Potentiometric map based on integrated piezometer data with geophysical results, Manaus-AM

Mapa potenciométrico a partir de dados de piezômetros integrados com resultados de geofísica em Manaus-AM

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ABSTRACT
The research carried out consisted of a field survey upstream of the Lago Amazônico area and close to the Ecological Effluent Treatment Station (ETEE) of the National Institute for Research in the Amazon - INPA. The objective of the study was to detect possible impacts on the quality of groundwater due to the ETEE and the waters of Lago do Bosque da Ciência, which requires knowledge of the direction of groundwater flow at the site. The geophysical resistivity method,

through the technique of vertical electrical sounding with the Schlumberger arrangement, was applied with the purpose of defining the depth of the top of the saturated zone in the study area as well as detecting possible impacts of the effluents of the treatment plant in subsurface. The resistivity method, through measurements by equipment placed on the surface, determines the electrical resistivity of the materials and their subsurface contrasts at different depths. In the area, three piezometers were installed, which enabled the calibration of the interpretation of the results of vertical electrical sounding. The survey of geophysical data provided a volume of information about the subsurface situation of the layout, lithological content and the depth of the water level of the subsurface layers through the seven vertical electrical surveys carried out around the INPA Lake and close to the ETEE. The results of the interpretation of the vertical electrical sounding and water level depth measurements in the piezometers were integrated to produce a potentiometric map to understand the hydrogeological behavior from the point of view of underground flow. The electrical resistivity values, relatively high in the study area, attribute a predominantly sandy lithological constitution, a result that is consolidated with the lithological description of the piezometers. The top of the saturated layer around the lake is deeper compared to the lake, causing its waters to seep into the aquifer. This is because the lake is artificial, constantly receiving water to maintain its level. The potentiometric map indicates a practically radial flow direction, with a slight inclination towards the north. The electrical surveys carried out near the treatment plant showed lower resistivity values, which may be related to the influence of effluents in the subsurface. The study was carried out with resources provided for in Law No. 8,387 and in accordance with Article 21 of Decree 10,521 / 2020 - INPA / SAMSUNG Partnership.

Keywords: geophysical methods, groundwater flow, urban groundwater

RESUMO

A pesquisa desenvolvida constituiu-se de levantamento de campo a montante da área do Lago Amazônico e próximo à Estação de Tratamento Ecológica de Efluentes (ETEE) do Instituto Nacional de Pesquisas da Amazônia - INPA. O objetivo do estudo foi detectar possíveis impactos na qualidade das águas subterrâneas devido à ETEE e nas águas do Lago do Bosque da Ciência, o que demanda conhecimento da direção do fluxo de águas subterrâneas no local. O método geofísico da eletrorresistividade, através da técnica de sondagem elétrica vertical com o arranjo Schlumberger, foi aplicado com o propósito de definir a profundidade do topo da zona saturada na área de estudo como também detectar possíveis impactos dos efluentes da estação de tratamento em subsuperfície. O método da eletrorresistividade, através de medições por equipamentos dispostos na superfície, determina a resistividade elétrica dos materiais e seus contrastes em subsuperfície a diferentes profundidades. Na área foram instalados três piezômetros os quais possibilitaram a calibração da interpretação dos resultados de sondagem elétrica vertical. O levantamento de dados geofísicos proporcionou um volume de informações sobre a situação em subsuperfície da disposição, conteúdo litológico e a profundidade do nível de água das camadas em subsuperfície através das sete sondagens elétricas verticais realizadas no entorno do Lago do INPA e próximas à ETEE. Os resultados da interpretação da sondagem elétrica vertical e medidas de profundidade de nível de água nos piezômetros foram integrados para produção de um mapa potenciométrico para assim compreender o comportamento hidrogeológico do ponto de vista de fluxo subterrâneo. Os valores de resistividade elétrica, relativamente altos na área de estudo, atribuem constituição litológica predominantemente arenosa, resultado esse que consolidado com a descrição litológica dos piezômetros. O topo da camada saturada no entorno do lago é mais profundo comparado com o lago, fazendo com que as águas do mesmo infiltrem para o aquífero. Isso ocorre porque o lago é artificial, recebendo constantemente água para manter seu nível. O mapa potenciométrico indica direção de fluxo praticamente radial, com leve inclinação para direção norte. As sondagens elétricas executadas próximas à estação de tratamento apresentaram valores de resistividade menores o que podem estar relacionados à influência de efluentes em subsuperfície. O estudo foi realizado com recursos previstos na Lei nº 8.387 e de acordo com o Art. 21º do decreto 10.521/2020 – Parceria INPA/SAMSUNG.

Palavras-chave: métodos geofísicos, fluxo de águas subterrâneas, águas subterrâneas urbanas

1 INTRODUCTION

Due to the expansion of urban and rural centers in the country, the study of groundwater quality, once neglected, has become fundamental from the point of view of its economic use. However, the great importance of the underground resource for the social and economic development of the population contrasts with the lack of knowledge of its potential and the stage of exploitation of aquifers in the country, which thus poses great challenges for adequate water management.

Pollution in the saturated layers originates, for example, from the location of dumps and industries in unfavorable geological environments, leakage from gas stations and refineries in the inadequate form of disposal of industrial waste and effluents or even by the intrusion of salt water into the aquifer of areas coastal areas due to poorly located or poorly exploited supply wells. In assessing groundwater pollution, two factors must be considered. The first is the geological and hydrogeological knowledge of the site and the other is related to the characteristics of the pollutants. The recognition of these factors makes it possible to determine the behavior of pollutants in the physical environment.

Among the methods used in the assessment of aquifer contamination are the geoelectrical methods. Among them, the electroresistivity method is widely used in groundwater prospecting and has sufficient sensitivity to even detect the presence of some types of contaminants. It is a geophysical method that studies the physical property called electrical resistivity to identify subsurface materials. It expresses the greater or lesser ease with which the electric current injected into the soil flows through the material and depends on the nature and physical state of the body considered.

The research carried out consisted of a field survey upstream of the Lake Amazônico in the Bosque da Ciência area and close to the Ecological Effluent Treatment Station (ETEE) of the National Institute for Research in the Amazon - INPA. The objective of the study was to detect possible impacts on the quality of groundwater due to the ETEE and the waters of Lake of Bosque da Ciência, which requires knowledge of the direction of groundwater flow at the site.

The geophysical resistivity method, through the technique of vertical electrical sounding with the Schlumberger arrangement, was applied with the purpose of defining the depth of the top of the saturated zone in the study area as well as detecting possible impacts of the effluents of the treatment plant in subsurface.

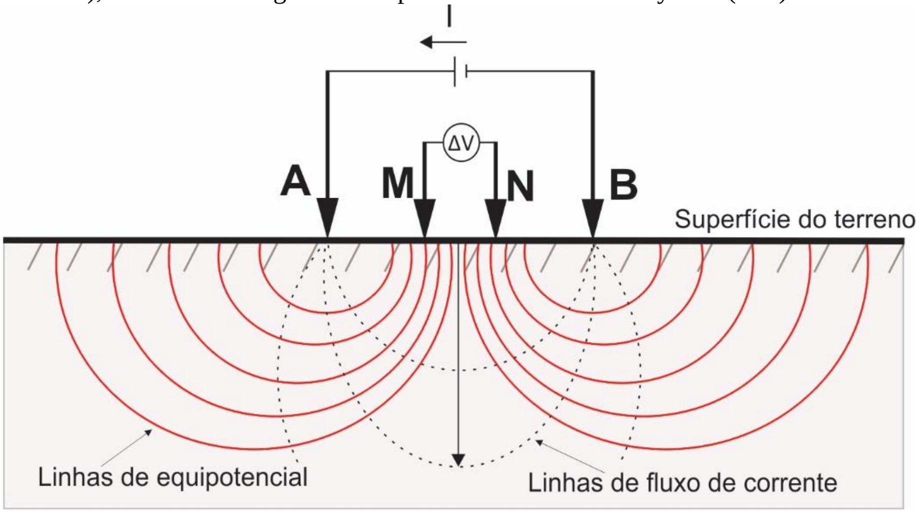
2 METODOLOGY

The resistivity method, through measurements by equipment placed on the surface, determines the electrical resistivity of the materials and their subsurface contrasts at different depths. In the area, three piezometers were installed, which enabled the calibration of the interpretation of the results of vertical electrical sounding.

Vertical Electrical Sounding (VES)

The field technique consisted of introducing an electric current into the subsoil, making it possible to determine the resistivities at various depths. In general terms, the equipment (resistivimeter) consists of a current source, a milliammeter, a millivoltmeter and accessories. Also required for field work are 4 electrodes that are embedded in the ground. Two electrodes (AB or current electrodes) have the function of introducing electric current into the subsoil, while through the other two (MN or potential electrodes) the potential difference due to the generated electric current is measured. Point O (Figure 1) is under which electrical resistivity measurements are being determined (Orellana, 1982).

Figure 1. General configuration of equipotential and current flow lines, through the two-point current emission system (A and B), and the resulting electrical potential measurement system (MN).



Telford *et al*. (1990).

The measured parameters allow calculating the apparent resistivity (ρa) of the investigated volume (soil or rock) in the subsurface through the following equation:

$$\rho a = K.\frac{\Delta V}{I} \quad \text{Equation 1}$$

where K is called the geometric configuration factor, as it depends solely on the geometry of the distribution (distances) of the electrodes on the topographic surface.

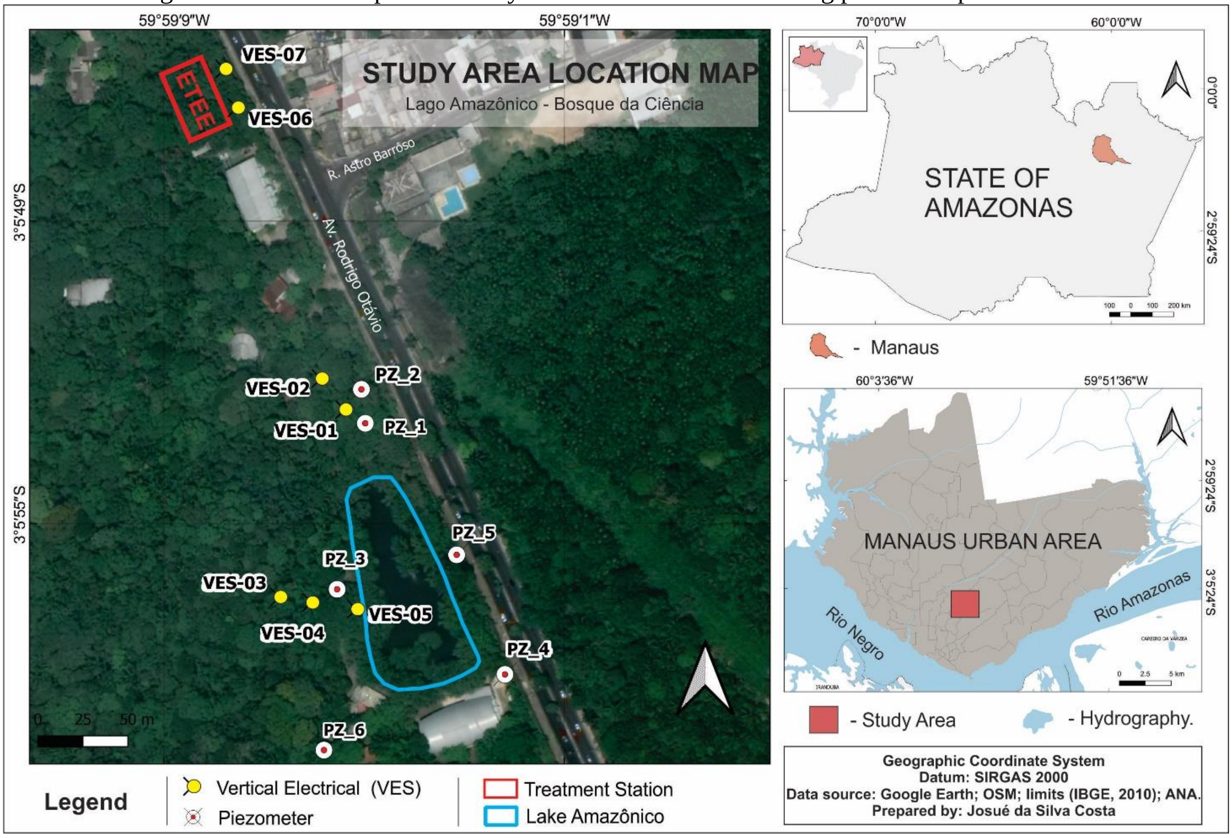
Finally, performing the VES means carrying out a series of measurements to define the subsurface electrical resistances carried out with the same type of arrangement and increasing separation between the current electrodes. As the distance between A and B increases, the total volume of the sampled subsurface also increases, raising the distance deeper and deeper.

The apparent resistivity data (ρ_a in ohm.m) are represented on a logarithmic scale as a function of the distances between the current electrodes (AB/2 in meters) also on the same scale. Thus, an VES curve is obtained, called Apparent Resistivity Curve, which is then interpreted through specific software. With the interpretation made, the true resistivities of the layers and their respective thicknesses are obtained, which, together with other information on the geological content of the region, allow the evaluation of the geological structure below the studied surface. The software used for interpretation was the public domain IPI2win developed by the Russian State University (USSR).

The survey of geophysical data provided a volume of information about the subsurface situation of the layout, lithological content and the depth of the water level of the subsurface layers through the seven vertical electrical surveys carried out around the INPA Lake and close to the ETEE (Figure 2).

The results of the interpretation of the vertical electrical sounding and water level depth measurements in the piezometers were integrated to produce a potentiometric map to understand the hydrogeological behavior from the point of view of underground flow.

Figure 2. Location map of the study area with electrical sounding points and piezometers.



3 FIELD SURVEY

Five electrical soundings were carried out (VES-1 to VES-5) upstream of INPA Lake in 2019, and two electrical soundings were carried out near INPA's Effluent Treatment Station in October 2000 (VES-6 ETEE and VES-7 ETEE).

Figure 3. Photos of some points during the survey of electrical surveys carried out around the Lake area (VES1, VES2, VES3, VES4 and VES5) and the INPA Treatment Plant (VES6 and VES7).

The equipment used was the resistivity set manufactured by TECTROL – Equipamentos Elétricos e Eletrônicos Ltd., model TDC 1000/12R2A.

4 INTERPRETATION OF ELECTRICAL SOUNDINGS

Summary of the interpretation of electrical soundings with depth (**P**$_n$) in meters and electrical resistivity (ρ_n) in ohm.m of the geoelectric layers (n=1, 2, 3, 4, 5 and 6).

	P_1	ρ_1	P_2	ρ_2	P_3	ρ_3	P_4	ρ_4	P_5	ρ_5	P_6	ρ_6
VERTICAL ELECTRIC SOUNDING AROUND THE LAKE.												
VES-1	0,0	836	0.9	2867	2,1	1267	7.3	3162	-	-	-	-
VES -2	0,0	1608	1.2	5533	4.6	2147	-	-	-	-	-	-
VES -3	0,0	2091	0.9	7418	1.9	1267	4.2	8884	16.8	616	-	-
VES -4	0,0	3232	0.9	6232	5.2	1592	10.6	3522	-	-	-	-
VES -5	0,0	1014	0.9	5363	2.3	528	15.1	4329	-	-	-	-
VERTICAL ELECTRIC SOUNDING AROUND THE EFFLUENT TREATMENT STATION.												
VES -1 ETE	0,0	418	0.6	2299	0.9	551	7.6	156	11.6	937	-	-
VES -2 ETE	0,0	530	1.9	272	10.3	1022	-	-	-	-	-	-

In red electrical resistivity value corresponding to the saturated layer

1.9 Water level depth

The first and second layers, in all surveys, with the exception of the VES-2 ETE, probably correspond to dry and more compacted dry soil, respectively, therefore, to the unsaturated zone of lithological characteristic, predominantly sandy, whose presence causes relatively high values of electrical resistivity as seen in these layers. In the case of the second layer, it may be a very compacted layer and a silicified sandstone due to the electrical resistivity value being significantly higher.

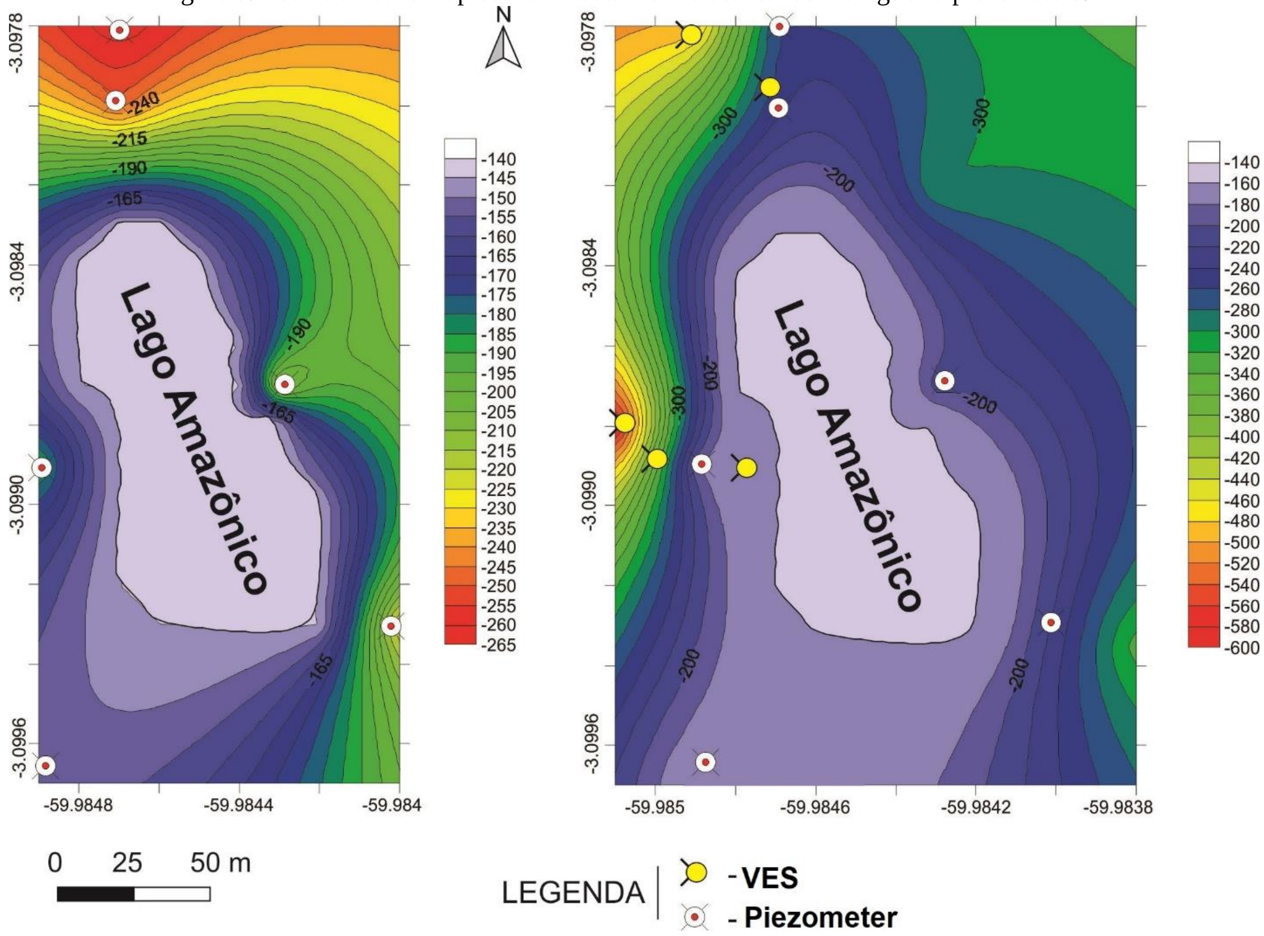
The third layer presents a significant decrease in electrical resistivity values. In the case of the VES-2 ETE this occurs in the second layer. This layer corresponds to the saturated zone.

The last layer of the soundings, with the exception of VES-3, presents an increase in electrical resistivity, which may represent the base of the unconfined aquifer. In the case of VES-3 this last layer seems to be indicative of a second saturated level.

The electrical resistivity values of the soundings close to the treatment plant were significantly lower, which may be the influence of subsurface effluents.

The potentiometric map generated from the level measurements in the piezometers and the water levels identified in the VES is presented below.

Figure 3. Potentiometric map based on data from electrical soundings and piezometers.



The potentiometric map in figure 4 (left) presents a potentiometric surface from the mean static levels in the piezometers. The map shows that the flow direction is preferentially from south to north, with the waters of the Amazon Lake seeping into the aquifer. The second map in Figure 4 (right) presents the potentiometric map with the static level data from the piezometers and the static level data obtained from the VES. From this map it is possible to observe the preferential flow from south to north, similarly to what is seen in the figure on the left. The map also shows that the flow direction goes from the Amazon Lake towards the ETEE.

5 CONCLUSIONS

The electrical resistivity values, relatively high in the study area, attribute a predominantly sandy lithological constitution, a result that is consolidated with the lithological description of the piezometers. The top of the saturated layer around the lake is deeper compared to the lake, causing its waters to seep into the aquifer.

This is because the lake is artificial, constantly receiving water to maintain its level. The potentiometric map indicates a practically radial flow direction, with a slight inclination towards the north. The electrical surveys carried out near the treatment plant showed lower resistivity values, which may be related to the influence of effluents in the subsurface.

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The study was carried out with resources provided for in Law No. 8,387 and in accordance with Article 39 of Decree 10,521 / 2020 - INPA / SAMSUNG Partnership.

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