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# MANAGEMENT OF THE GUARATIBA AQUIFER

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## ABSTRACT

The Guaratiba Aquifer was preliminarily considered as an intergranular pore that occurs in Quaternary clayey-sandy sediments and residual soils, with contributions from a fractured system, associated with the rocks present in the elevations and in the rocky substrate of the region. This aquifer is large and important for human supply. Studies carried out in the region prove that the quality of groundwater is compromised by the lack of basic sanitation and urban planning, requiring that public agencies adequately manage this water resource that is so important to the population.

**Keywords:** Guaratiba Aquifer. Groundwater. Water Quality. Vulnerability. Management.

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## INTRODUCTION

THE GUARATIBA AQUIFER

The Guaratiba Aquifer is located in the Guandu River Basin in the State of Rio de Janeiro. Based on the project developed at UFRRJ, coordinated by the author, entitled “Avaliação Hidrogeológica e da Qualidade das Águas Subterrâneas das Regiões Administrativas de Campo Grande e Guaratiba” (CARVALHO, 2009), where the objective was to evaluate the potential of the groundwater resources of the aforementioned region, an aquifer of relevant importance in the regional hydrogeological context was characterized, located in the administrative region of Guaratiba. The aquifer was preliminarily delimited and named “Aquifer Guaratiba”, modified in the present study (Figure 1).

The Guaratiba Aquifer is an intergranular porous aquifer that occurs in Quaternary clayey-sandy sediments and residual soils, with a relevant contribution from a fissure system, associated with the rocks present in the elevations and in the rocky substrate of the region. The two systems are closely related to each other. The large size and geographical position of the municipality of Rio de Janeiro further increases the importance of this aquifer for both human supply (VICENTE; DE CARVALHO; BARBOSA, 2010) and for maintaining the balance of the region's hydrological conditions in the face of climate change. It is, therefore, an important hydrogeological unit.

Hydrogeological studies have found that the existing aquifer allows for the intensive use of groundwater through wells in both aquifer systems, the porous and the fissure. In the fissure aquifer, water can also be used through surface springs that arise through the fracturing of outcropping rocks (CARVALHO, 2009).

The relevant importance of groundwater in supplying homes and other uses, such as irrigation and animal husbandry, is well known in a significant territorial area of approximately 10,000 ha.

In recent years, the territory that encompasses the limits of the Guaratiba Aquifer has been the target of urban expansion in the city (LIMA; QUERINO; DE CARVALHO, 2016; CARVALHO; FRANCISCO, 2020). The scarcity of basic public water supply and sanitation services, combined with the lack of occupation planning and territorial management that prioritizes environmental conservation in this region, often ends up affecting the

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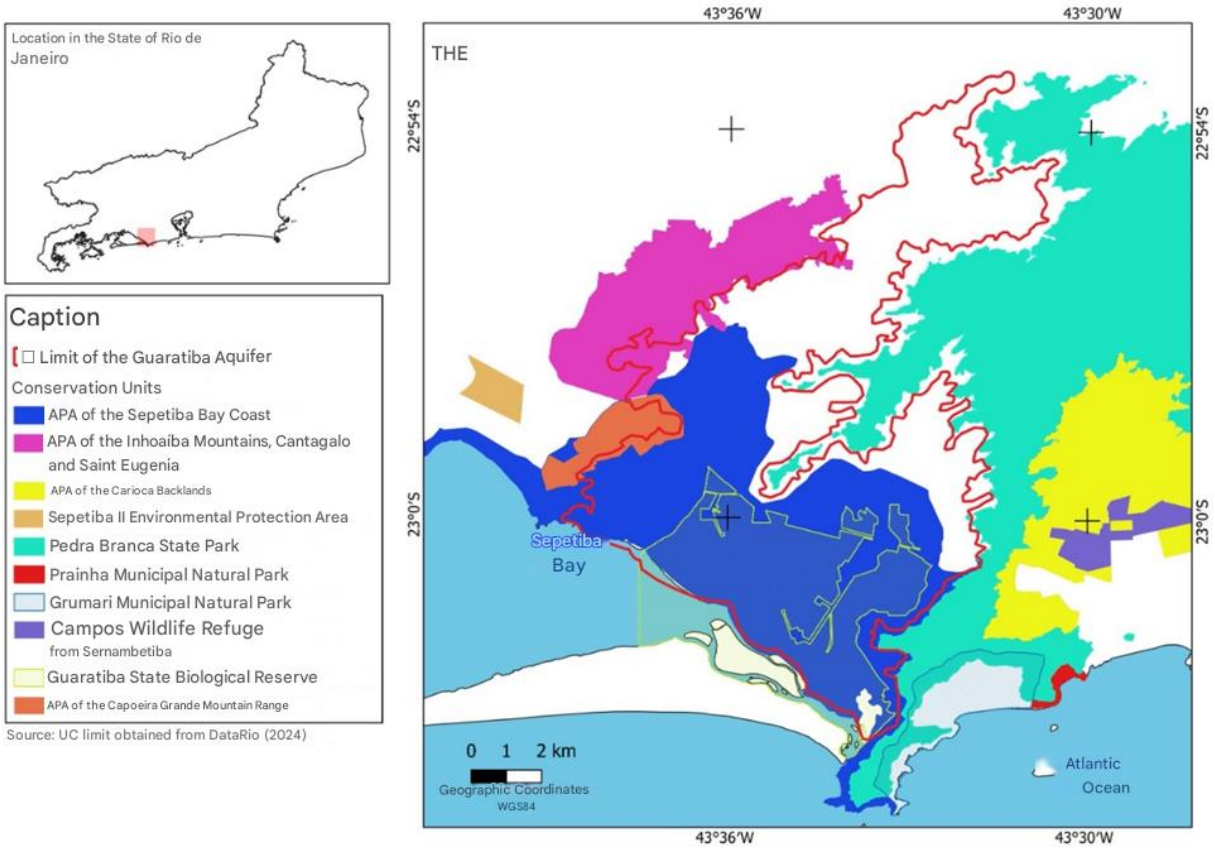
hydrological processes of aquifer recharge, water availability, and the quality of surface and groundwater (LIMA; QUERINO; DE CARVALHO, 2016). The Guaratiba Aquifer is predominantly found in the Guaratiba lowlands, surrounded by elevations, which are characterized as Conservation Units (Figures 1 and 2) inserted in the Inhoaíba/Cantagalo Mountain Ranges - Municipal APA of the Inhoaíba/Cantagalo and Santa Eugenia Mountain Ranges, in the Pedra Branca Massif - Pedra Branca State Park, Serra da Capoeira Grande - Municipal APA of Capoeira Grande and coastline - Guaratiba Biological Reserve (mangrove) - APA of the Sepetiba Bay Coastline.

Figure 1 - Preliminary delimitation of the Guaratiba Aquifer and surrounding Conservation Units.




Source: The author.

The region has a dense drainage network, where the main rivers are Portinho, Piracão, and Cabuçu/Piraquê, as shown in Figure 2. Many of these drainages have been rectified and represent straight channels that connect to the drainage network.

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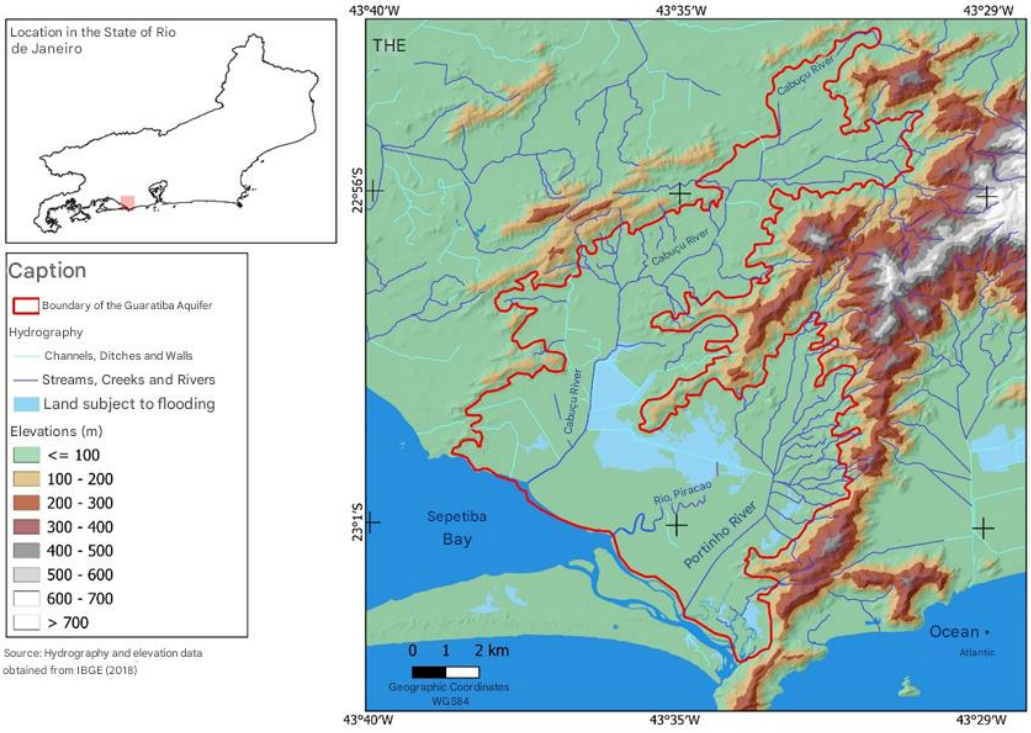
Figure 2 – Limit of the Guaratiba Aquifer, distribution of the drainage network, and elevations.




Source: The author.

## TYPES OF AQUIFER SYSTEMS

The porous aquifer system is represented in the area by deposits of Quaternary sediments, related to alluvial deposition from the watersheds in the region, including ancient areas, adding residual soil layers resulting from the alteration of crystalline rocks, which occur in the mountains and underlie the sedimentary package as bedrock. The sediments have varied constitutions and grain sizes. This composition allows for the storage of groundwater with different chemical compositions. Areas closer to the coastline have the contribution of saline wedges. To aid in understanding the fissural aquifer system near the slope and the sedimentary system in the adjacent lowlands, as well as to preliminarily assess the quality of the groundwater, the geophysical method of electrical resistivity was applied in the western portion of the Pedra Branca Massif. The obtained data estimate the thickness of the sedimentary package at about 20 meters deep (VICENTE; DE CARVALHO; BARBOSA, 2010). Brackish water may occur at depths above 32 meters due to the influence of the saline wedge (LIMA et al., 2012).

The groundwater stored in the porous system is located at shallow depths, commonly occurring at an average depth of 1.24 meters from the surface. However, the

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variations in sediment grain size, ranging from clay to coarse sand, allow for permeability with variable behavior (CARVALHO, 2009). The drilling work conducted by Rosa; and Marques (2019) in the Guaratiba lowlands verified the presence of clays and extremely shallow groundwater levels in some areas, with groundwater even surfacing. Clays, in general, exhibit low permeability behavior.

Santos; Carvalho; and Borges (2018) characterized the sediment grain size in the Guaratiba lowlands region using material collected at three drilling points. The depths reached approximately 11 meters. It was found that, in general, sediments with grain sizes ranging from medium to coarse sand predominated, likely associated with coastal environments such as beaches and tidal plains. The deposition of these sediments is related to fluctuations in the relative sea level during the Quaternary. At all three points, black soil rich in organic matter was observed, extending to depths of approximately 70 cm.

The fissural aquifer system is characterized by crystalline rocks that compose the local sub-watersheds. It is related to the behavior of discontinuities in the region's rocks, represented by fractures, foliations, and contact relations between interlocking rocks, dikes, and pegmatites. The rocks predominantly exposed in the region are granites and subvolcanic rocks. Granites have varied mineralogical compositions and grain sizes, and they can occur in association with subvolcanic intrusive rocks and pegmatites. They occur both in the mountains and in the bedrock, providing the foundation for residual soils and unconsolidated sediments.

Pires (2017), through the geometric analysis of lineaments and their relationships with groundwater associated with the Guaratiba Aquifer, sought to establish patterns of lineaments observed in the study area and their relationships with the occurrence of nearby wells or wells coincident with specific structural classes of lineaments, considering the dynamics of groundwater. It was found that wells installed in the fractured system, located along NW-direction lineaments, exhibit good hydraulic characteristics. Wells located along NE-direction lineaments were identified as the main fractures, possessing better hydraulic characteristics.

Lima (2018) characterized the petrography and structures of the fissural aquifer in the Ilha de Guaratiba region, Rio de Janeiro, RJ, based on two borehole samples collected via rotary drilling in the Guaratiba Aquifer region. The depths reached approximately 24 meters. The samples were characterized both macroscopically and microscopically regarding their hydrogeological behavior in the subsurface. Discontinuities such as

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fractures, microfractures in minerals, and lithological contacts were identified. Based on the observed pattern of the fissural system, it can be concluded that the hydrogeological behavior contributes to the water-holding capacity of these rocks, with favorable conditions for percolation, distribution, and storage of groundwater.

Nascimento (2017) studied the geology of Pedra de Guaratiba and Serra da Capoeira Grande, Rio de Janeiro, RJ. The primary objective was to create a semi-detailed geological map at a scale of 1:20,000 for the Pedra de Guaratiba neighborhood, covering both the urban area and the Serra da Capoeira Grande. The work also aimed to provide information that could be used as tools for understanding the influence of the local geological structure on the recharge, storage, and chemical dynamics of the Guaratiba Aquifer. The area is predominantly formed by granites, intersected by mafic alkaline dikes oriented ENE, which are sub-concordant with the general NE orientation of fractures in the granites and dikes. Structural and petrographic characteristics suggest that the rocks of Pedra de Guaratiba represent a geological extension of the Pedra Branca Massif, whose characteristics were described by Porto Jr (1994, 2004).

In hydrogeological terms, the area presents structural features conducive to aquifer recharge, justified by the medium to high dip values of the fractures (36° to 89°), the homogeneous distribution of these fractures in the neighborhood, parallel to orthogonal fracture patterns, and the presence of fractures ranging from open to closed in the rocks, generally open in the weathered dikes.

## QUALITY OF GROUNDWATER CAPTURED FOR USE IN THE GUARATIBA AQUIFER AREA

Bueno (2017) characterized the hydrochemistry of groundwater collected from ten (10) domestic wells in the Serra de Inhoaíba area. The groundwater from these wells is also used for human consumption. Potability analyses of the waters studied were also performed, based on the potability standards defined by Ordinance No. 2,914/2011 of the Ministry of Health. All samples presented total and fecal coliforms. Of the ten water samples analyzed, 7 are used for human consumption.

Lima; Querino; de Carvalho (2016) studied the environmental behavior of groundwater extraction in the Guaratiba Aquifer. They stated that the incentive for the occupation of this region by the City of Rio de Janeiro has caused some environmental problems for the region. One of the problems is related to the contamination of groundwater

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in the Guaratiba Aquifer. This problem has been recurring due to the poor construction, maintenance, and use of semi-artesian wells, many of which are built close to septic tanks or sewage areas. Fifteen (15) samples collected from wells in the region of Estrada do Magarça and surrounding areas, and Estrada do Cantagalo and surrounding areas, the regions chosen for the study, were analyzed. These regions have been suffering drastically from the increase in population and urbanization, which may be influencing the results. The results showed that twelve (12) of the fifteen (15) samples analyzed presented contamination of at least one component, the majority of which were fecal coliforms.

## CAPTURE CHARACTERISTICS

In wells installed in the porous aquifer, the depths are shallow, reaching around nine (9) meters, and, in general, the volume of water collected is around 1,000 l/h. Groundwater in the fractured system is obtained from springs as well as from wells with varied characteristics, ranging from twenty (20) to one hundred (100) meters in depth, and, in general, the volume of water collected is around 2,000 l/h in wells from twenty (20) to thirty (30) meters in depth.

## VULNERABILITY

The aquifers (porous and fissure systems) in question must be preserved since part of the water supply for various uses currently comes from their reserves, either through the use of shallow wells with low flow or deep wells with higher flow rates. The reserves may become a future complementary source of water supply for the aforementioned municipality, due to the demand caused by population growth.

Carvalho; and Francisco (2020) studied the vulnerability to contamination of the Guaratiba Aquifer, located in an urban area. Using the DRASTICA system, the anthropogenic impact characterized by the land use and land cover map was included, together with the population density, measured through the census tracts. Assessments were made using the DRASTIC and DRASTICA methods. The DRASTIC map revealed three vulnerability classes (low, medium, and high) where the influence of the Cabuçu River, due to the high-energy sedimentation depositional environment, demarcated sandy lenses along the river, which were relevant for the formation of the high vulnerability area. In the DRASTICA map, three vulnerability classes were also mapped, however, the inclusion of the anthropogenic impact parameter, especially census tracts with higher occupation

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densities, was responsible for the highest vulnerability rates. In addition, the incorporation caused the expansion of the high-vulnerability class area to the urban area, increasing its extension fivefold.

## WATER RECHARGE AREAS

The recharge of the intergranular aquifer system can be carried out by direct action of rainfall as well as by the contribution of the fissure aquifer system. The recharge of the fissure aquifer system comes from precipitation in the headwaters of the hydrographic sub-basins, where the rocks of the crystalline basement are outcropping, or with the contribution of the soil and sediment cover of the intergranular aquifers by percolation.

Irmão (2018) in his work “Geoenvironmental and Water Recharge in the Porous Aquifer in the Region of Guaratiba/RJ”, mapped the geoenvironmental units by geoprocessing, allowing to understand and characterize the spatial organization, for territorial management, sought to study the water characteristics of the Guaratiba Aquifer region, starting from the analysis of water recharge in various environments through pedological, vegetative and also anthropic factors that characterize the geoenvironmental units. It was concluded that the pedological criterion was a determining factor for defining the water recharge capacity of the geoenvironmental units, where the soil characteristics were shown to be relevant for analyzing infiltration in these areas, thus differentiating the geoenvironmental with very high and high water recharge and geoenvironmental with very low and low water recharge. It emphasized the relevance of water recharge areas as an important factor for the preservation of the Guaratiba Aquifer.

## CURRENT MANAGEMENT

In general, although the use of groundwater is intense in this area, there is no concern with the management of available water resources. This fact can lead to the depletion of the aquifer, as well as allow disorderly use to lead to contamination processes. The relationship between land use and occupation reflects not only the dynamics of the region's water resources but also the transformation of the landscape and society's interaction with space and its use of water resources.

Figure 3, obtained from data from the MapBiomas Project, reveals urban growth, defined as a “Non-vegetated area”, in the Guaratiba Aquifer area in almost forty (40) years

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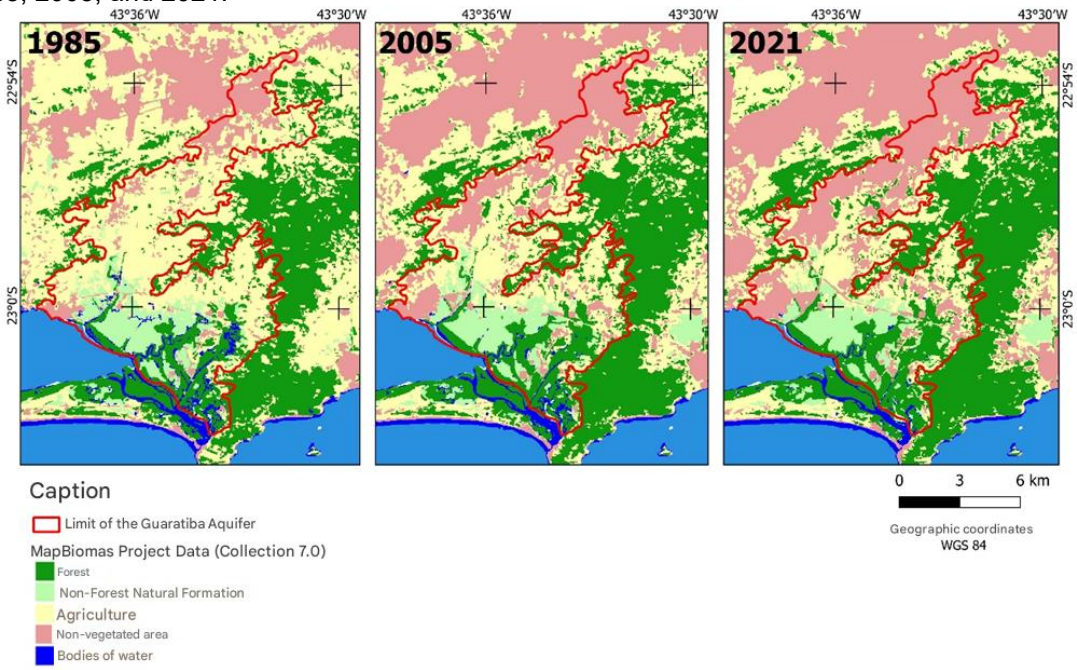
of land use and occupation. An increase in forested areas can also be observed in the headwater regions of the watercourses that supply the aquifer.

Figure 3 – Limit of the Guaratiba Aquifer and land use and cover obtained from the MapBiomas Project for the years 1985, 2005, and 2021.




Source: The Author.

GENERAL CHARACTERIZATION OF DRAINAGE NETWORKS

There are three main sub-basins in the study area: Sub-basins of the Cabuçu/Piraquê River, the Portinho River, and the Piracão River.

**Sub-basin of the Cabuçu/Piraquê river**

The Cabuçu/Piraquê River sub-basin is characterized as being of great importance. The Municipal APA of the Inhoaíba/Cantagalo and Santa Eugenia Mountain Ranges is home to several streams and springs that flow towards the Cabuçu River, located in the lowland region, installed in the Guaratiba Aquifer. Its basin is of relevant importance in its functions for the aquifer. Its flow from upstream to downstream is directed from the mountains to the Sepetiba Bay. Its springs are located in the Pedra Branca Massif and discharge into the Guaratiba Mangrove. It suffers from anthropic influences due to poorly planned occupation, lack of sewage treatment, and dumping of chemical waste of all kinds. The river originates in a UC, the Pedra Branca State Park, and along its course, it receives strong contributions from the APA of the Inhoaíba/Cantagalo and Santa Eugenia Mountain

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Ranges and the APA of the Sepetiba Bay Waterfront, and flows into an important UC, the Guaratiba Biological Reserve. It is of fundamental importance to the environmental health of the region. According to Campos (1996), the Cabuçu River receives groundwater in its most downstream course, that is, in the vicinity of the Serra de Inhoaíba. Due to the lack of water supply for its various uses by the local concessionaire, there is an intense extraction of groundwater through wells, which are predominantly installed on the slopes of the mountains, in the fractured system.

In the area of the Serra de Inhoaíba/Cantagalo and Santa Eugenia APA, a large part of the population does not have a water supply from the public system. They resort to wells, whether of the kalimba or artesian type, to meet their needs. The majority of artesian wells do not have any technical control over their drilling, nor are protective measures established regarding environmental control parameters.

**Portinho River Sub-Basin**

The Portinho River Sub-Basin has a dense drainage network, with rivers and streams that have their headwaters preferentially in the Pedra Branca massif (Pedra Branca State Park Conservation Unit) and/or confluences of rivers, streams, and canals. The Portinho River is 8 km long, and the drainage network is made up of smaller rivers, streams, and canals that can reach 0.9 km.

Like the Cabuçu River, it receives chemical and biological waste of all kinds, with disorderly occupation.

It has intense groundwater exploitation, with capture by wells and springs in the fissure aquifer system and wells in the porous system. It is worth noting that the natural drainage of groundwater is directed to the Mangrove Swamp of the Guaratiba Biological Reserve.

The scenario of installation near sinkholes is frequent and worrying.

Regional potentiometry was performed for the Administrative Region of Guaratiba, generating potentiometric maps (VICENTE; DE CARVALHO; BARBOSA, 2010). The analysis of the maps shows the discharge of the aquifer in the general direction of the mouth of the Portinho (Barra de Guaratiba Region) and Piraquê-Cabuçu (Ilha and Pedra de Guaratiba Regions) rivers. The potentiometry shows a relationship between the underground and surface sources. Characterizing the studied aquifers (fissural and porous) as having an effluent nature in the main river channels. A general tendency of the

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underground flow in the direction of Sepetiba Bay is also observed. 7.1.3 Piracão River Basin

The Piracão River has its sources in the Pedra Branca massif (Pedra Branca State Park Conservation Unit), is 8.5 km long, runs through areas of the Guaratiba lowlands, and flows into a tidal channel, which is important in the water dynamics of the relationship between fresh and saltwater in Sepetiba Bay.

## CONSIDERATIONS

The Guaratiba Aquifer is important for the storage and supply of groundwater for various uses and also has a regulatory function for the water and environmental systems of the region. It should be studied, with a view to preserving both the quantity and quality of groundwater.

Groundwater resources constitute strategic reserves due to their importance for the socioeconomic and sustainable development of the territory and are invisible at first glance. By themselves, they are vulnerable to any type of contamination. Its structure includes porous and fissure systems. Due to their characteristics, porous systems can be regenerated when contaminated. Fissure systems, due to the interconnection between fractures, do not have a pre-established determination of the flow of groundwater. Once contaminated, it is difficult to decontaminate them.

The area is generally occupied by well-preserved forest cover. This fact results in high evapotranspiration, high rainfall, and permanent infiltration. Rock fractures allow infiltrated water to percolate, making this a region with environmental conditions that ensure the recharge of the underground aquifer. The permanence of surface water sources can also be ensured. Irmão (2018) established the geoenvironments classified as important, with the conservation of recharge areas being a determining factor for the water availability of the aquifer. It was possible to observe the significant nature of geoenvironments in the knowledge of the territory and its natural aspects.

## RECOMMENDATIONS

According to studies carried out in the Guaratiba Aquifer and current legislation, we can recommend the following actions:

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1. Government Actions

- Encourage and propose complementary hydrogeological studies of the porous and fissure aquifer systems, to obtain data that will allow the preservation of the quality and quantity of existing water resources.
- The government must adhere to its obligations as a manager, with actions that promote the sustainability of the surrounding UC areas, using water resources appropriately, since there is currently a tendency to not preserve groundwater and surface water, whether in quantity or quality.
- There must be a water supply to the local population by the concessionaire, since without this action in a satisfactory manner there is a need to use groundwater through wells and springs, without any control over collection and consumption. • Guidance and promotion of the installation of septic tanks, since the population often consumes water from wells and springs contaminated by coliforms, due to the proximity of sinkholes.
- A limit should be established for the protection area around where there is groundwater collection, whether by wells or springs. This measure is of a conservationist nature, allowing the preservation and good functioning of the ecosystem with the collection of water free of pollutants.
- Recharge areas should be preserved in lowlands adjacent to elevations. When there is a need for occupation, rainwater infiltration points should be established, avoiding impermeability, the formation of “heat islands” and flooding.
- Areas for groundwater collection should be determined by the government, either through multiple wells or the creation of storage structures such as “basins”. This action is intended to store water for public supply, in the event of a need due to a lack of water resources or to regulate possible excesses, in view of climate change scenarios. This should be done through detailed hydrogeological studies.
- The installation of a meteorological station to collect data of interest for calculating more realistic aquifer recharge for the study area is desirable.
- Collection, transportation, and treatment of sewage.
- Collection of garbage of various forms and origins, giving it different destinations.

2. Educational actions

- Education and knowledge are excellent tools for spreading the importance of preserving Environmental Protection Areas and Conservation Units in general, so

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it is necessary to encourage and guide children on what it means to have a balanced and preserved environment in these places (Barizão, 2013).

- The preservation of groundwater should be encouraged among the local population, both residents and business owners so that future generations can enjoy it.
- Instruct users of wells and springs that collect water from the fissure aquifer system, which is a complex system with often unexpected flow and reserve behavior.
- That groundwater users themselves monitor their use.

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