Preliminary analysis of Barreiras Aquifer protection rating from geoelectric data in the River Catu basin, NE Brazil.

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Abstract

This paper refers to hydrogeophysics studies developed in the River Catu basin, located on the east coast of Rio Grande do Norte. The Barreiras Aquifer, subject of this research, is responsible for water supplying around 80% of the cities within the east coast of Rio Grande do Norte, and the arable's irrigation perimeter, which occupies about 95% of the basin and with extensive cultivation of sugarcane. However this fountainhead, because of its predominantly free hydraulic behavior, seems to be quite susceptible to contamination, particularly by chemical fertilization excess. In this context, the present study aimed to develop a qualitative preliminary analysis of contamination risks for the Barreiras Aquifer in this area.

In this aspect, the geophysical methodology used was the electric resistivity, in the modality of Vertical Electrical Soundings (VES) performed with Schlumberger arrange of electrodes. The interpretation of VES enabled the elaboration of a longitudinal conductance mapping in order to emphasise the zone overlying the arquifer, which represents a higher or lower risk of contamination of this fountainhead against contaminant loads imposed on the surface.

This geoelectric mapping showed that the Barreiras Aquifer have higher risks of contamination both on the northeast and east study areas, considering relative values reduced of longitudinal conductance, which are equal or less than 0.01 Siemens. On the other hand, the southwestern area presents less risk of contamination, given by higher values of longitudinal conductance greater than 0.03 Siemens.

Introduction

The River Catu basin, including parts of counties Canguaretama, Goianinha, Tibau do Sul and Vila Flor, located on the east coast of the state (figure 1), has about 95% of its entire area occupied by the monoculture of sugarcane. This activity traditionally receives nutritional supplements on the form of chemical fertilizer. Nitrogen, which is the fundamental component of this fertilization, when not assimilated by plants tends to be oxidized both during and after the leaching process to form nitrate. The nitrate represents a diffuse contamination at concentrations above 10 mg / L for groundwater (Feitosa *et al*., 2008; Lucena *et al*., 2013).

The Barreiras Aquifer is the main water sources of the east coast of Rio Grande do Norte because is responsible for the water supply of cities and rural communities throughout the region, including the irrigation of grown perimeters. The lithostratigraphy of the area is composed by a non-outcropping and an outcropping sequence. The first sequence is represented by a crystalline basement and sedimentary rocks of Mesozoic basin featuring a basal sandstone formation and other carbonate formation on the top. The second sequence involves the regional Cenozoic sedimentation including the Barreiras Formation and its quaternary coverage (Bezerra, 1998; Lucena 2005). The Barreiras Formation and the namesake aquifer are quite diverse in lithological features involving from claystone to conglomeratic sandstone, with predominance of clayish sandstones from the Tertiary-Quaternary age. In the Quaternary cover, which predominates in the unsaturated zone overlying the aquifer, there are various generations of dunes, sandy hedges, mudslides and wetlands (Bezerra, 1998; Lucena *et al*.,2006).

According to Rodrigues *et al.,* (2011), the lower limit of the Barreiras Aquifer is the top of the non-outcropping Mesozoic carbonated sequence of the region, which was identified in well drillings as being composed by sandy argilite to argilitic of calciferous composition and low hydrogeological potential. The regional structure, which was characterized in previous works (Bezerra *et al.*, 2001; Lucena, 2005; Nogueira *et al.*, 2006), appears to be quite prevalent, regarding the thickness variations of the aquifer and the Barreiras Formation. Rodrigues *et al.,* (2011), defines saturated thickness in the River Catu basin ranging from 20 to 90 meters. Part o this variability was associated with local faulting.

According to the reports developed by IPT (1982), the Barreiras Aquifer has a hydraulic behavior ranging from free to semi-confined around the entire east coast of the state. This hydrodynamic characteristic makes the aquifer particularly vulnerable to contamination especially in areas of reduced unsaturated thickness. This fact happens because the unsaturated thickness superimposed represents the main line of defense against a possible leaching of a contaminant load imposed on the surface, considering a case of free aquifer (Foster 1987, Foster and Hirata, 1988; Lucena *et al*., 2010).

Braga (2006) affirms that the application of the geoelectrical Dar Zarrouk parameter, in this case the longitudinal conductance, may contribute significantly to studies of environmental management of some particular area with aquifer occurrence. This parameter allows us to have the estimation of the risk contamination for having a hydrogeological system affected by any contaminant load, considering values of resistivity and thickness of the layers overlying the aquifer concerned. In this context, the present work aimed to develop a preliminary analysis of the risk of contamination of the Barreiras Aquifer in the River Catu basin, using hydrogeophysical data available from wells and geoelectric surveys performed. Both of these informations have helped to define the top of the aquifer through the measure of the unsaturated thickness over the entire area of the basin, as well as the respective values of resistivity. These data allows us to elaborate a longitudinal conductance mapping, supporting the preliminary assessment of the aquifer contamination risk.

Method

In this paper, the geometric characterization of the context that surrounds the Barreiras Aquifer and especially the unsaturated adjacent zone used the geophysical methodology of electric resistivity with exploratory and qualitative form. The technique used was the Vertical Electrical Sounding (VES) with Schlumberger arrange of electrodes. This technique allows us to investigate the variations of resistivity values versus the depth, as for the area it's valid the model of plane and parallel layers (Orellana, 1972). The field data acquired were interpreted with the WinSEV (W-Geosoft) software, that ultimately provides models of "electric resistivity x thicknesses", making possible the identification of punctual values of unsaturated and saturated thicknesses.

The equipment used in the survey was a resistivimenter model GeoTest RD-300B (Geotest – Indústria e Comércio de Equipamentos Eletrônicos Ltda). This apparatus is able to minimize the instability of readings caused by electrode polarization phenomena, in addition to make an electronic filtering on the signal, reducing noises from telluric currents and transmission lines. 15 geoelectric soundings were performed and the data field (AB/2 x ρ_a, where AB is the distance between currents electrode and ρ_a is the apparent resistivity) were interpreted with WinSEV (WGeosoft) software, as described previously. The qualitative and quantitative analyses refined of the VES were based on geoeletric calibrations performed by Lucena (2005).

In a stratified environment, which is represented by a right prism with square crossed section and the perpendicular axis to the orientation of its layers, whose sides have unit lengths, the flow of electric current from the subsoil can take two preferred ways: A perpendicular and another parallel to the layering (Orellana, 1972; Kirsch, 2006; Braga, 2007). In this context, the parameter of longitudinal conductance (S_i) is associated with the flowing current parallel to stratification and given by the ratio between the thickness of the layer and its resistivity. For a set of n layers of a section, this conductance is defined by:

$$S_i = \sum_i \frac{E_i}{\rho_i} \quad \text{(Equation 1)}$$

Where E_i and ρ_i are respectively the resistivities and thicknesses of each layer belonging to the unsaturated zone, which was characterized and interpreted in the WinSEV software. Thus, the calculation of longitudinal conductance parameter was conducted in a punctual way for each VES executed, and subsequently subjected to gridding and interpolation along the studied area, obtaining a map of isolines related to the "S" parameter. In this aspect, if the value of the longitudinal conductance (S) is larger, the groundwater protection rating against contaminant loads imposed on any surface is greater too because of the unsaturated increased thickness (E) or a decrease in the electric resistivity value of the unsaturated zone (ρ), associated with sedimentary rocks with more clay composition (more waterproof rock). It is noted that the displacement of the contaminant load is regarded as being vertical.

Results

The regional hydrogeological system has three main geoelectrical horizons (Lucena, 2005; Rodrigues *et al.*, 2011) characterized by performed VES's. The first horizon is associated with the conductive geoeletrical basement of the Barreiras Aquifer (top of the non-outcropping carbonate sequence associated with the calciferous sandstone-argilitic) with resistivities lower than 70 ohm·m, and the second is related to the saturated zone (the Barreiras Aquifer itself) presenting resistivity between 40-900 ohm·m, where the lowest and highest resistivities are associated, respectively, to the clayish sediments and sandier. These latter are usually selected for the positioning of filters for groundwater extraction. The third and most superficial horizon, which is the target of this research, corresponds to the unsaturated zone, which has a resistivity greater than 1.500 Ohm·m. Some of the geophysical field curves (AB/2 x ρ_a) show the upward trend of this resistivity related to the unsaturated zone (asymptote of 45°), which is associated to the influence of carbonate rocks with purest composition and positioned further in the Mesozoic sedimentary sequence.

The models obtained from the field data inversion characterized ponctual values (thick and resistivity associated with the unsaturated zone) related to each VES. Considering equation 1, longitudinal conductance values (S) were calculated for the entire unsaturated zone, which occasionally involve more than one geoelectric layer. Table 1 shows the values of thickness and longitudinal conductance for each interpreted VES, which are given as locally represented.

The map of longitudinal conductance was elaborated from the interpolation and gridding of data for each VES arranged along the study area. Such mapping (Figure 2) revealed from the setting of a gradient to the characterization of longitudinal conductance anomalies located relatively, and these features are associated with higher or lower protection rating of the Barreiras Aquifer in the area from possible contaminants loads imposed on the surface, specially those from chemical fertilizers in the River Catu basin.

Considering a preliminary analysis of the contamination risk of the aquifer under study, the variation of values obtained in the map of longitudinal conductance (S) indicates an intermediate longitudinal conductance on the order of 0,025 Siemens. Therefore the sectors north and east of the map provides more susceptibility to contamination with longitudinal conductances around 0.01 Siemens, while the southwestern with S values greater than or equal to 0.03 Siemens seems more protected.

Table 1: Unsaturated thickness and longitudinal conductance values of VES performed in the River Catu basin; geoelectric data were interpreted considering the geoelectric calibrations by Lucena (2005).

VES	*X*	*y*	*Unsaturated thickness (m)*	*Longitudinal Condutance (S)*
VES 01	259948	9296646	20,55	0,02
VES 02	257278	9298415	65,72	0,054
VES 03	262757	9297930	27,89	0,034
VES 04	260539	9308256	12,33	0,012
VES 05	266251	9310920	19,46	0,023
VES 06	269823	9310928	19	0,02
VES 07	268370	9310058	5,04	0,002
VES 08	270330	9304236	26,09	0,018
VES 09	268304	9303375	7,29	0,006
VES 10	266500	9301640	11,18	0,008
VES 11	263523	9300966	24,65	0,016
VES 12	260812	9303524	7,18	0,016
VES 13	262745	9306840	21,1	0,021
VES 14	265875	9307718	32,57	0,04
VES 15	267062	9308822	2,91	0,002

The unsaturated thickness values predominate on the determination of those areas analyzed, since the resistivity values have no significant variations. That is, regions which have a thicker unsaturated sedimentary bed are the ones with less risk of contamination against any contaminant load imposed on surface.

Whereas the longitudinal conductance is given by the product of the resistivity features and thickness of a non-saturated bed in the present context, S values are associated with relatively low or high reduced thicknesses. These are associated with sedimentary rocks or unconsolidated sediments with mainly sandy composition. This type of lithology gives higher permeation rates, reflecting a greater vertical hydraulic permeability, what makes the aquifer more susceptible to qualitative degradation.

Moreover, there is more protected aquifer in the sub-areas which the longitudinal conductance is higher. This relative higher rating of protection is conferred to as a primarily unsaturated thick equally high, since there are not substantial lithological variations that could corroborate high variability in resistivity parameter. Thus, the longitudinal high conductance associated with the greater non-saturated zone thickness adjacent to the Barreiras Aquifer gives greater filtrate as regards percolating of any contaminant load. In addition, however, high values of S could also be relatively related to low resistivity of the unsaturated zone, which is a characteristic fact of predominantly argillaceous lithologies, this means lower vertical permeability. In this case, the hydraulic access to saturated zone for a particular contaminant load will be hindered. However, this context is not applicable to the study area, especially in the range of work herein presented.

When it comes to the influence of regional structure on the Barreiras Formation and consequently on the namesake aquifer, it can be assumed as a speculative mode that the configuration of sub-areas with greater or lesser rating protection can also be conditioned by the regional structure. This influence may come from the kinematics of local faults, which also affect the Quaternary cover, which are integral to the unsaturated zone adjacent to the Barreiras Aquifer. But this hypothesis requires more improvement and integration of geophysical data about hydrogeology and especially structural toward a detailing of structural-tectonic context in the study area and adjacent to River Catu basin.

Conclusions

The resistivity method, which is non-invasive, fast and has a low cost, proved to be quite effective in obtaining a preliminary mapping of risk contamination of the Barreiras Aquifer in the River Catu basin. This cartography, which was elaborated with the interpolation and gridding of longitudinal conductance data, revealed that the sectors north and east of the map are more susceptible to contamination with longitudinal conductance around 0.01 Siemens, while the southwest sector shown to be more secure with longitudinal conductance values higher or equal to 0.03 Siemens.

The data presented here, specially the longitudinal conductance map, should support studies involving from capture to monitoring and preservation of the Barreiras Aquifer in the region. Such information will even enable the development of an aquifer vulnerability mapping, which makes possible to improve the hydrogeological management of irrigation soil, particularly those growing sugar cane and extensive use of chemical fertilizers.

Acknowledgments

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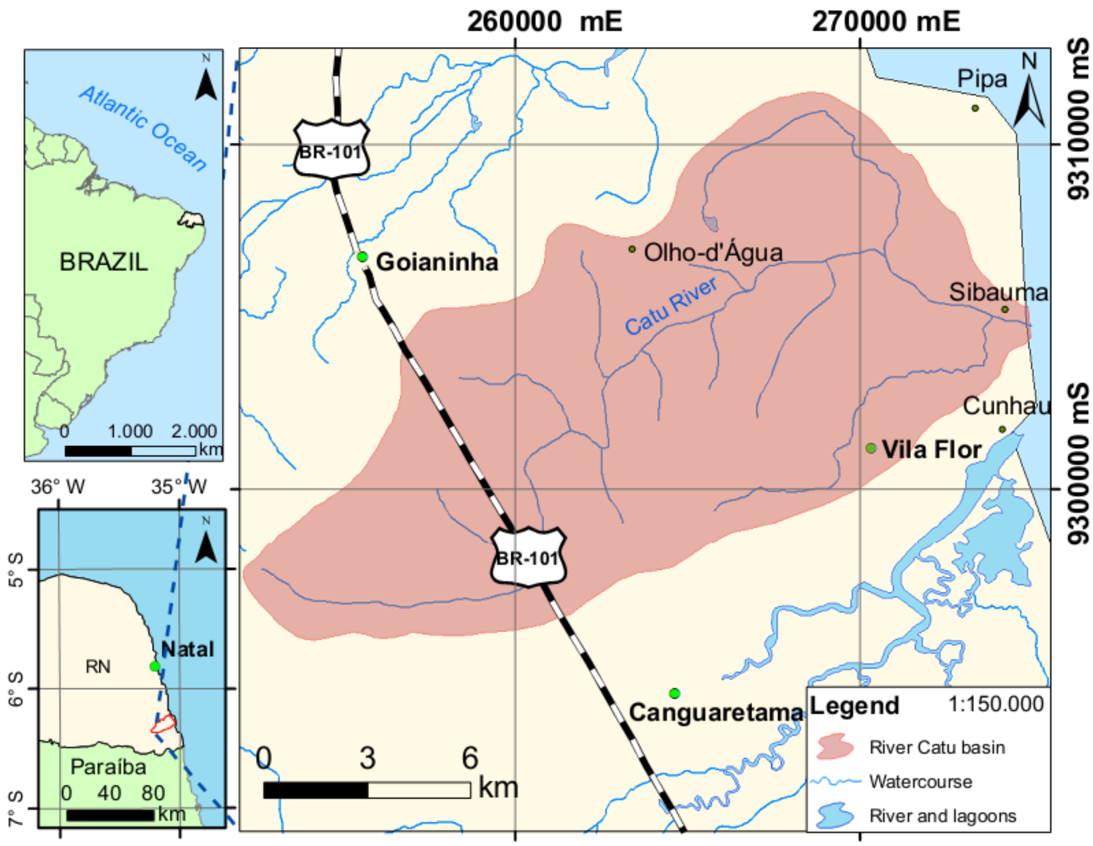

Figure 1: Localization of River Catu basin.

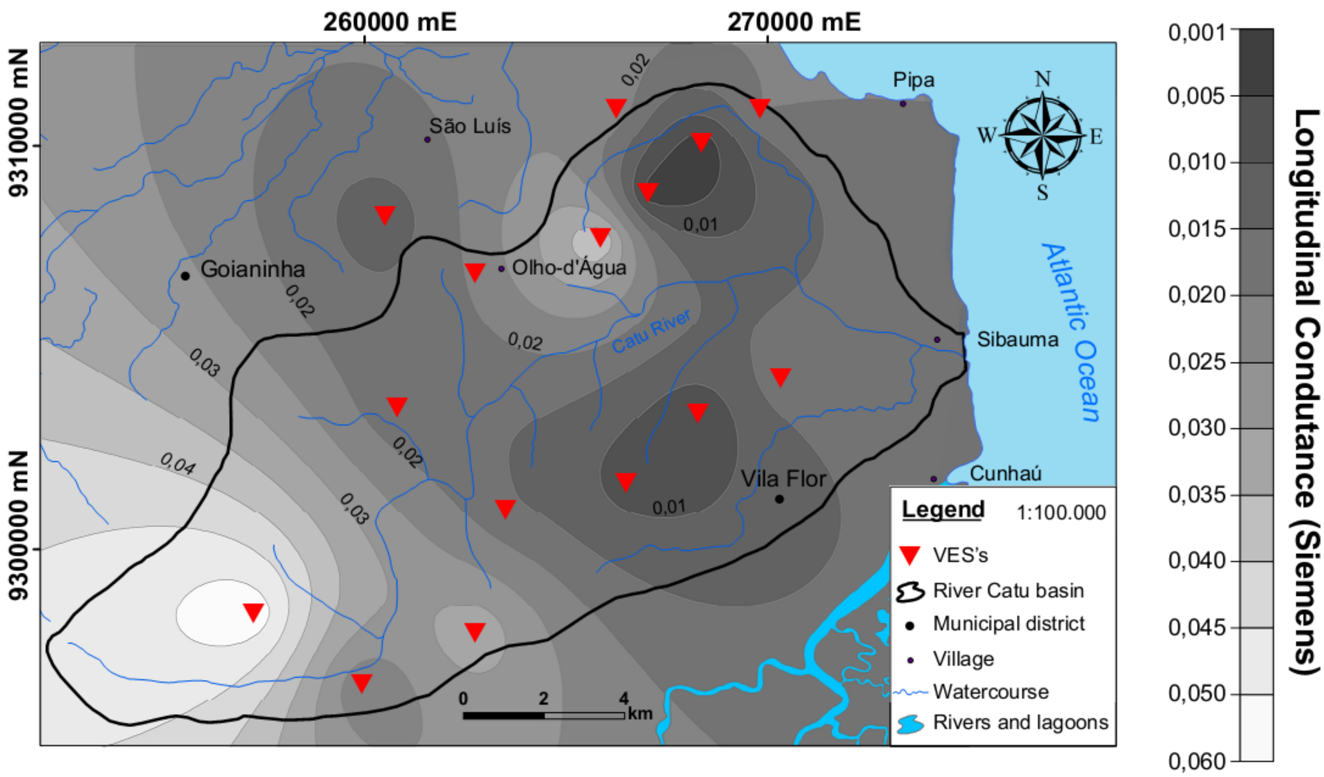

Figure 2: Longitudinal condutance map in the River Catu basin area.