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Transboundary Aquifers

Challenges and the way forward

Published in 2022 by the United Nations Educational, Scientific and Cultural Organization,
7, place de Fontenoy, 75352 Paris 07 SP, France

ISBN 978-92-3-100563-3

How to cite this document: UNESCO, 2022. Transboundary Aquifers: Challenges and the Way Forward. Sanchez, R. (Ed). Paris, UNESCO.

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Printed by UNESCO

Printed in France

TOPIC 3/Paper 15

Advances in Geological Knowledge in the Transboundary Outcrop Area of the Guarani Aquifer System, Artigas City and Surroundings, Uruguay.

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Abstract

The Guarani Aquifer System (GAS) is one of the most important transboundary aquifers in the world. Its extension includes part of Argentina, Brazil, Paraguay and Uruguay, where it is used both for human consumption and for agricultural and recreational activities. More specifically in Uruguay, it is found in both unconfined and confined form. In Uruguay, the Guarani Aquifer System consist of Mesozoic sandstones represented by the Tacuarembó and Rivera formations. It is found as an unconfined aquifer in two regions of the territory and, in a confined way when covered by Lower Cretaceous basalts of the Arapey Formation.

This contribution focus on the stratigraphic and structural analysis of the Guarani Aquifer System outcrop located in the easternmost part of the department of Artigas, the Artigas microregion, an area within the Cuareim river Basin that involves an international political boundary with Brazil. Here, groundwater is used as a water source for agricultural activities, and largely for human consumption representing in many cases the only source of drinking water in the area.

The outcrop area of the Guarani Aquifer System constitutes an uplifted block that extends from the Artigas microregion towards the Brazilian territory in a NW-oriented regional structure (Cuareim lineament). The block is bounded by normal faults of N-NE direction in the north of the study area while its outcrop extension is controlled by a E-W strike-slip fault zone in the southern area. Uplift processes allowed erosion of the basalt cover exhuming the sandstones of the uppermost levels of the Guarani Aquifer System and generating the so-called "Window of Artigas".

New geological mapping, stratigraphic correlations and structural modeling allowed us to interpret that in some areas sandstones previously mapped as being part of the GAS are in fact intertraps of the Arapey Formation. Thus, the new data restricts and reduces the extension of the outcropping sandstones of the GAS in the Artigas microregion. In summary, the new geological evidence allowed us to define more precisely the location of the outcropping sandstones of the GAS in the Uruguayan side of the Cuareim River Basin and to establish the structural control of local and regional structures in its distribution. This model will result in a better understanding of the Guarani Aquifer System and its dynamics and, therefore, will provide new tools for the sustainable management of the transboundary aquifer in the Artigas-Quarai area.

Keywords: Guaraní Aquifer System, geology, transboundary

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Introduction

The Guaraní Aquifer System (GAS) is a transboundary aquifer shared by four countries: Argentina, Brazil, Paraguay and Uruguay. In Uruguay, the GAS is developed in its north-northwest region, occupying around 40,000 km^2. It is made up of the Tacuarembó and Rivera formations (Jurassic to Early Cretaceous) occurring in different forms; when confined, the aquifer is covered with up to 1000m of basalts and intertraps of the Arapey Formation. Most of the outcropping GAS develops in the north-central region of Uruguay, in the departments of Tacuarembó and Rivera, along an extensive sub-longitudinal strip structure and adjacent to the basalt cover.

Other locations where the GAS crops are the so-called "windows" that are associated with strong NW structural controls exhibited by the basin in the basaltic region. One of these "windows" is located in the area surrounding the city of Artigas, which is the object of this study. Windows are considered vulnerable areas as they behave as unconfined sedimentary aquifers, susceptible to anthropogenic contamination and climatic variations.

The geological features of the GAS in the study area, a transboundary zone supplying freshwater to the local population as well as resources for the agricultural production, make the existing "window" in the surroundings of the city of Artigas a sensitive area. In order to asses groundwater vulnerability to contamination, more detailed about the distribution, geological and structural features as well as hydrogeological characterization of the GAS in the area is needed. Thus, this works attempts to provide detailed geological mapping and a structural model of the Artigas microregion.

Location of the area

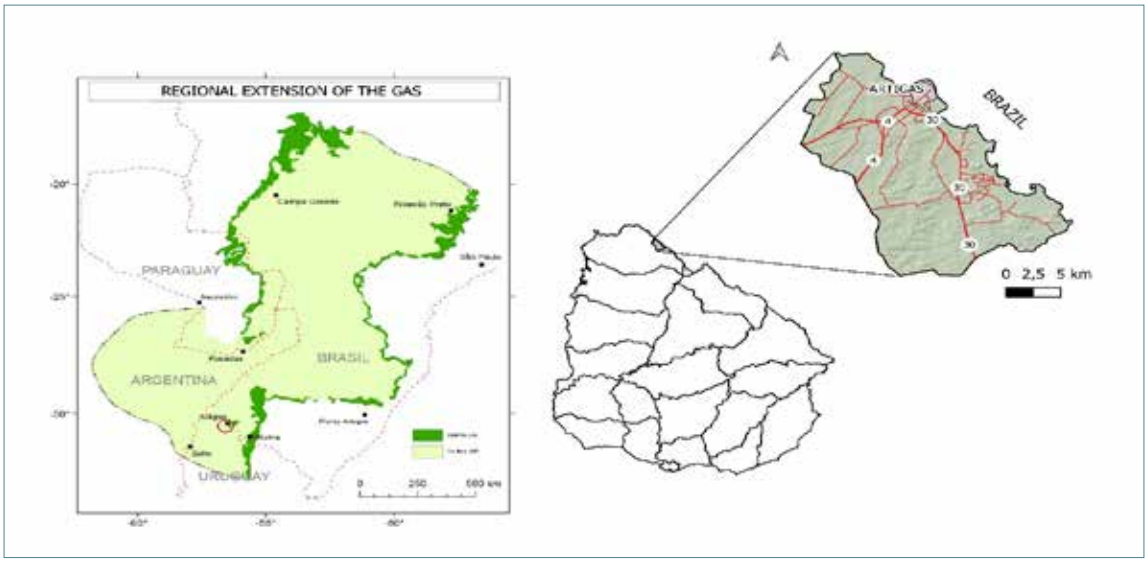
The study area includes the microregion of Artigas, an administrative name defined by the Departmental Administration. It covers an approximate area of 312 km^2 including the Cuareim River as its north-eastern limit, which constitutes the territorial boundary with Brazil (Figure 1). The main city (Artigas) lies along the Cuareim River across from Quaraí city.

The microregion includes vast rural areas, dedicated to agricultural activity particularly associated with tobacco plantation and livestock in a lesser extent.

The GAS and its transboundary aspect in Artigas

The Rivera and Tacuarembó formations (Jurassic-Early Cretaceous), constituents of the GAS, are outcropping in the study area. In Brazil both units correlated with the Botucatú and Guará formations, respectively; however, only the Botucatú formation is found in the Quarai city (Brazil). Thus, the Tacuarembó formation (Uruguay) and its counterpart Botucatú formation (Brazil) are physically separated by the Cuareim river, corroborating the transboundary nature of the aquifer (Figure 2).

Figure 1.
Left: Location of the study area within the extension of the GAS



(modified from Techera et al., 2017). Right: Location of the study area within Uruguay.

Use of groundwater in the area and importance of conservation of quality and quantity

Unconfined aquifers (in this case the outcropping GAS) have greater vulnerability to contamination, being threatened by anthropogenic activities carried out over them. Some activities that can affect the quality of the aquifer are: solid waste disposal, cesspools (in places where there is no sanitation), use of pesticides in agriculture and forestry. Each of these activities generates typical chemical elements, which can be leached and affect the natural quality of groundwater.

In addition to the possible anthropogenic sources of contamination, there is a lack of knowledge of the actual volumes of groundwater extraction, since a large part of the water wells (and their respective flows) are not registered within the government agencies.

The lack of these data makes the management and sustainable use of the aquifer a difficult task.

The area of the outcropping GAS present in the surroundings of the city of Artigas is the object of greater emphasis in this study, as due to its location near the departmental capital there is an intensive use of the land, which generates an extra pressure from the point of view of the water quality (due to its exposure to potential sources of contamination) and quantity of the water (due to the increasing demand). The lack of sanitation in rural areas is a negative point to consider when studying the vulnerabilities of the area.

Groundwater is an essential resource for human and productive supply in the study area. In the city of Artigas, groundwater resources make up 50% of the total volume of water used for public supply, while this percentage increases in the surrounding rural areas where, apart from domestic use, groundwater is used for agricultural production.

Figure 2.
Left: Outcrop on route number 293 located SE of the city of Quaraí (Brazil). Right: Outcrop on a local road south of the city of Artigas (Uruguay)

(© Own Elaboration)

Methodology

The cartographic study was carried out using aerial photos from the Military Geographic Service of Uruguay, and the Digital Terrain Model and images from the Spatial Data Infrastructure of Uruguay (IDEuy). Over 300 water wells were analyzed to check the stratigraphic distribution of the GAS, and the overlying and underlying units in subsurface. Field work was performed to analyze the stratigraphic and structural features of the area and add control points to the subsurface correlation. Geophysical data was also included to control the extent of the GAS in subsurface.

Results and discussion of updated geological mapping

The study area comprises a sector of the Paraná Basin, and three lithostratigraphic units are present which, from base to top, are: the Juro-Cretaceous sandstones that make up the Tacuarembó and Rivera formations and the Early Cretaceous basalts of the Arapey Formation. These basalts are found surrounding the so-called sandstone windows.

In the Tacuarembó Formation (Upper Jurassic-Lower Cretaceous) fine to very fine sandstones predominate, white to whitish, with sub-horizontal to horizontal stratification, with occasional intercalations of pelitic levels. Its fossil content was extensively described by Perea et al. (2009). This unit is interpreted as a succession of fluvial and wind deposits, forming extensive shallow sandy plains associated with ephemeral and/or permanent channels (Bochi de Amarante, 2017).

The Rivera Formation is assigned to the Lower Cretaceous and is made up of medium-fine sandstones, orange to brown in color, showing high-angle cross-stratification and medium grain-size. The sandstone presents a good selection, with a quartz-feldspathic composition and a moderate presence of lithic clasts. It is interpreted as aeolian dune deposits. In the window, the average thickness of the sandstones is 60 m, which coincides with the

average depth of the wells in the area, so the thickness can be even greater.

On the other hand, the Arapey Formation is composed of basalts that rest on the sandstones of the Rivera and Tacuarembó formations (Figure 2). The basalts in the study area are generally massive, with different degrees of alteration and colorations ranging from dark gray to reddish. In most cases, in the area of the window they occasionally appear forming small hills, which facilitates their identification.

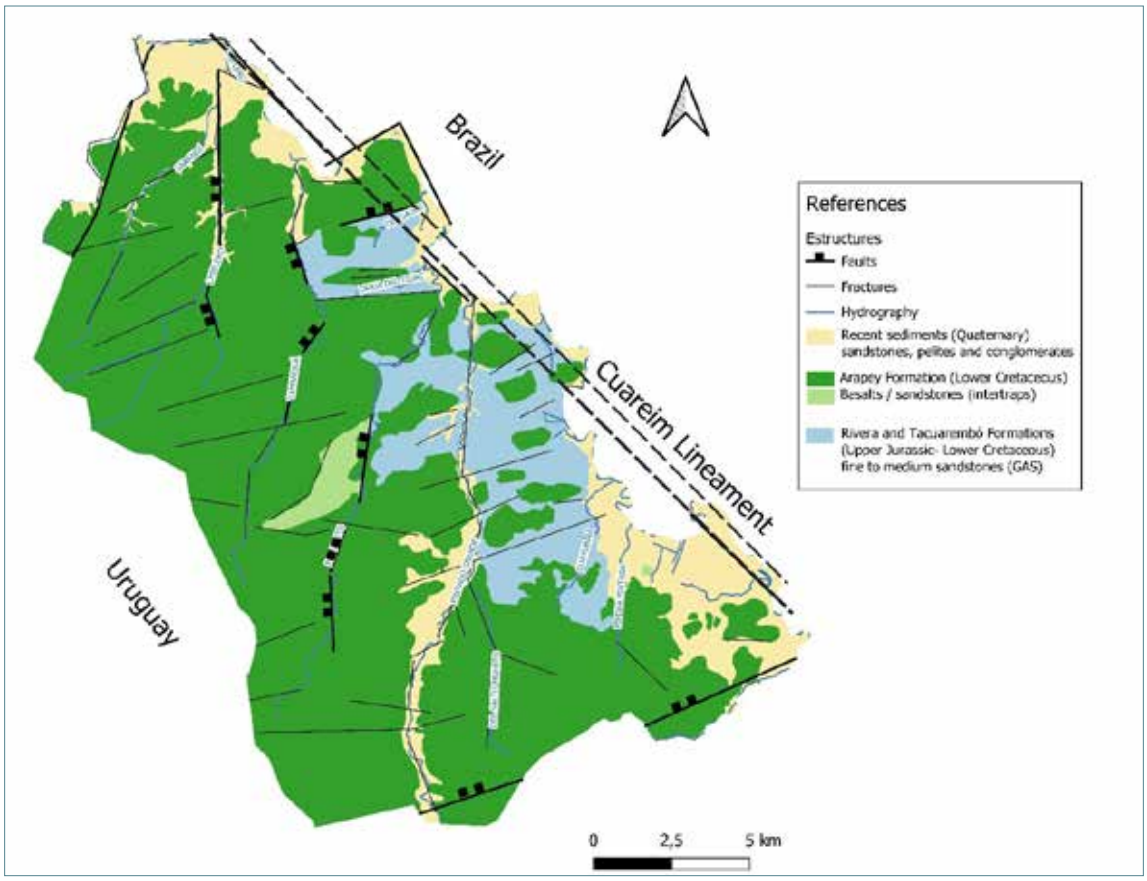
Geophysical surveys carried out in the area allow us to know that the basalts have a thickness of more than 200 m to the east of the microregion (Ramos et al., 2015).

One particular feature of these basalts is that they have sandstone inter-traps that can often be confused with the units belonging to the GAS.

As a result of the geological mapping, the inter-trap sandstones were separated from the GAS units and the main structural features were defined (Figure 3).

Local morpho-structural lineaments control the relief and drainage being several of these features normal faults that compartmentalize the GAS.

Figure 3.
Geological map of the Artigas microregion



(© Open Street Maps, Own Elaboration)

The detailed geological mapping allows us to define that only the outcropping sandstones found in the Central-East sector of the microregion, nearby the Cuareim river boundary

are part of the GAS. The rest of the sandstones present in the region correspond to inter-traps and, therefore, are part of the Arapey Formation (light green).

From the analysis of the morpho-structural features, supported by the field and subsurface surveys, two large families of structures with NE and NS orientation have been defined that are associated with regional structural features recognized in the basin. These directions, associated with the NW direction of the Cuareim Lineament, controlled the vertical to subvertical faults that compartmentalized the area and allowed the lifting of a block that controls the development of the GAS window.

These vertical faults, with dislocations that would reach almost 200 m of rejection, are documented in boreholes and magnetotelluric soundings. (Ramos et al., 2015).

Acknowledgments

The authors thank the ANII FMV Project _1_2019_1_155736 and the L.S. postgraduate scholarship. Likewise, the support of PEDECIBA Geociencias is appreciated.

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