous shale, Calcilutite, Sandstone	Sedimentary - Intergranular / –
Supracrustal Coverage	Siltstone, Shale, Argilite, Sandstone Unconfined	Sedimentary - Intergranular /

Source: Prepared by the authors (2017).

Table 1 shows the supracrustal cover, which is associated to the sequence of the Marizal For-mation of the Tucano region, is the unit that best represents the recharge area for Tucano basin, due to the fact that it is covered by sedimentary package (MESTRINHO et al. , 2006) and because of the characteristics of the ligotipo, which has a higher permeability index, although it has a clayey characteristic with local silico-sandy spots, whereas the permeability index is lower for the Crystalline Basement sector even if it is fractured, conferred by the ligotipo composition.

The degree of groundwater confinement is directly related to the depositional cycle of the basin and to the lateral continuity of the sedimentary layers, indicating a free vertical and horizontal dynamic of the water flow at the most sandy recharge points; consequently, these points will have a higher permeability. Note that the groundwater in the studied area is mostly unconfined, assuming the highest values in the confinement stage (FIGURE 2), while the regions of geological compositions of fissured rocks obtained the lowest values.

Figure 2. Maps with values assigned by the GOD method for each phase: confinement, lithology and depth in the municipality of Tucano-BA.



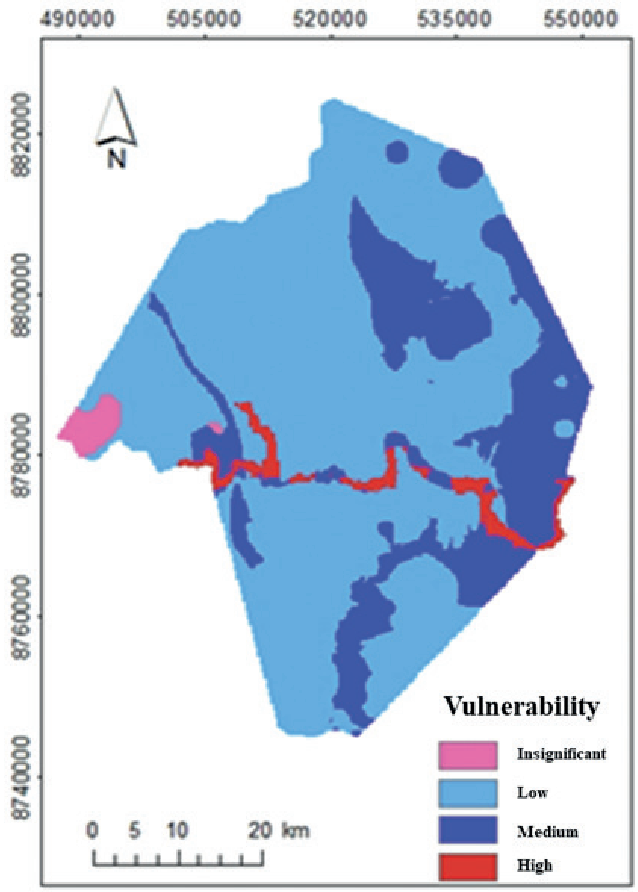
Source: Prepared by the authors (2017).

Lithology considers the values for the texture typologies, soil and rocks present in the vadose layer, this layer is located above the water table of each well; the lowest value (0.4) was characterized by the presence of clay deposit. In the wells with sandstone sediments, values of 0.6 to 0.8 were accepted, values of 0.5 (in the central portion of the studied area) were the most representative, influenced by the clay layer of the lithological material. 0.7 value was observed in all eastern regions, being also spatially significant in the area, indicating the influence of strata occurrence.

In terms of distance values from the surface to the static groundwater level, the most representative values were 0.8 and 0.9, which shows how superficial the aquifer is in the studied region, since the lowest value of 0.6 (depth greater than 50 m) was verified in some points throughout the entire municipality.

From the analyzes of the three phases of the GOD method, it was observed the groundwater of the study area expresses a low (71.99 %) and average (23.79 %) vulnerability (FIGURE 3), with small areas considered (1.28 %) regarding contamination risk, and only the section referring to the Itapicuru river showed itself as high (2.94 %), obtaining a value of 0.504; this section is in the limit for the class of medium to high and it is related to deposits of sand and gravel. This result of higher risk of contamination associated with the fluvial plains was also verified by Montero and Peixoto (2013), they observed extreme values of vulnerability along the Aguapeí and Tibiriça rivers, therefore, the authors recommend rigid restrictions for handling and transporting contaminating substances and for implanting polluting activities near those areas.

Figure 3. Map of the vulnerability of the aquifer by the GOD method, in the municipality of Tucano-BA



Source: Prepared by the authors (2017).

The low vulnerability index for the Tucano region was also observed by Mestrinho et al. (2006), when analyzing the GOD method in the whole extension of the Itapicuru River Basin, they found values under 0.5; according to them, that is due to the presence of the Tucano sedimentary basin. However, they do not detail the mapping of groundwater in the municipality as it was carried out in the present study.

Although Phase 3 indicates shallow groundwater, which increases the risk of contamination, the other Phases of the GOD method (confinement criteria and lithological occurrence) were condition factors to classify the area vulnerability. Meira et al. (2014) observed a similar situation, observing the predominance of the moderate vulnerability class in 2/3 of the area of the Guarani aquifer, where there is the influence of soil type (Argisol) with high depth of the water table. The same conclusion was reached by Reginato and Ahlert (2013), who studied the Serra Geral aquifer system. Both aquifers, with groundwater level close to the surface, presented an expressive average and low vulnerability. However, for the Guarani, high risk areas were associated exactly to the shallow sites, in association with the other components of the method, while in the present study, high vulnerabilities were related to the sandy layer.

Duarte et al. (2016), when studying groundwater of Humaitá and Amazonas, verified a medium and high vulnerability to the contamination, explained by the fact that it is an unconfined aquifer, with a shallow static level, and it had the influence of the lithological Phase, which had sandy sediments of the vadose layer as its constituents. On the other hand, Souza et al. (2015) did not verify a high risk to the contamination even though they had a free, superficial aquifer, with silts and clays as cover layers, which guarantees less permeability to the contaminants.

There is a significant low vulnerability of groundwater contamination in the municipality of Tucano and, according to Oliveira et al. (2007), groundwater alternates from good quality to acceptable quality, for the authors, there is an improper pattern of these waters in areas close to the municipality, and it should be noted the underground water flows from neighboring regions may harm the water quality of the aquifer, paying attention to the underground water flow that has its preferential hydrodynamics in the Itapicuru Basin NW-SE, subordinated locally to a NS flow, towards the river channel, NS alignment in the central part of the sedimentary domain (Tucano municipality) (PURIFICATION et al., 2016).

Therefore, even if there is no high risk of environmental vulnerability of groundwater in the municipality of Tucano, it is important to monitor the study region in order to reduce anthropic impacts that may favor the contact of pollutants to aquifer waters.

Conclusions

The GOD method allowed mapping the vulnerability of groundwater in the municipality of Tucano, indicating a low risk of contamination for the aquifer; there are points classified as medium to insignificant and only the Itapicuru River index pointing out a high vulnerability.

The assessment of potential groundwater contamination must be continuous and include other methods in order to observe different potentials of the methods and differences on them, aiming to ensure the aquifers good quality and the proper management of water resources.

Vulnerabilidade das águas subterrâneas na região semiárida da Bahia, município de Tucano, pelo método GOD

Resumo

As atividades humanas podem promover a contaminação dos aquíferos, comprometendo a qualidade das águas subterrâneas. Por isso, é importante mapear os riscos de vulnerabilidade dos ambientes naturais, um dos métodos mais utilizados para tanto é o GOD (sigla de *Groundwater occurrence; Overall aquifer class; Depth to groundwater*). Sendo assim, o presente trabalho tem o objetivo de analisar a vulnerabilidade à contaminação dos aquíferos do município de Tucano utilizando o método GOD. Para o estudo foram analisados dados geológicos e hidrogeológicos de 449 poços tubulares obtidos no banco de dados SIAGAS (CPRM). O parâmetro G foi definido na maioria da área como aquífero não confinado, o parâmetro O recebeu valores entre 0,4 e 0,8 (devido à variação da composição litológica ao longo da área) e o parâmetro D, correspondente à profundidade do nível estático ficou entre 0,6 e 0,9, indicando um lençol freático superficial. O método GOD indicou a ocorrência de quatro classes de vulnerabilidade: insignificante (1,28 %), baixa (71,99 %), média (23,79 %) e alta (2,94 %). Verificou-se que o município de Tucano, na maior parte do território, possui uma

vulnerabilidade baixa a média, indicando um baixo risco de contaminação do aquífero, tendo apenas na porção do Rio Itapicuru um índice apontando alta vulnerabilidade.
Palavras-chave: Aquífero. Contaminação. Geoprocessamento.

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