THE GUARANI AQUIFER IN SANTA CATARINA

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Summary
This is a study on the Guarani Aquifer in the state of Santa Catarina. Groundwater is a very important source both for its economic and social value. Drinking water is an essential natural resource for maintaining life on the planet, but it is becoming scarce due to factors such as irregular rainfall, climatic conditions, combined with population growth and irrational use. Therefore, a bibliographical research was carried out with the aim of deepening knowledge about the Guarani Aquifer System, its location and its use in this State. This study addresses: water as a precious liquid; groundwater and the formation of aquifers and more specifically the Guarani Aquifer, its characteristics, uses and vulnerability and its connection with the Serra Geral Aquifer System in Santa Catarina. The importance of the involvement of the countries that are part of the Guarani Aquifer (Brazil, Paraguay, Argentina and Uruguay) in the search for more effective and controlled ways to use these transboundary waters is also highlighted.

Key words: Groundwater. Guarani Aquifer. Natural resource. Awareness.

Abstract
This is a study about the Guarani Aquifer in the state of Santa Catarina. Groundwater is a very important source both for its economic and social value. It is known that drinking water is an essential natural resource for the maintenance of life on the planet, but that it is becoming scarce due to factors such as irregular rains, climatic conditions, combined with population growth and irrational use. Thus, a bibliographic research is carried out in order to deepen the knowledge about the Guarani Aquifer System, its location and its use in that State. This study addresses: water as a precious liquid; groundwater and aquifer formation and more specifically the Guarani Aquifer its characteristics, uses and vulnerability and its connection with the Serra Geral Aquifer System in Santa Catarina. It also points out the importance of the involvement of the countries that are part of the Guarani Aquifer (Brazil, Paraguay, Argentina and Uruguay) in the search for more effective and controlled ways to use these transboundary waters.

Keywords: Groundwater. Guarani Aquifer. Natural resources. Awareness.

1. Introduction

Much has been heard about the constant scarcity of water and the serious consequences for production and consumption caused by factors such as periods of drought, population growth, combined with pollution and contamination that compromise water supply and its potability. The choice for this theme is due to the constant

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concerns about the need to save water and rethink the use of this liquid that is so important for life on the planet. This study is a bibliographical research, based on authors who dedicated themselves to studying the topic in more depth. Its main objective is to deepen knowledge about the Guarani Aquifer System, its location and its use in the state of Santa Catarina.

Therefore, this study is divided into topics. The first, “Water – a precious liquid” reflects on the importance of water for life on the planet and its distribution. Next, “Groundwater and Aquifers” highlights the formation of aquifers, which can be porous, fissure or karst. In “The Guarani Aquifer” there is a contextualization regarding the formation and location in the countries (Brazil, Paraguay, Argentina and Uruguay). Most of them are located in Brazilian territory. And finally, a study is presented on the presence of the “Guarani Aquifer in Santa Catarina” and its connection with the Serra Geral Aquifer System, which functions as a kind of protection for the Guarani Aquifer System. There is also concern about the constant growth in the use of water from this aquifer as an alternative to the scarcity/lack of water, as well as the need for efficient management to preserve it.

2 Theoretical foundation

2.1 Water – a precious liquid

Currently, issues related to water are on the agenda in the most varied spheres, from classrooms at all levels of education, to conferences and the news. This is because, more and more, the importance of this liquid, so precious and essential to all forms of life on Earth, is being realized. There are many factors that lead to these concerns, as it is known that water is a natural resource that, over time, has had its use expanded and always has a great influence on people's lives. Since the beginning of civilizations, water has had fundamental importance, since the first human beings inhabited places close to rivers to facilitate access to water. Later, it began to be used to irrigate plantations and even as a way to travel from one place to another, transporting people and goods. It is well known that there is a lot of water on the planet, so much so that it is popularly called the “Blue Planet”, covering two thirds of the surface, but its scarcity is being highlighted as a major and worrying problem. Czapski (2011)

points to waste and lack of planning regarding the rational use of water as factors that contribute to this concern.

For a long time, water was considered an infinite natural resource, which man made use of without the slightest concern about its exploitation. However, population growth and deforestation, combined with the misuse of surface water resources, have generated a lot of anguish due to the frequent scarcity of this precious liquid.

Waste occurs from collection, through distribution and mainly in the daily use of the population. Another important issue is the growth of population and urban centers, combined with industrialization and the production of substances responsible for water pollution and contamination.

Especially because drinking water, or even fresh water available in nature, is quite restricted, as 97.61% of the total is ocean water; ice caps and glaciers represent 2.08%, groundwater 0.29%, fresh water from lakes 0.009%, salt water from lakes 0.008%, water mixed in the soil 0.005%, rivers 0.00009% and water vapor in the atmosphere 0.0009%. It is also noteworthy that of these percentages, only 2.4% of the water is fresh, however, only 0.02% is available in lakes and rivers that are responsible for supplying cities and can be consumed. (FREITAS, 2016).

Wisely, Scariotti (2011) states that each continent, each nation and each people needs to assume their responsibility for the rational use of water. Thinking about its protection should be everyone's concern, as well as preventing it from being wasted, polluted or poisoned. Its use must be made with awareness and discernment to avoid shortages, exhaustion or loss of quality.

Second, the National Water Agency (ANA, 2009) in Brazil is the largest freshwater reserve on the planet, around 12% of the world's total. But, as the country is large, distribution and quality are not uniform throughout the territory. In the northern region of the country, where the Amazon is located, there is the largest river basin in the world, but on the other hand it is the least inhabited region, whereas the large capitals and urban centers in other regions of the country are very populated, thus generating a inequality in the distribution of water resources and their use.

2.3 Groundwater and Aquifers

The exploitation of groundwater has become an alternative to scarcity in some regions and the tendency is to increase even further, due to scarcity and contamination.

surface water, groundwater resources began to be explored for consumption and use in various sectors of the economy.

> Groundwater is water that occurs below the Earth's surface and is stored through faults and fissures in compact rocks, playing an important role in maintaining soil moisture and the flow of rivers, lakes and marshes. Groundwater depends on climatological conditions, as it is part of the hydrological cycle. (MARIM, 2006, p. 27).

The use of groundwater is constantly growing not only in Brazil, but throughout the world, as it presents a series of advantages in relation to surface water, among which Feitosa*et. al*. (2008) points out that it does not need to take up space for storage, as the catchment and protection area is much smaller and thus does not imply the expropriation of land areas as is the case with dams; requires no treatment and has better quality; they are not subject to evaporation like surface waters and do not depend on climatic conditions for recharge; wells are built according to need, more quickly and the distribution system can be implemented gradually according to need or increased demand; maintenance is safer, since the replacement of parts or equipment can be carried out without compromising supply; Another very important point is the long useful life when the wells are drilled following technical standards and regulations.

Thus, it is clear that groundwater has many advantages over the use of surface water, particularly in terms of quality, since aquifers are less vulnerable and subject to contamination. In this context, in recent times, we have heard more and more questions regarding the extreme importance of aquifers. The term aquifer refers to

> [...] an underground geological formation capable of storing water and which has sufficient permeability to allow it to move between the pores of the sediments that accumulate it. They are true underground water reservoirs formed by rocks with porous and permeable characteristics that retain rainwater, which infiltrates through the soil, and transmit it, under the action of a hydrostatic pressure differential, so that, little by little, it supplies rivers and artesian wells (BATISTA, 2017, p. 18).

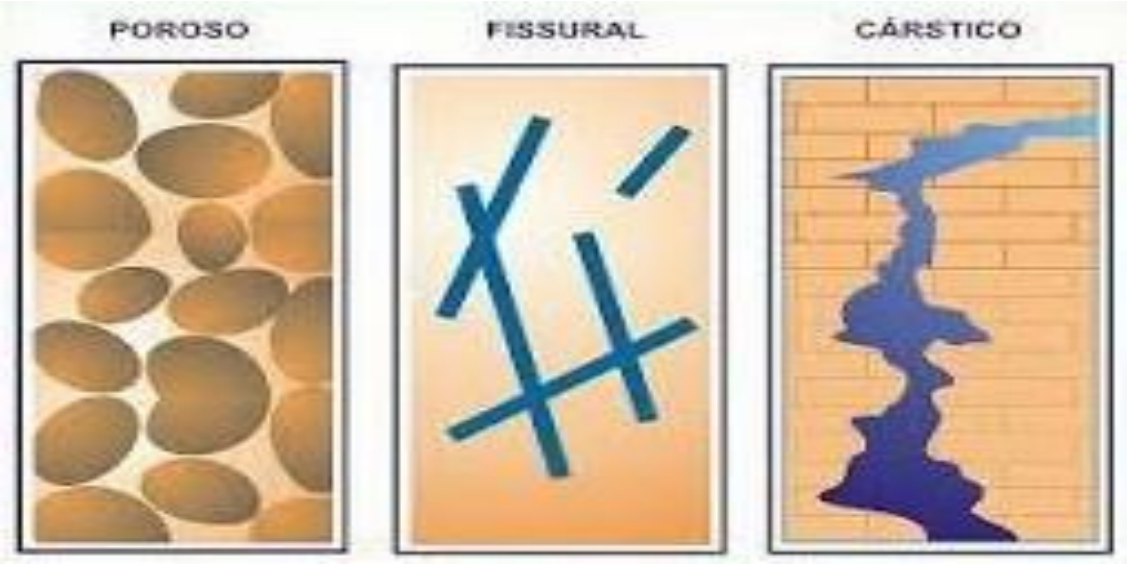
Thus, aquifers are extremely important and considered true underground reservoirs of drinking water, but they are being increasingly exploited. According to Resolution no. 15/2001, from the National Water Resources Council (CNRH) “Aquifer is the hydrogeological body with the capacity to accumulate and transmit water through its pores, fissures or spaces resulting from the dissolution and transport of rocky materials”. (BRASIL, 2001, p. 19). Thus, the quality, quantity and speed of water in an aquifer are related to its geological constitution. According to Borguetti*et.*

al. (2004), lithology arises from its geological origin, which can be fluvial, lacustrine, wind, glacial and alluvial (sedimentary rocks), volcanic (fractured rocks) and metamorphic (limestone rocks), thus determining the different types of aquifers.

Regarding Borghetti porosity*et. al*. (2004), highlights three types of aquifers. These are porous, fissural and karst. The fractured or fissural aquifer is formed by hard and massive igneous, metamorphic or crystalline rocks, and water circulation occurs in fractures, fissures and faults, which opened due to tectonic movement. The water storage capacity depends on the number of fractures that allow infiltration.

The porous or sedimentary aquifer is formed by sedimentary rocks, unconsolidated sediments or sandy soils that facilitate the circulation of water in the pores formed between the grains of sand, silt and clay. These aquifers can store a large volume of water that extends over large areas. It is noteworthy that in this type of aquifer, the porosity is practically homogeneous, which allows water to flow in any direction, with only a difference in hydrostatic pressure, that is, isotropy. (BORGHETTI *et. al*., 2004).

In turn, a karst-type aquifer is made up of limestone or carbonate rocks and water circulation occurs in fractures (diaclases) resulting from the dissolution of carbonate by water. These openings can sometimes reach large dimensions, even forming underground rivers. (BORGHETTI*et. al*., 2004). Figure 1 presents the three types of aquifers mentioned above.



Source: Borghetti*et. al*. (2004).

Aquifers are also classified according to the water pressure on their boundary surfaces and according to their water transmission capacity. Feitosa *et. al*. (2008) highlights that a confined or pressured aquifer is one in which the water pressure at the top is greater than atmospheric pressure.

The free aquifer, also called phreatic or unconfined, is one whose upper limit is a phreatic surface and the pores are only under atmospheric pressure (FEITOSA *et. al*. 2008).

> The suspended aquifer is a special case of free aquifer that can exist temporarily because it is formed on an impermeable or semi-permeable layer, has a limited extension and is located between a regional phreatic zone and the ground level. (FEITOSA *et. al*., 2008).

2.4 The Guarani Aquifer

Although people had been talking about, studying and even using its waters for some time, from the year 1990 onwards the Guarani Aquifer System (SAG) began to be studied more intensely, which began to represent a great expectation, as it is a reserve with a lot of drinking water capacity and potential.

It was named in honor of the indigenous people who inhabited the region where the aquifer is located and it was the Uruguayan geologist Danilo Anton, in 1996, who called it the Guarani Aquifer System or SAG. According to Rebouças and Amore (2002), this aquifer is formed by wind sandstones of Jurassic age from the Botucatu Formations in Brazil, Taquarembó in Argentina and Uruguay, and Misiones in Paraguay. And also from the fluviolacustrine deposits of Triassic age from the Pirambóia/Rosário do Sul formations in Brazil, Buena Vista in Argentina and Uruguay, and Misiones in Paraguay.

The Guarani Aquifer System, according to Foster *et. al*., (2009) is considered a porous and confined aquifer. Its waters are very old, reaching approximately 35,000 years old in its most confined portions and they have a low circulation speed.

Conicelli (2008) highlights that the Guarani Aquifer is extremely relevant for Brazil, as the Guarani Aquifer System (SAG) is the second largest aquifer in Brazil and is among the largest in the world with a total area of approximately 1,195,000 km^2. Of this total, they are located in Brazil (840,000 km^2), in Paraguay (71,700 km^2), in Argentina (225,500 km^2) and in Uruguay (58,500 km^2). The following map shows the

location of the Guarani Aquifer in South America and the eight Brazilian states that have the privilege of having this great wealth in their subsoil.

Source: http://www.megatimes.com.br/2008/04/aquifero-gurani_11.html

Thus, it is clear that the waters of the Guarani Aquifer System are transboundary, that is, they do not belong to a single country. However, as most of its waters are found in Brazilian territory, it is also essential that there is greater concern for its preservation.

The aforementioned map also presents the eight Brazilian states where this aquifer extends: Mato Grosso, Mato Grosso do Sul, Goiás, Minas Gerais, São Paulo, Paraná, Rio Grande do Sul and Santa Catarina. Chang (2001) highlights that these Brazilian states that are part of the aquifer have fertile land, and production is concentrated in agriculture.

In this sense, Borghetti*et. al.* (2004) points out in their studies that Brazil is the country that extracts the most water from the Guarani Aquifer, for various purposes, including public supply, irrigation, thermal tourism, and others. In other countries, it is used for recreational activities and hydrotherapy. According to studies by Arantes, (2008) the natural recharge of the aquifer occurs directly and indirectly. It is considered direct when

It occurs through the infiltration of rainwater in the outcrop areas of the Guarani rocks and indirectly, when there is vertical filtration or drainage in the discontinuities of the rocks, thus favoring descending flows.

2.5 The Guarani Aquifer in Santa Catarina

In Santa Catarina, the Guarani/Serra Geral Integrated Aquifer System (SAIG/SG) covers approximately 185 municipalities. In these regions, Scheibe and Hirata (2008) point out that this is the main water reserve used both to supply the population, as well as for animals, industry and agriculture.

Another important factor to be highlighted is that the watershed in the state of Santa Catarina is the Serra Geral. This works as a kind of protective cover for the Guarani Aquifer.

> In the state of Santa Catarina, its hydrographic network can be subdivided into two large independent drainage systems in the state territory:
> 2.5.1 Vertente do Interior System - drains its waters into the La Plata Basin, covering the southern part of the South American continent.
> 2.5.2 Atlantic Slope System - drains its waters into the Atlantic Ocean. The Serra Geral Aquifer is mainly responsible for the separation of the Systems, known as the water divider of the State. (CORREA, 2014, p. 19).

In the Serra Santa Catarina, the presence of the Guarani Aquifer is visible to the naked eye. According to the G1 report (2013), in the Serra do Corvo Branco region there are stones that provide the necessary conditions to help in the formation of both the Guarani Aquifer and the Serra Geral Aquifer. There is even a place known as Garganta, located on a highway between the municipalities of Urubici and Grão Pará, where there are walls on both sides of the highway. On one side of the wall it is humid because of the East-West slope of the Botucatu sandstone that forms the Guarani Aquifer and on the other side, on the contrary, it is dry, as can be seen in the figure of the Gorge that cuts the mountain in half.

Source: https://prefiroviajar.com.br/brasil/serro-do-rio-do-rastro-urubici-santa-catarina, adapted by the author.

The Serra Geral Aquifer is classified as a fractured and free aquifer (REBOUÇAS, 1976). Since its waters, according to Scheibe and Hirata (2008), represent the main source of groundwater in the west of the state of Santa Catarina. As these waters are more superficial, their exploration is carried out through shallower wells than those in the Guarani Aquifer. If on the one hand this is a facilitating factor, on the other it also makes it more vulnerable to different forms of contamination.

Freitas*et. al*. (2001) adds that the wells that extract water from the Serra Geral Aquifer have an average depth of 117 meters and a maximum depth of 310 meters. And they are located in different spaces, but mainly, there is a large concentration of tube wells in urban areas, mainly residential buildings. Another way of using groundwater from the Serra Geral Aquifer in western Santa Catarina is in thermal water spas, which are waters considered unsuitable for human consumption due to the high concentration of minerals, but excellent for use in spas, such as Águas de Prata in São Carlos, Ilha Redonda in Palmitos, Águas de Chapecó and Quilombo, the waters in these places can reach 38 °C (FREITAS*et. al*., 2001).

> The water temperature tends to gradually increase from the recharge areas towards the basin gutter, depending on the natural geothermal degree, approximately 1°C/35m. Temperature measurements in outcropping areas

> indicate values around 22°C, increasing towards the west of Santa Catarina, where it can exceed 48°C, in confined areas (ZANATTA; COITINHO, 2002, p. 7).

The tubular wells that capture water from the Guarani Oeste Leste Aquifer are much deeper, 360 m 1267 m, and at a temperature that allows such use. The best-known and most important spas are: Balneário de Piratuba and Estância das Águas Quentes, and Termas de São João where water is extracted from the Guarani Aquifer and reaches temperatures of up to 42° C. (FREITAS*et. al.*, 2001).

The thermal waters found in the Upper Uruguay River region are part of the hydraulic interconnection between the fractured aquifer of the Serra Geral Formation and the Guarani Aquifer System. Freitas*et. al.* (2001) that there are two types of abstraction, one by natural sources and the other by gushing tubular wells and water analysis suggests that the two aquifers are hydraulically connected.

Thus, it is important to highlight the need to raise public awareness regarding the rational use of water, as according to studies by Viegas (2005) there is the possibility of contamination of aquifers from soil infiltration caused by irregularly discarded waste, sanitary leaks , industrial waste, among others.

Machado (2013), adds that groundwater is also at risk of contamination due to factors such as abandoned wells, the use of pesticides, sewage and waste from both industries and livestock farming that may end up being infiltrated into the aquifer loading areas.

> The Guarani Aquifer System in its confined portion is protected from surface contamination due to high confinement pressures and the lithologies of volcanic spills. In the outcropping areas, deep water levels reduce their vulnerability, however, the presence of very porous, permeable sandy lithologies and high rainfall indicate that this area must be protected. (MACHADO, 2013, p.80).

Therefore, the importance of a management program for the exploration of the waters of the Guarani Aquifer is also highlighted, as there must be a commitment to the preservation of the aquifers. Even though there is an initiative with international treaties and conventions specifically aimed at transboundary aquifers. Based on international documents, an agreement on the Guarani Aquifer was drawn up and signed.

> The Agreement on the Guarani Aquifer was signed by Argentina, Brazil, Paraguay and Uruguay, on August 2, 2010, but only came into force in 2018, with Paraguay ratifying it. It was prepared after a study that lasted from 2004 to 2009, with the participation of researchers, technicians and representatives of the four

> nationalities. The study, called Environmental Protection and Sustainable Development of the Guarani Aquifer System [...]. (SCHAPPO, 2018, p.16).

Among the main objectives of this agreement are the preservation of the Guarani Aquifer System and guaranteeing the sovereignty of each country over the area covered by the aquifer. (SCHAPPO, 2018).

Therefore, it is necessary for these countries to understand and assume their responsibility for the preservation of these waters, avoiding damage that could occur due to the lack of protection measures, since "The current and future development of the MERCOSUR region depends, in large part, from this immense freshwater reserve, which makes the guarantee of its sustainable exploitation necessary and fundamental". (AMORIM, 2013, p. 615).

In this context, it is considered essential that measures aimed at the rational use of the waters of the Guarani Aquifer System are considered and implemented, with wells planned, following technical standards and monitored periodically to maintain and preserve water quality.

Another essential issue is educational campaigns aimed at raising awareness among the general population, exposing the need to rethink their consumption habits, becoming more aware and responsible for this liquid that is so precious and indispensable to life on the planet.

Final considerations

Water is essential to the life of all living beings and there is a lot of water on planet Earth. However, it is necessary to be clear that only a small portion of all existing water is considered suitable for human consumption.

The scarcity of this important resource has led to more and more knowledge and exploration of groundwater stored in aquifers. The Guarani Aquifer is a huge source of transboundary and underground water, located in four countries in South America (Brazil, Paraguay, Argentina and Uruguay). Most of it is found in Brazilian territory, since eight states in Brazil have this precious water reserve in their subsoil.

In Santa Catarina, the Guarani Aquifer is linked to the Serra Geral Aquifer System, which functions as a kind of protection for it. Thus, the constant lack

of water has led to the drilling of wells, which mostly remove water from the Serra Geral Aquifer System.

These waters are widely used in the western region of the state, mainly for human consumption. In the case of thermal waters, their properties and temperature are unsuitable for consumption, but they have great therapeutic properties, which make the spas very popular in all seasons of the year and demonstrate the connection between the two aquifers.

Efficient management of the waters of the Guarani Aquifer is considered fundamental, considering its preservation and raising awareness among the population regarding the responsible use of this resource so as not to compromise its quality and guarantee access to drinking water for future generations.

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