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Geothermal Soil Analysis of the Rio de Janeiro State, Brazil

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Abstract **– This work presents the research of the geothermal data from 132 wells distributed in the state of Rio de Janeiro and Campos Basin, Brazil. These data were used to create maps of geothermal gradient, surface temperature, thermal conductivity and geothermal flux of the region. Through the maps, it was possible to identify the regions with the highest gradients and geothermal flow that are the regions of Itaguai, Costa Verde, Middle Paraiba and the southern part of the Northern Fluminense. The geothermal flow of the state of Rio de Janeiro ranged from 39 mW/m² to 95 mW/m², even so, the entire region studied had a geothermal flow far below that needed for electricity generation, although the artisanal use of geothermal energy such as water heating is not yet ruled out.**

Keywords **– Alternative Energy, Thermal Conductivity, Geothermal Flow, Geothermal Energy, Rio de Janeiro.**

I. INTRODUCTION

The Brazilian energy matrix has maintained a high participation in renewable sources in recent decades. The use of biomass almost doubled and the use of hydroelectric energy was prioritized reaching a very high participation when compared to the rest of the world. In order to maintain the tradition of having an energy matrix with a large renewable share, we seek even more energy alternatives for Brazil [1].

According to Arboit *et al.* [2], the economic viability of geothermal energy exists as long as areas with good geothermal flow and with low environmental impacts can be selected. The use of this type of energy can make a significant contribution to a country like Brazil that has a large part of its energy matrix consisting of renewable sources.

Although it is already widely used in the world, geothermal energy in Brazil is still used only for direct use as for leisure as the Caldas Novas region in the Goias state.

In the context of a lack of research in geothermal in Brazil, geothermal data offer a great opportunity to evaluate the geothermal potential of the state of Rio de Janeiro, it helping to plan a possible exploration of this type of alternative energy. These data were used to promote the geothermal mapping of the region in an attempt to change this scenario and place Brazil as a major user of geothermal energy.

Thus, it is intended to evaluate the geothermal potential of the Rio de Janeiro state through the mapping of thermal conductivity, geothermal gradient, geothermal flow and subsoil temperature, it contributing to the planning and management of future projects of this type of energy in the state.

II. GEOTHERMAL ENERGY

Planet Earth has an interior whose temperature ranges from a few hundred degrees Celsius to about 5,000°C. The Earth has a basic constitution with two nuclei: a solid internal and a fluid external, in addition to a mantle consisting of melted rocks (Figure 1). The high temperature of the interior of the planet is mainly attributed to the energy released by the radioactive decay of isotopes such as potassium-40 (40K), thorium-232 (232Th) and uranium-235 (235U). The Earth's crust is divided into plates that are called "tectonic plates" located on the mantle [3].

In its cooling process, the heat of the Earth's interior can be dissipated at any point on the surface. There are regions where the release of this heat is more abundant, usually coincident with active zones of the borders of the tectonic plates of the globe. Volcanoes, geysers, water sources, hot mud and geothermal generation plants that use steam or groundwater from wells with a depth of 1.5 km or more are evidence of the heat that exists below the Earth's crust [4].

The heat from the Earth's interior is transferred through the thermal convection of magma, it can reach the rocks of the crust and originate heated regions. On some occasions, water can penetrate these rocks and create pockets of water and steam at very high temperatures. This occurs mainly at the edges of tectonic plates and in faults because in these regions, magma can reach close to the surface by the action of volcanoes [5].

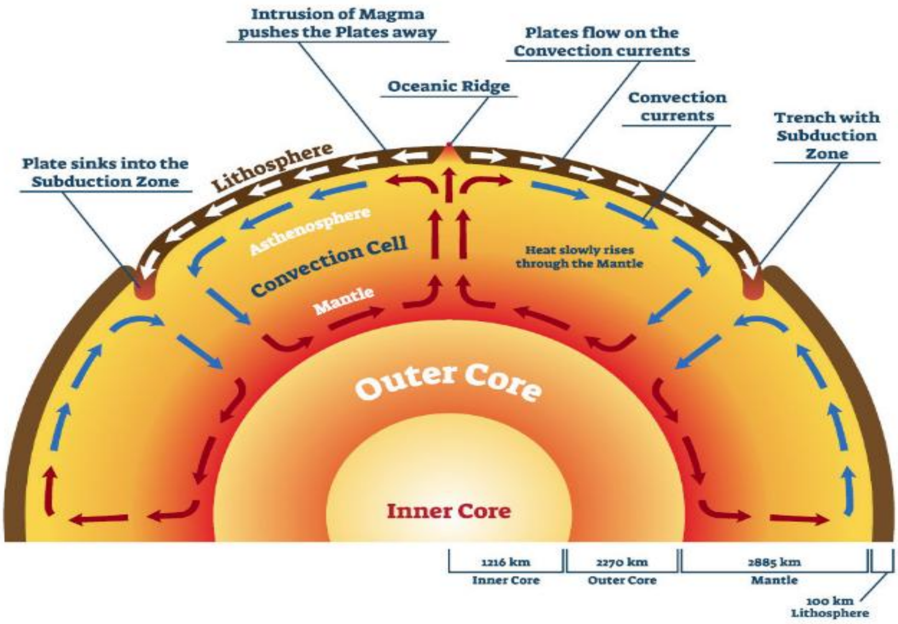

Fig. 1. Theory of the mantle convection [6]

III. Thermal Conductivity and Geothermal Flow

Thermal conductivity is a characteristic of solids that allows heat conduction. It presents the ability of each material to conduct heat, it allowing the transmission of energy in the form of heat that reaches the surface [7].

According to Gomes [8], the heat flow can be determined from the heat coming from the matrix rock from the Fourier Law that can be written as: In that:

$$q = k\, dT/dz \quad (1)$$

q - the heat flow; k - the thermal conductivity of the material; dT/dz - the geothermal gradient of temperature T with distance, in the z direction of the heat flow in °C/m.

Thus, according to Gomes [8], the proportionality factor k that is called thermal conductivity. It is nothing more than a property that determines the material's capacity for heat conduction. This value varies with the type of material and the type of rock and minerals that exist there.

IV. Description of the Rio de Janeiro State

The Rio de Janeiro state currently has 92 municipalities, its capital is the city of Rio de Janeiro. In 2014, the estimated population was around 16,461,000. The total area of the Rio de Janeiro state is 43,777 km², with a geographical density (inhabitant/km²) of 365.23 [9] [10].

According to Silva e Cunha [11], in nature, we were able to highlight the rocks in 3 types:

(a) Magmatic (or igneous) where cooling forms magma (molten rock). Through this process, the rock moves from the liquid state to the solid (crystallization);

(b) Sedimentary that are generated through sediment compaction. Sediments are equivalent to tiny fragments of rock that deteriorate by the action of winds, rivers, seas, ice, etc. Sedimentary rocks can also be created by the concentration of organic utensil, shells and the anticipation of dissolved material in water;

(c) Metamorphic, they are resulting from pre-existing rocks (magmatic and sedimentary) and which were transported to great depths in the Earth and dominated to high temperature and pressure conditions, it supporting the process of recrystallization and/or deformation called metamorphism.

The transformations in the thermal conductivity of the rocks that form the crust have a significant effect on the position of heat in them. Crystalline rocks (granites and basalts) generally have superior thermal conductivity than sedimentary rocks [12].

The three types of rocks (magmatic, sedimentary and metamorphic) are distributed in the state of Rio de Janeiro, according to Figure 2 and Table 1.

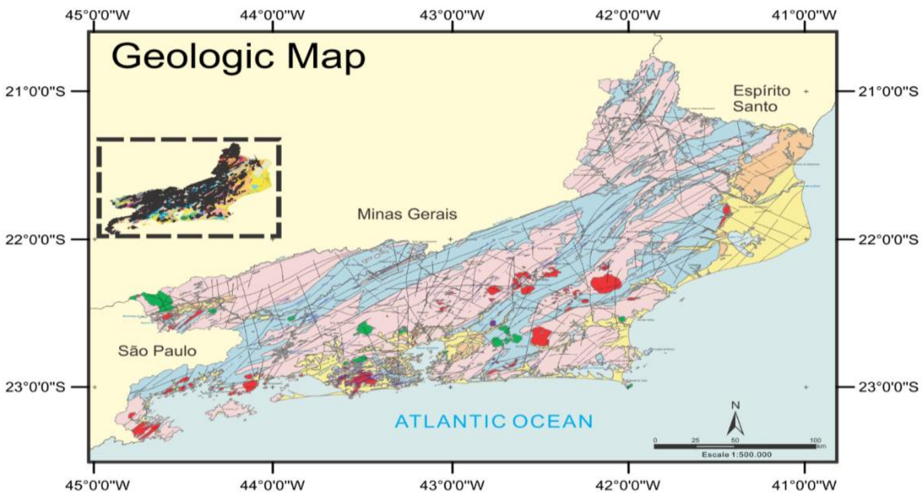

Fig. 2. Simplified Geological Map of the Rio de Janeiro State [11].

Table 1. Geological units of Rio de Janeiro.

	Quaternary Sediments (recent): they are represented by slats, peat, sands, gravels and conglomerates deposited between the present and 2 million years ago.
	Tertiary sediments: they were deposited between 65 and 2 million years ago. They are sedimentary rocks or unconsolidated sediments, deposited by river and marine processes.
	Alkaline rocks: these are magmatic rocks characterized by being rich in the elements Sodium and Potassium. It having formed between 70 and 40 million years.

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	Diabase dikes: they are magmatic rocks with the presence of minerals rich in iron and magnesium, about 130 million years ago.
	Homogeneous granites: granites are the most common.
	Basic rocks: it has a very different composition from granites, being more similar to the diabase dikes.
	Orthoderivative rocks: they are formed from metamorphism on igneous rocks. The most common orthoderivative rocks in the state are the so-called orthogneisses.
	Paraderivative rocks: they are formed from the metamorphism of sedimentary rocks, and it can also be called metasedimentary. The most common in the state of Rio de Janeiro are paragnaisses.
	Faults, Fractures and Folds: rock reaction structures to the efforts that they have undergone.

Topographic map of the Rio de Janeiro state was made using satellite data of the TOPEX V.18.1 model with a resolution of 1 minute. The result is shown in Figure 3.

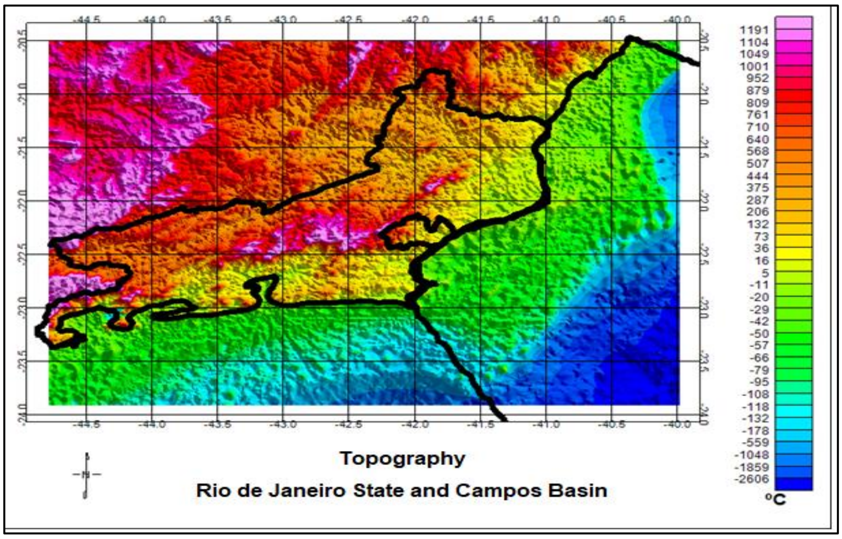

Fig. 3. Topographic Map of the Rio de Janeiro State.

In general, the continent altitude of the state varied between 0 and around 1,200 m. On the coast, from the beach to the end of the continental shelf the depths ranged between 0 and around -500 m. The abyssal plain region reached depths of up to 2,600 m.

V. Processing and Results

Geothermal gradient, surface temperature, thermal conductivity and geothermal flux data were used. These data come from 132 wells distributed in the Rio de Janeiro state and Campos Basin. The data were processed in Oasis Montaj software from Geosoft. The geothermal data used come from direct subsurface temperature measurements, lithological profiles of the wells, indirect temperature estimates in aquifers based on geochemical thermometry, hydrogeological data, experimental measurements of the thermophysical properties of the main geological formations, and radiogenic heat estimates.

The thermal conductivity map reveals the most conductive regions of the state of Rio de Janeiro, with rocks that allow the transmission of energy in the form of heat to the surface more efficiently. The average thermal conductivity map was made (Figure 4).

The thermal conductivity of the Rio de Janeiro state ranged from 2.1 W/(mK) to 3.0 W/(mK). Analyzing Figure 4, it can be affirmed that the highest average conductivities of the soil were found in the regions of Itaguai, Serrana and Santo Antonio de Padua. The lowest medium conductivities of the soil were found in the regions of Macaé, west of the Costa Verde and southeastern part of the Northern Fluminense region. The low conductivity of the municipality of Macae (brown) in relation to the rest of the state is highlighted, reaching close to 2 W/(mK). We also highlight the low values of thermal conductivity of the Campos Basin around 2.5 W/(mK) and the Santos Basin around 2.0 W/(mK).

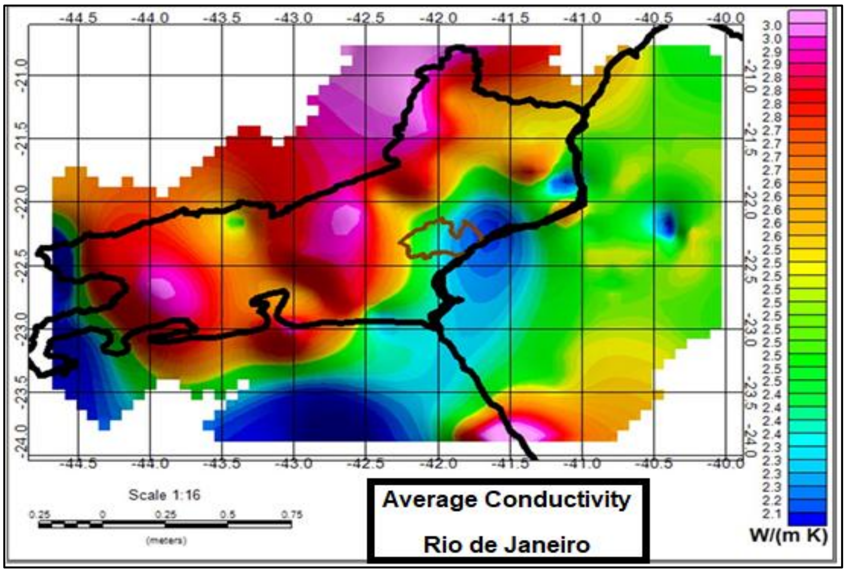

Fig. 4. Map of average thermal conductivity of the state of Rio de Janeiro.

In general, the thermal conductivity of the state of Rio de Janeiro in relation to topography (Figure 3) presented the highest values in the regions of higher altitudes and the lowest values of lower altitudes and more coastal.

The comparison with the geological map reveals the most conductive regions associated with orthognaisses of the Orthoderivative Rocks complex and paragnaisses of the Paraderivative Rocks complex.

On the other hand, the smallest conductivities are mainly associated with the Quaternary Sediment complex represented by slats, peat, sands, gravels and conglomerates and the Tertiary Sediments complex that is represented by sedimentary rocks or unconsolidated sediments, deposited by river and marine processes.

The Geothermal Gradient map for the state of Rio de Janeiro reveals the regions with the highest temperature differences per unit of depth. The geothermal gradient map of isovalues was made (Figure 5).

The geothermal gradient of the state of Rio de Janeiro ranged from 14 ºC/km to 39 ºC/km. Analyzing Figure 5, it can be affirmed that the highest geothermal gradients were found in the regions of Costa Verde and Northern Fluminense Region. The lowest geothermal gradients were found in the regions of Barra do Pirai, Santa Maria Madalena and Macae.

The low geothermal gradient in the municipality of Macae in relation to the rest of the state stands out, reaching close to 18 ºC/km. The Campos and Santos basins also presented much higher gradients than the continental region of the state.

The comparison with the geological map reveals the regions with the highest gradients such as the regions of tertiary and quaternary sediments around the city of Rio de Janeiro and the extreme east of the state in the Northern Fluminense region. The smallest gradients are associated with orthoderivative and paraderivative rocks.

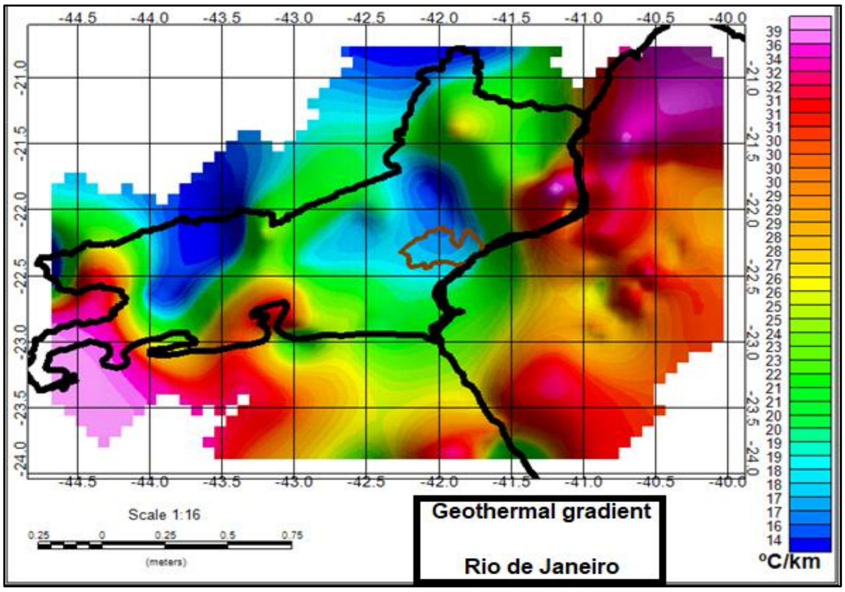

Fig. 5. Geothermal gradient map of the Rio de Janeiro state.

The geothermal flow is the product of geothermal conductivity presented in Figure 4 with the geothermal gradient presented in Figure 5. The Geothermal Flow map reveals the regions of the Rio de Janeiro state where there is greater transport of geothermal energy per unit of time. The geothermal flow map of isovalues is presented in Figure 6.

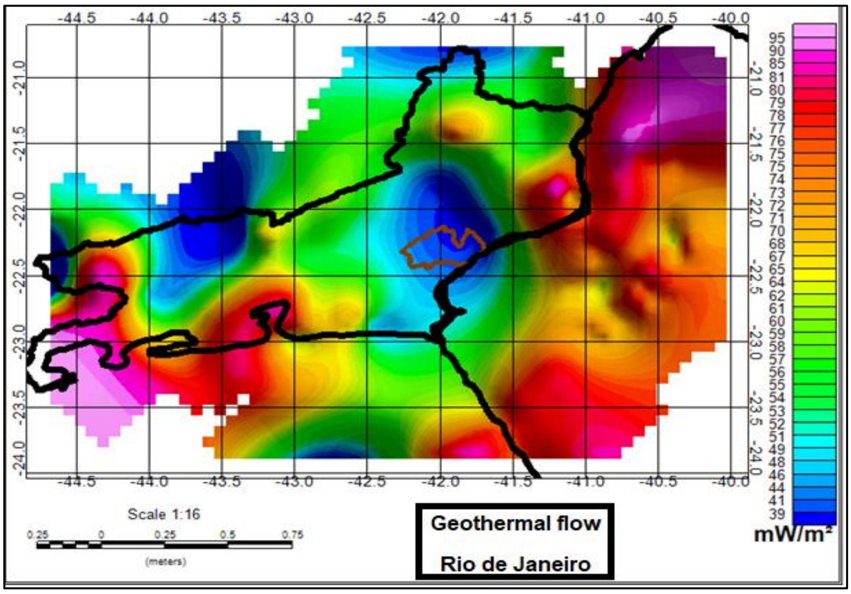

Fig. 6. Geothermal flow map of the Rio de Janeiro state.

In general, the geothermal flow map was more sensitive to the geothermal gradient than in relation to geothermal conductivity. The regions with smaller and larger geothermal flows coincide with the regions with smaller and larger geothermal gradients.

The geothermal flow of the state of Rio de Janeiro ranged from 39 mW/m² to 95 mW/m². Analyzing Figure 6, it can be affirmed that the largest geothermal flows were found in the regions of Itaguai, Costa Verde, Medio Paraiba and Norte Fluminense. The smallest geothermal flows were found in the regions of Barra do Pirai, Santa Maria Madalena and Macae.

We also highlight the low geothermal flow in the municipality of Macae (brown) in relation to the rest of the state, it reaching close to 39 mW/m² and the large gradients associated with the Santos and Campos basins compared to the continental part of the state. As with the geothermal gradient, the comparison with the geological map reveals the regions with the highest flows associated with tertiary and quaternary sediments around the city of Rio de Janeiro and the extreme east of the state. And the smallest flows associated with orthoderivative and paraderivative rocks.

The surface temperature map reveals the soil temperature of the Rio de Janeiro state, which in addition to being useful in geothermal projects, it can also help environmental studies. The isovalue surface temperature map is present in Figure 7.

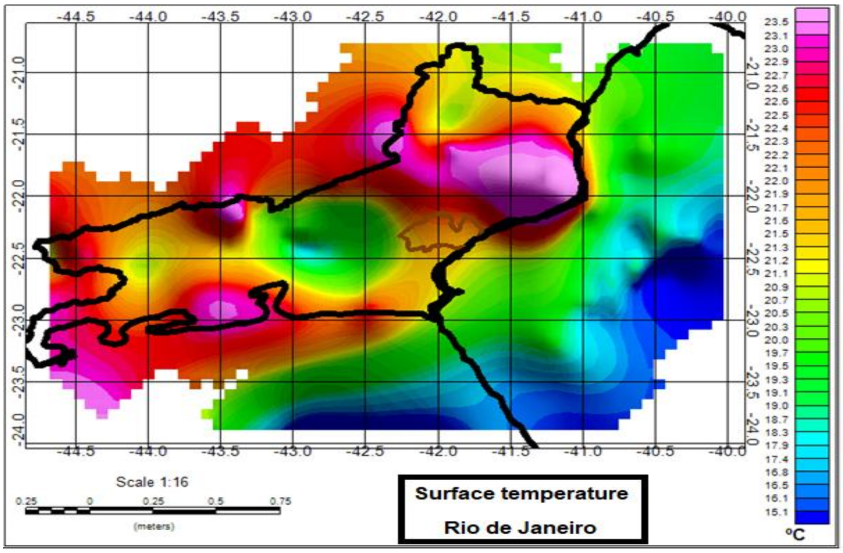

Fig. 7. Surface temperature map of the Rio de Janeiro state.

The surface temperature of the Rio de Janeiro state ranged from 15.1 ºC to 23.5 ºC. Analyzing Figure 7, it can be affirmed that the highest surface temperature values were found in the regions of Itaguaí, Norte Fluminense and Santo Antônio de Padua.

The lowest surface temperatures were found in high altitude regions such as Serrana, Northwest Fluminense and Medio Paraíba. The city of Macaé has been located in a region of intermediate temperature with temperatures ranging between 21 ºC and 22 ºC. Also, it is possible to notice a great change in temperature when the transition between the continental shelf and the abyssal plain occurs where the water becomes very deep.

According to Gomes [8], in the case of Brazil, the disappearance of tectonic activities and volcanic eruptions meant that the thermal regime of much of the crust of the South American platform is considered to be in a steady state. Therefore, conditions of this nature are favorable for the occurrence of low enthalpy geothermal resources that promote a geothermal use more focused on recreational and leisure purposes, as we found in the state of Rio de Janeiro.

The fact that Rio de Janeiro State is located in the middle of a tectonic plate makes it much less conducive to the use of geothermal energy. However, there are places in the state that have rocks heated to depths suitable for geothermal use. Despite the low geothermal flux found, artisanal use in geothermal energy is still recommended.

VI. Conclusions

Geothermal maps of medium thermal conductivity, thermal gradient, thermal flow and surface temperature were made. These maps were compared with topographic and geological maps.

It was possible to identify the regions with the highest gradients and geothermal flow that are the best regions for the use of geothermal resources. The regions of Itaguai, Costa Verde, Middle Paraiba and the southern part of the Northern Fluminense region stand out.

As for the municipality of Macae, it stands out among the lowest values of geothermal conductivity, geothermal gradient and geothermal flow in which the municipality is located in relation to the state.

In the same way as Brazil, the Rio de Janeiro state does not have very large geothermal flows. However, the direct use of geothermal energy can be explored. It is suggested greater applications in agriculture, aquaculture, heating of houses and buildings, hydrothermal and industrial uses.

For further studies, it is recommended to collect data and search for hot water sources in the regions where higher geothermal flows were found. It is also recommended a research to evaluate future environmental impacts caused by the installation of a geothermal plant.

References

[1] A. Ventura Filho, Brazil in the World Energy Context**.** NAIPPE/USP. 2009.
[2] N.K.S. Arboit; S.T. Decezaro; G.M. Amaral; T. Liberalesso; V.M. Mayer; P.D.C. Kemerich, *Potential for the Use of Geothermal Energy in Brazil.* Journal of the Department of Geography - USP, Volume 26, p. 155-168. 2013.
[3] P.M. White, Internal structure of the Earth. cprm. 2014. Available in: http://www.cprm.gov.br/publique/cgi/cgilua.exe/sys/start.htm?infoid=1266&sid=129>. Accessed: Oct. 25. 2014.
[4] C. Bicubo, Geothermal Energy. Feel and Interpret the Azores (SIARAM). 2010. Available at: < http: //siaram.azores.gov.pt/energia-recursos-hidricos/geotermia/energia-geotermica.pdf>. Accessed: 25 Oct. 2014.
[5] A. L. Domingos, Convection chains. 2006. Available at: <http://domingos.home.sapo.pt/correntes_1_convecao.jpg>. Accessed Oct. 25. 2014.
[6] World In Maps, Tectonic plates and their boundaries**.** Available in https://worldinmaps.com/tectonic-plates/
[7] A. J. L. Gomes; V.M. Hamza, Geothermal gradient and heat flow in the state of Rio de Janeiro. Brazilian Journal of Geophysics. 325-347 p. 2005. Available in: < http://www.scielo.br/pdf/rbg/v23n4/a01v23n4.pdf>. Accessed: 25 Oct. 2014.
[8] A. J. L. Gomes, Evaluation of geothermal resources of the Paraná Basin**.** National Observatory. Rio de Janeiro, 2009.
[9] IBGE, National Survey by Continuous Household Sample**.** Research, Coordination of Work and Income. 2014.
[10] TURISRIO, Geographic Guide of Rio de Janeiro. Map of the Regions of the State of Rio de Janeiro**.** 2015. Available in: http://www.mapas-rio.com/mapas/regionais.jpg
[11] L. C. Silva; H. C.; S. Cunha, Geology of the State of Rio de Janeiro: explanatory text of the geological map of the State of Rio de Janeiro. Brasilia: CPRM. 2nd edition. 2001.
[12] E.C. Molina, Investigating the Earth. IAG-USP. 2000. Available in: http://www.iag.usp.br/siae98/default.htm

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