

# The Guarani Aquifer System (Gas) and the Challenges for Its Management\*

Maria Luísa Telarolli de Almeida Leite<sup>#</sup>, Wagner Costa Ribeiro

Department of Geography, University of São Paulo, São Paulo, Brasil

Email: <sup>#</sup>mltaleite@usp.br, wribeiro@usp.br

**How to cite this paper:** Leite, M.L.T. de A. and Ribeiro, W.C. (2018) The Guarani Aquifer System (Gas) and the Challenges for Its Management. *Journal of Water Resource and Protection*, 10, 1222-1241.  
<https://doi.org/10.4236/jwarp.2018.1012073>

**Received:** October 31, 2018

**Accepted:** December 26, 2018

**Published:** December 29, 2018

Copyright © 2018 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

## Abstract

It is a huge reserve in South America region and it is considered one of the largest sources of groundwater on the planet. The GAS has strategic value for its countries, especially in a context of increasing scarcity. Its size, its physical and political complexity, as well as its “invisibility” and insufficient treatment in the international scenario, constitute some of the challenging elements for management. The article will, in the first instance, summarize the management cases for transboundary aquifers in the world. Subsequently, a physical and political characterization of the GAS will be made, so that, finally, the existing challenges for the management of this resource will be presented. In order to carry out this work, a bibliographical review of the articles and documents published in recent years concerning the management of transboundary aquifers in the world was carried out, as was done with respect to the Guarani Aquifer and its international framework.

## Keywords

Guarani Aquifer System, Transboundary Aquifers, Management

## 1. Introduction

Through the last years the important role of aquifers in the world has become more evident, especially the transboundary ones. Recently 592 transboundary aquifers were identified, from which 226 are transboundary subterranean hydrous bodies, according to the definition from Internationally Shared Aquifer Resources Management [1]. The American continent holds 79 transboundary aquifers and among them 29 are in South America; Brazil, in turn, shares 11 cross-border aquifers [2].

\*This article was only possible with the funding of Conselho Nacional de Desenvolvimento Científico e Tecnológico process number 310631/2014-9.

The groundwaters constitute the biggest fresh water reservoir in the world and represent more than 97% of all the fresh water available in the planet (except for the glaciers and polar ice caps). The left 3% are above all constituted by superficial waters (lakes, rivers and swamps) and by the humidity above the soil surface. The use of this resource is growing and, according to the Food and Agriculture Organization of the United Nations [3], the aquifers represent 25% from the total of the water used in Asia [4].

Continuously water resources present challenges for its access and shared use. A growing demand, based on diverse economic activities, pressures the retreat of water from superficial water bodies and also groundwater.

This situation can cause tension and management difficulties, mainly regarding an aquifer lying along two or more countries. In these situations many difficulties to guarantee its use and replenishment can occur, as well as to allow its adequate management, in order to respect the social demands. In the third section six challenges will be pointed regarding the management of GAS and they are: the need to continue the studies and common projects related to GAS; the absence on the international scene of new legal mechanisms that are the basis for the management of transboundary groundwater; the need for specific management instruments in the Guarani Aquifer Agreement for the management of GAS; the slowness in the process of bringing into force the Agreement of GAS; the institutional structure necessary to the implementation of Guarani Aquifer Agreement and its integrated management and the legislations for Guarani Aquifer Agreement and the risk of privatization of water resources.

This article questions this difficulty dealing with Guarani Aquifer System (GAS), lying in South America. To do so, it used documental and bibliographic research. Before presenting the SAG case, it is necessary to evaluate how this theme was brought up in other transboundary aquifers. Therefore in the first item some management cases of transboundary aquifers around the world are presented. After that, GAS is characterized in physical and political terms, so that finally the difficulties for its management are discussed.

## **2. Discussion**

### **2.1. The Management of Transboundary Aquifers in the World**

With the increasing search for water, groundwater has been more used, which led to the need of discussing cross-border aquifer management, more specifically the ones lying along more than one country. Consequently the management of these aquifers is a recent phenomenon in the international scenario. This theme has been approached especially by the International Hydrology Programme (IHP) of United Nations Educational, Scientific and Cultural Organization (UNESCO) by the International Law Commission from United Nations (ILC); in international scientific organizations like International Law Association (ILA) and International Association of Hydrogeologists (IAH), as well as in technique bodies such as International Groundwater Resources Assessment Centre (IGRAC)

and Internationally Shared Aquifer Resources Management (ISARM) [5] [6]. However, the civil society and the stakeholders still have little knowledge about these waters [7] and we can add to this scenario the fact that there is only one international legal base document for transboundary groundwater what makes its governance and management a major challenge, despite of the increasing number of organizations, agencies and international institutes that deal with this issue.

Recently the Transboundary Water Assessment Programme (TWAP) was created, a project financed by Global Environmental Facility (GEF), aiming to lead the first global evaluation of transboundary water systems base. The evaluation was thought as of five components, the cross-border watersheds, transboundary lakes, the great marine ecosystems, ocean and transboundary aquifers and groundwater systems. The last component had IGRAC as partner, who organized regional meetings and is developing an Information Management System for TWAP, holding all the data collected from groundwater [8].

The International Law Association (ILA) formulated the Helsinki Rules about the use of international rivers in 1966, which proclaimed the principle of equal water resource using and hydric management in watersheds, base topics to the ILC. The groundwaters became fulcrum in the international law scenario in 1986, when ILA formulated the Seoul Rules, through which it was determined that the transboundary aquifers are object of protection, even when not connected to the superficial waters, nonetheless not having binding nature. The groundwater have been and approached theme since Mar del Plata Conference, Rio-92, Dublin Conference, and other important environmental and hydric marks, but in an overly wide way.

In 1999, the International Association of Hydrogeologists (IAH) formed an investigation commission that longed for the identification of international initiatives to shared management of transboundary aquifers. This meeting of specialists happened in parallel to the International Conference of Regional Aquifer Systems in Barren Zones Managing Non-renewable Resources, organized by UNESCO. The result of the consultation indicated the necessity to create an international network connected to IAH, the UNESCO, Food and Agriculture Organization of the United Nations (FAO) and United Nations Economic Commission for Europe (UNECE). With UNESCO and IAH's support in cooperation with FAO and UNECE, a specialists meeting took place at UNESCO, which resulted in an international initiative proposal of transboundary aquifers program, the ISARM, and along with the GEF support and the World Bank, encouraged a series of projects about these resources, such as the Guarani Aquifer [2] [9]. ISARM is the major program for groundwater mapping and studies.

It was after the Convention about Law Related to the Using of International Non-Navigation Watercourse, from 1997, that the groundwaters became officially object of the international law, but in a very wide way and restricted to

certain kinds of aquifers, not extended to all, because it only considered aquifers linked to superficial hydric bodies and excluded those that are confined or in a condition that does not allow replenishment (such as part of Guarani Aquifer and Arenito Nbia); and the aquifers with exclusive refill from the rain [6] [10] [11].

The limitation to treat these waters in their particularities led to a certain difficulty among the countries of applicability and management. This blank in treating in a more accurate way the transboundary aquifers was decisive to the initiative of research and creation of a legal mark to this theme ILC's scope [11]. This way, it was adopted by the United Nations General Meeting, in 2008, the Resolution 63/124 about International Law for Transboundary Aquifers from ILC, which was base to the Guarani Aquifer Agreement. The articles from ILC are the first to regulate the underground fresh waters [10]. Their principles, very similar to the ones in the 1997 Convention, are of equal and rational use of this resource, of not causing significant damage, of cooperation and of sovereignty. Despite being an important progress to aquifers in the international scenario, its principles are overly wide and little accurate [10], something that can also be transposed to the Guarani Aquifer Agreement.

The aquifers look like superficial waters in a few aspects, which can lead to the application of certain common principles, but there are other specific points that demand specific guidelines. The aquifers, when infected or polluted, are not only hardly accessed, but also their damage repair is of high cost. Furthermore, as in parts of their system the waste drainage is slower, it couldn't be adopted, as happened, the principle of avoiding significant damages, since there is the necessity to explain in a more explicit way what is significant damage, as well as consider the damage impact to the superficial body linked to this aquifer, its loading and unloading zones and other factors [10].

However, the reports made by the commission created to formulate the mark for cross-border aquifers showed that the concept of significant did not need accuracy, once the term is flexible and relative and national authorities should strive to control and avoid the damage [11]. Therefore, in this structure, the concern with the legal and political issue is noticeable, especially with the sovereignty, one of the principles in this mark.

There are few agreements for this theme [12], which has been approached through regional and international agreements as a way to deepen its treatment and guarantee that the governance and management of resources fit themselves to the global molds current to the theme [5] [6]. The formal and informal arrangements have been models to the dealing of the issue [13].

The first formal arrangement to institutionalize and instrument the governance of shared aquifers is the Protection, Using, Replenishment and Monitoring Convention of Geneva Aquifer, or the Geneva Conference, originated in 1978 e revised in 2008. In its first version in 1978, the Convention covered important initiatives, such as the creation of an exploration committee based on articles about its composition, mission and performance. The Convention emphasized

the following topics: annual aquifers management program, installation of underground waters replenishment, establishment of water rights, water cost, which has seemed to be a commitment to the management and monitoring of Geneva Aquifer since the beginning. A fact that helped the development of this regulatory mark was the commitment to surpass the State sovereignty to make the common use of the transboundary system possible [14].

This arrangement refers to quality, quantity and replenishment of underground waters and was created by the Geneva Aquifer Management Commission, in partnership with France and Switzerland. All that is produced by the Commission is highly considered, despite being an advisory organization, and there is a balance between the State sovereignty and responsibility in its governance scheme, emphasizing cooperation and openness. The international document avoided creating a political and legal apparatus that could motivate attitudes related to State or the waters sovereignty [13] [14] [15], adopting the local and non-national level to the solution of issues related to management. Therefore it is considered a pioneer benchmark to the theme.

One aspect of Geneva Convention that must be highlighted is the role of the European Union's decisive institutionality to the hydric theme, because in 2008, when the document referring to the Geneva Aquifer was renewed, the base to its governance and management was the Board Guideline of European Union's Water, from 2000, which received, in 2006, guidelines to groundwater.

The guidelines are incorporated by countries from the European Union, such as France, which is part of the Geneva Convention, and Switzerland, which, even not being a member of the European integration block, has also started to follow this standardized treatment to hydric resources, a recurrent discussion theme and reason for forums carried out every year by the European parliament, which aims the formation of a common European policy to water [14] [16]. The Guideline from 2000 aimed to base itself on three pillars, the economy, the environmental and ethical perspective, here thought as civil participation and information openness [17].

Concerning Asia, the aquifers represent 25% of the water used in the continent. The amount of extraction of underground water in Asia represents the majority, around 72%, of the global use number, caused by intensive agricultural activity and explosive population growth in the region [3]. Despite the intensive use of these resources, they still need greater attention from the government and the scientific community, and also, due to the complexity of these waters, the legal administrative frameworks are little significant [4].

After 2000, through ISARM, there was a gradual progress in management and knowledge about Asian transboundary aquifers. IGRAC identified, in 2015, 129 transboundary aquifers, but these reserves are dealt with through bilateral agreements, especially in China and Mongolia. The hydric theme has been focus of attention and agreements between the Chinese and their neighbors, but the groundwater has been little discussed. The lack of legal and institutional

instruments is a representation not only of the few global mechanisms for the theme, but also of the few policies for water in the region [4] [18]. According to Lee *et al.* (2018) [4] and He (2017) [18], the current climate changes, plus the intensive exploitation by underground waters irrigation demand from Asia a cooperative board emphasizing efficient governance and management mechanisms.

Africa's case is not different from Asia's, because there are 72 mapped aquifers in Africa, from which only 11 have gone further in terms of study since 2000, despite the acknowledgment of the important role of groundwater. The cooperation was formalized in 7 cases, most of them in the north of Africa and Sahara. The continent general statement is of low availability of data in the national level, which complicates the regional evaluation and highlights the need of further research. There are prevailing agreements for African rivers and lakes, but there is inconsistency of data among the signatory countries, which suggests limited implementation [19].

Both in cases of Africa and Asia it can be noted a bigger generation of data and knowledge as of studies by ISARM in these continents, as well as TWAP has also been important in the information systematization and mapping of Asian and African aquifers, which boosted the cooperation with the issue. In 2002 the African Ministers Council for Water is created to support the actions related to the theme. ISARM made an inventory of 38, from which IGRAC produced a map of 20 in 2005.

The International Atomic Energy Agency (IAEA), in cooperation with UNESCO, GEF and United Nations Program for Development (UNPD) has supported the aquifer investigation in North Africa. The case of Arenito Núbria Aquifer System is known as one of the biggest aquifers in the world and is an experience that moved forward in the region. The aquifer embraces around 2,500,000 km<sup>2</sup> from Egypt, Libyan, Chad and Sudan. The exploitation of this huge reserve of freshwater increased in the last forty years, with great exploitation by Egypt and Libyan to irrigation and public water supply. The countries that own this aquifer have cooperated since 1992. In 2013 they established the Regional Action Program to an integrated management of this cross-border aquifer financed by GEF and implemented by UNDP, IAEA and IHP-UNESCO. Besides the integrated management, the project promotes regional Strategic Action Plan (SAP), which later will be turned into actions to a sustainable management of the aquifer, besides creating a greater data and knowledge base to this reserve [19] [20].

Some topics for the subject in Africa must be highlighted as to evince the challenges to be fought, among them the need to improve the management, including the shared monitoring; standardization of information of the aquifers among the countries borders; information blanks; lack of active monitoring systems or archives of monitoring with historical series; major disabilities in the monitoring of shared aquifers shared in Central Africa states, given the low institutional capacity and low importance assigned to groundwater resources

and the least attention from the donators [19].

Finally, in the American continent, the initiative ISARM-Americas identified 73 transboundary aquifers systems, 4 in the Caribbean, 18 in Central America, 21 in North America and 29 in South America [9]. Regional organizations, such as the American States Organization (OAS), get progressively involved with the hydric themes and their projects. Like the other continents, ISARM has also influenced projects for transboundary aquifers.

There are 7 cases of potential studies, from which 3 are located in South America: Yrenda-Toba-Tarijeño Aquifer, Pantanal Aquifer and Zarumilla. Besides the project started in 2003 for Guarani Aquifer, which is base of this work, the other projects for shared aquifers are Artibonito/Massacre, shared by Dominican Republic and Haiti; Hueco del Bolsón, between Mexico and the United States; Ostua-Metapan between El Salvador and Guatemala and Real-Rio Negro Honduras-Nicaragua [21].

According to Forti (2013) [22], South America holds 28.9% of the world hydric resources (freshwater), with a natural annual renewal of more than 20,000 m<sup>3</sup> per capita. Furthermore, the region holds 25 transboundary watersheds, among them Prata Watershed and Amazonas Watershed. However, the initiatives for mapping, protection and cooperation are still scarce. The shared resources usually demand the cession of the sovereignty on behalf of a shared management, which is not always seen in a positive way by sovereign countries such as the South Americans.

Despite this scenario, Guarani Aquifer is a benchmark to the South American region, since it was the first to count on the international agreement to regulate its protection, sustainability and to promote cooperation to a shared management among its holders, besides being an initiative that was not originated in any previous conflict, but in preventive diplomacy [23] [24]. This was the first agreed document based on the Resolution 63/124 about International Law for Transboundary Aquifer.

It is important to notice that the international conferences for water resources, the organizations and the agencies, especially that ones linked to United Nations, like FAO, UNESCO, UNECE, UNPD, they all play central role in the studies and initiatives for groundwater common projects. The groundwater is an issue of increasing international importance and this can be demonstrated by the growing number of international and regional instances dealing with this subject as well as the large number of projects for it on the continents of the globe. However, these advances have not yet been translated into effective instruments for proper management of transboundary groundwater, including the projects supported by GEF.

There are various formal and informal arrangements, as well as action plans being developed. The cooperation in the case of groundwater is mandatory. The gap of data and knowledge in both national and regional level around the world is a big problem for a proper evaluation and highlights the need of further

research. There are prevailing agreements for rivers and lakes, but there is inconsistency of data and instruments for groundwater management. The Geneva Convention is the most advanced case in this area, which still prevails in informal arrangements. It is possible that the case of Geneva is more advanced, because it has as an apparatus on which it is based that is the European Union's directives for the theme.

In cases of Africa and Asia it can be noted a bigger generation of data and knowledge as of studies by ISARM in these continents, as well as TWAP has also been important in the information systematization and mapping of Asian and African aquifers, which boosted the cooperation with the issue, but there is still a long way to go to achieve a successful international management for transboundary aquifers.

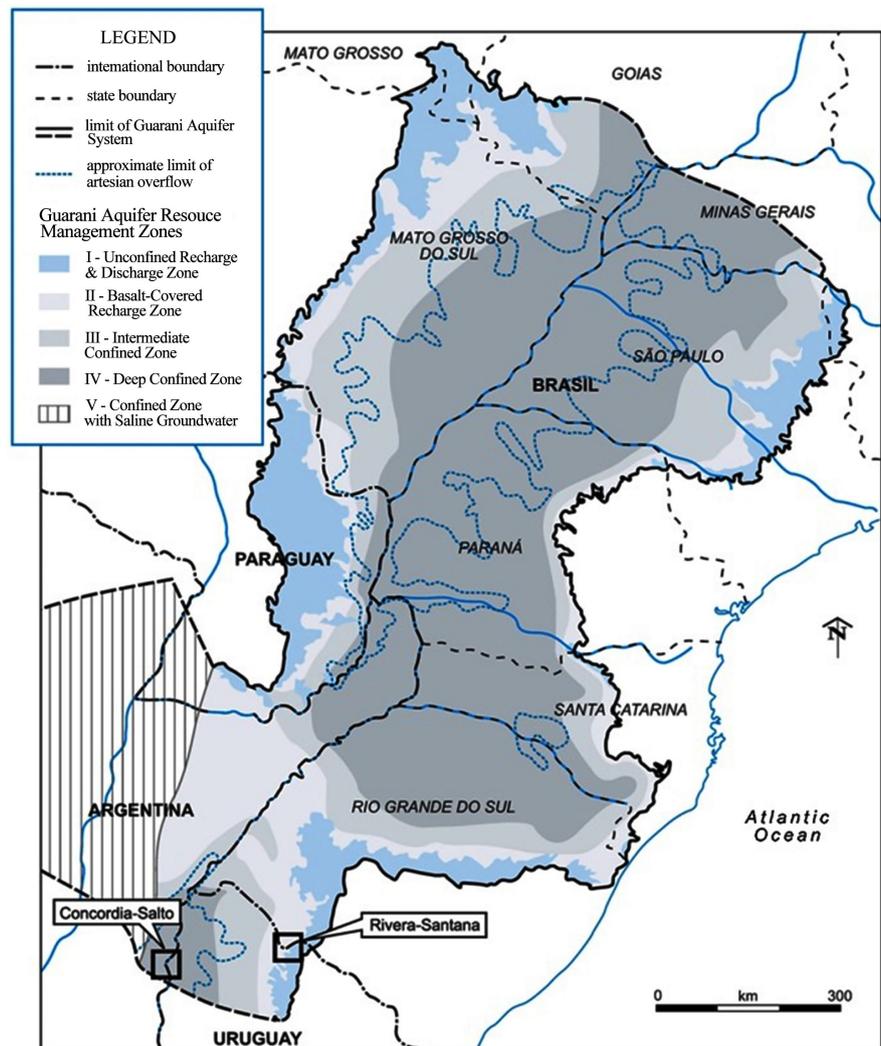
## **2.2. The System of Guarani Aquifer (GAS)—Physical and Political Characterization**

### **2.2.1. Physical Characterization**

Guarani Aquifer emerged as a unifying nomenclature of the formations Parambóia/Botucatu, in Brazil; Misiones, in Paraguay; Tacuarembó, in Argentina and Buena Vista/Tacuarembó, in Paraguay. It is a porous aquifer, confined in 90% of its area, with sandstones from the Mesozoic Era of wind and fluvial-wind deposits from Pirambóia and Botucatu formation. Guarani Aquifer is overlaid by the basaltic tholeiitic spillage from Serra Geral formation, some areas by the sediments that constitute the group Bauru Caiuá. The three-phase layer are in the basis of Pirambóia, Rosário do Sul and Buena Vista. About the Jurassic layers, they are in the aquifer summit, in Misiones, Tacuarembó and Botucatu [25].

The total area of this aquifer is 1.087.879 km<sup>2</sup>, which are distributed among Argentina (225.500 km<sup>2</sup>); Brazil (735.918 km<sup>2</sup>); Paraguay (71.700 km<sup>2</sup>) and Uruguay (45.000 km<sup>2</sup>); once constituted as a reserve of expressive numbers in a context of growing hydric crisis, it is a strategic aquifer to the region. Its waters lie over a major part of Brazilian territory, which holds 61.65% of it among eight states from the southeast, center and south of the country. Brazil is also the main user of hydric resources from Guarani, consuming 93.6% of the total amount extracted, 1.04 km<sup>3</sup>/year, with emphasis on São Paulo state, which is responsible for 80% of this use [24] [26] (**Figure 1**).

The groundwater exploitation in São Paulo State, in Brazil, has been intense and an increase is foreseen for the next years, due to the expansion of the economic activity and to the impairment of superficial waters by the pollution. In average 80% of the cities use totally or partially underground water for their public supply, and especially the industrial use and the irrigation contribute to the lowering of the groundwater levels. In 2007 a document was created, called Programed Action of Groundwater in São Paulo State, which updates and completes the Programed Action, summing up what was accomplished between



**Figure 1.** Guarani aquifer system [33].

2007 and 2015, describing the advances reached during this period and proposing projects and actions considered priority to the period between 2017-2020 and covers governmental sectors, universities and others [27].

The document brought a report of Groundwater Map in São Paulo State (2005) and showed that the exploitable reserves of groundwater are bigger than the current demand, around 12%, but clarified the strategic importance of aquifers in most management units. It also showed that the resource is mostly dented in the Units of Integrate Water Resources Management from Turvo Grande (52%), Pardo (44%) and Alto Tietê (41%) [27].

The contamination is source of concerns because, according to CETESB, the list of polluted areas shows that in November 2006 there were 1822 confirmed cases of contamination, in a total of tens of thousands potential contamination sources. By the end of 2015, the total of polluted areas was 5376 (CETESB, 2016), 680 of them were restored to declared use and 1307 areas were in monitoring process to closure [27].

The areas of unloading zones of GAS match its limits [26] and are composed by the sandstones outcrop. It must be remembered that the zones of recharge are more sensitive to contamination. On the other hand, the major part of Guarani Aquifer, which is confined, is result of meteoric water infiltration, from the outcrop regions. It is estimated that the bigger the outcrop, the bigger the water mineralization.

The Aquifer is almost completely in the confinement condition, which gives it the artesian condition, which means that through the internal pressure, the water easily gets to the surface, however, the water circulation speed in the Aquifer is low. The reservoir of Guarani Aquifer is heterogenous, with part of its waters permeable/available, but great part of them is semipermeable and impermeable in other areas.

GAS extends for a wide area, however that does not indicate that its hydric availability is unlimited, on the contrary, this reserve holds zones of limited recharges and therefore its waters are ancient, which concerns impermeability, which becomes high and taking this context into account "(...) more geological years are necessary to refill the water in its rocky formations" [28]. The water along GAS is not entirely proper to be consumed; as exemplified by Santos (2015) [28], the Thermal Corridor of Uruguay River presents high quantity of arsenic, being the water in this region used for recreational purposes.

The Guarani Aquifer System, for being reserve of huge proportions, is heterogenous, as said before. A possible example of this situation is the Formation of Serra Geral, because from the total GAS area, around 12.8% is represented by outcrop zones, 67.8% is in Brazil, close to 1,000,000 km<sup>2</sup> are above volcanic rocks of Serra Geral Formation, which can be seen as an aquifer of fracture kind. There are big flaws connecting this great formation to the Guarani Aquifer, so this connection led to the proposal of integrated management superficial and groundwater called "Integrated Aquifer System Guarani/Serra Geral" [29].

GASP allowed the knowledge deepening about this reserve that is considered one of the most important reservoirs of underground water in the planet. Within these studies it is important to highlight the variety of the research range, being one of them the studies about hydric resources within the rocks of Formation of Serra Geral, "whose diverse hydric-geologic characteristics represent a huge challenge to its proper evaluation and understanding" [29]. It is frequent to find the expression "Serra Geral Aquifer System" result of the hydraulic connectivity between this system and Guarani Aquifer System, more evident and concrete every day, mainly in the states of Santa Catarina, Paraná and Rio Grande do Sul.

The System Serra Geral and Guarani Aquifer can be separately studied, but a study about the inter-relation is necessary, seeing it as a management unit along with superficial hydric resources of each watershed, especially in the above referred areas, where these relations are more and more evident, as the demand of hydric resources increases, due to the productive processes, to diverse periods

of drought that have devastated in the last years and also to the amount of existing pollutants [29].

For this purpose, according to Scheibe and Hirata (2008) [29], between 2005 and 2006 a research project was elaborated, “Guarani/Serra Geral Network”, as a request from National Waters Agency, with Hydric Resources Fund from CTHidro and implemented by the National Council of Scientific and Technologic Development, with participation from universities and institutes from Santa Catarina, Rio Grande do Sul and Paraná. Wolkmer *et al.* (2013, p. 54) [30] “point the necessity to observe the diverse scale of coverage of the juridical mark”. Not only Guarani Aquifer System, but also Integrated Aquifer System Guarani/Serra Geral are in the four founder countries of Mercosul and eight Brazilian states, consequently they must be covered from local and cross-national scale.

### **2.2.2. Political Characterization**

Guarani Aquifer System was target of diverse researches through the 90s by the epistemic community that was formed around the question. None the less, it was only by the end of this decade that the theme got to attract the interest of the government and international organizations, being though as a project for this reserve. In 2003 the project Environmental Protection and Sustainable Integrated Management is launched (also known as Guarani Aquifer System Project (GASP)), which was established by four countries and counted on the support of many organizations [24].

The World Bank financed GEF and OAS was the executive agency of the project, which counted on a General Office in Uruguay, and each country established its National Unit of Project Execution, apart from a State Unit of Execution in each one of the eight Brazilian states that hold GAS. Moreover, offices were set in the following pilot areas: Concórdia (Argentina)/Salto (Uruguay); Rivera (Uruguay)/Santana do Livramento (Brazil); Itapúa (Paraguay); Ribeirão Preto (Brazil). Besides the creation of Support Committees to the Local Projects, composed by members of public authorities, academicians, civil society and users [6]. GASP opened a productive phase to management of groundwater in the region, which covered technical and scientific sectors, apart from diverse academic and institutional studies [31].

Among the aims of this project, the promotion of integrated management, protection and sustainability of GAS, the elaboration of an institutional mark thought in order to direct the management among the four countries that share the reserve [26]. For this purpose, Common South Market (Mercosur) was initially thought as instance to the elaboration of an agreement project and, in 2004, the Group Ad Hoc of High Level of Guarani Aquifer was created and counted on the support from the instances engaged with the environment in the block, to help the countries’ representants in the formation of this mark.

However, the group came to an end in 2005, after creating five versions to the Agreement, because there was no consensus among the countries about its text.

After almost five years of paralysis, the group was reestablished in 2010, so that on August 2nd, 2010, Brazil, Argentina, Paraguay and Uruguay would sign the Guarani Aquifer Agreement [28] [32]. This agreement established the creation of a Joined Commission that will coordinate the cooperation process among the countries and “Despite the hydric flow of the aquifer being shared only in border zones, the endorsement of this agreement would be very important” [23].

The Guarani Aquifer Agreement was endorsed in 2012, by Argentina and Uruguay, with promulgation of Lay number 26.780/2012 and Law number 18.913/2012. Brazil took part in the endorsement in 2017, through Legislative Decree number 52/2017 and, recently, it was Paraguay’s turn to endorse, through Law number 6037/2018. Paraguay is the official custodian of the Agreement but has not taken part in it yet. According to the international document for Guarani Aquifer, in its article 21, within the period of one month of its custody, the Agreement would come into effect [33].

The operationalization of the Agreement demands the deepening of cooperation among the countries, which, when endorse it, should establish terms of the proposed joined commission and define the system of controversies solution for this international document. In its text, Guarani Aquifer Agreement reproduces the principles of UN ILC 63/124 Resolution, once in its initial articles the sovereignty of the contracting countries above the reserve is highlighted and the principle of avoiding significant damages is evidenced, pointing to the necessity of notification only when the accomplished works in the aquifer area generate impacts over its protection and sustainability. The mechanism of controversies solution would take place in the Intergovernmental Committee of countries from Platin Basin (CIC), but all these important questions are made without being properly deepened. Article 12 of the Agreement points the necessity of initiatives for the elaboration of common projects, information trade, knowledge and cooperation [34], but without parameters for it.

### 3. Results: Challenges for GAS Management

Guarani Aquifer Agreement must be recognized has an important step to an issue that is still considered as secondary in the international context and of difficult conception, in order to get to adequate tools to its handling, since the groundwater are not visible [35]. The management of groundwater must therefore protect a hidden good that involves two mains resources of political nature: water and soil, which configurate power relations [36]. Through the framework presented in the first section of this article, it is noticeable that the groundwater and especially the transboundary aquifers are themes still in need of an adequate handling in the international area.

Guarani Aquifer is a reserve with huge proportions and its complexity, as well as the heterogeneity of its physical characteristics is a fundamental matter to be thought in its management. The first challenge we can point to is the need to continue the studies and common projects related to GAS. Despite the

accomplishment of GASP, it is extremely important to continue with the studies and projects in the internal and regional scope of Guarani Aquifer, given its interconnections. In the Brazilian case we can highlight the Programed Action from 2008-2015, regarding the groundwater in São Paulo state, once this action was based on the following guidelines: promote research and development; elaborate guidelines of use and protection of aquifers; stimulate good drilling practices, as well as wells legalizing; strengthen the integrated network of groundwater quality and quantity monitoring; produce and spread basic information about groundwater [27].

Regarding projects and researches of Integrated Aquifer System Guarani/Serra Geral, this point is potential to the creation of a supranational implementation model that would conciliate the international cooperation, in a board of historical concern from the South American region about sovereignty on one side, and the environment production regarding the interests and rights of the population from the whole region on the other. It must be remembered that the local management scale is primordial, because the protection of groundwater is related to the management of use and to the soil occupancy by the city [30].

However, despite initiatives like these ones, since the end of GASP, in 2009, and the signature of Guarani Aquifer Agreement, in 2010, the number of common projects and the trade of knowledge among the Agreement contracting countries became sparse [37]. Amore (2011) [31] reinforced in an article about GASP that the period following the project was extremely important to narrow cooperation relations.

The second challenge concerns the absence on the international scene of new legal mechanisms that are the basis for the management of transboundary groundwater, which specify important issues regarding the management of these waters. The Resolution 63/124 is pioneer in the handling of transboundary aquifers in the international scenario, but, since then, there has not been any other mark, except for Guarani Aquifer Agreement, to regulate the issue. The proposed guidelines are similar to the ones from the Convention of 1997 and do not go further specify fundamental aspects, such as the meaning of equal and sustainable use and significant damage [10] [11]. The city of Ribeirão Preto, in Brazil, summarizes this situation, since it presents an exploitative use of resources, once the water withdraw from the reserve is above the amount of rain exactly in a replenishment area of the aquifer, which seems to be more prone to pollution. This area lies in an urban expansion zone, which results in “impermeabilization of the replenishment area and in the generation of new risks” [38]. Therefore, it demonstrates that the use and damage should be issues better discussed in this international document.

The third challenge is that the Guarani Aquifer Agreement only replicates the principles presented in the Resolution 63/124 and does not specify instruments for a shared management of GAS according to its physical characterization [32]. None the less, it comes from the regional to the international, which should be

positive. However, it does not mention which policies and guidelines the States will have to internally promote to make it effective [39], in other words, in a different way from the Geneva Aquifer case, the management mechanisms are not emphasized, something that should be possible, once GASP has made it possible to map the formation of the areas of higher care in the aquifer and therefore “(...) the agreement follows general guidelines for joined management of transboundary resources, but does not notice the diverse geography of the aquifer in the four member-States” [39]. The geological formation is also determinant to make it able to analyze the water speed, quantity and adequacy as reservoir, that is to say, it is a theme that involves a series of specificities so that the management is efficient in its preservation and resiliency. There are numerous formations in Guarani Aquifer and its management depends on specific mapping. As [39] well observes, the agreement does not take into “account the characteristics and particularities of these groundwaters. This way the management is accomplished by each country, making it even likely the possibility of contamination and environmental damage, because the outcrop and replenishment areas of the aquifer are different in the four States” [39].

Though amore (2011) [31] claims that the management of water resources is not a linear process, the fourth challenge of GAS that we must highlight is the slowness in the endorsement process and now the entry into force of this document. Analyzing this challenge, Ribeiro's (2001) [40] concept of international environmental order helps us. The international environmental order is characterized as a heterogenous and multipolar subsystem of the international system and that counts, in its inner part, on a series of subsystems that are the result of each document produced for the environmental theme.

Going further, we realize that, despite this constant and growing emphasis in cooperation so that the international acts are established, the States do not necessarily demonstrate a will to cooperate, thus, some characteristics of political realism from International Relations are useful to interpret this complex board. An element that allows the understanding of this posture is the sovereignty emphasized in documents established in the international scenario, like Guarani Aquifer case, which is present in its three first articles, as well as it is and explanatory element of the Brazilian resistance posture since the negotiation of this mark [40].

Still regarding the sovereignty within the international environmental documents, despite the socio-environmental problems being from combined, anthropic and natural origin and not respecting the national borders, the search for the preservation of sovereignty and of national interests are fundamental issues so that we understand not only the great international environmental marks referred by Ribeiro (2001) [41], but also more specific agreements, such as Guarani Aquifer Agreement. Ribeiro (2008) [41] claims that, by outlining the management of Guarani Aquifer, the international environmental order highlights in its scope the tension between sovereignty issue above the resources

and the necessary international cooperation among countries to the resources that surpass the territorial limits.

The concern about any interference in the handling and entitlement of Guarani Aquifer is clear element in the text, despite being a cross-border reserve that demands necessary conformation among the legislation of the contracting countries; the fear of institutional braces that somehow affect the national sovereignty is something to be bypassed. Pillar and Ribeiro (2011) [23] conveniently observe that “The four Guarani countries, which always asserted their sovereign rights over the aquifer, may have considered that an agreement signed under Mercosur would allow other countries to interfere with the aquifer’s management” (VILLAR; RIBEIRO, 2011, p. 652) [23], that is to say, the concern about the sovereignty and, consequently, the interference either by an international or a regional body in the reserve and its interests is something current since the negotiations of the agreement.

The fifth challenge of GAS concerns the institutional structure necessary to the implementation of Guarani Aquifer Agreement, which could allow the integrated management of the reserve. Only in its article 15 the document presents the creation of a Commission to the reserve with representants from the contracting countries on the board of the Intergovernmental Committee of countries from Platin Basin. Regarding the Platin Basin Agreement, despite its importance and being chosen as legal base to the development of Guarani Aquifer Agreement, the strategic importance and the dynamic of this groundwater resource demand especial attention [42].

According to Villar (2017), “the operationalization of this agreement demands the deepening of the cooperation among the States, which must endorse it and stablish the joined commission terms and define the controversies solution system” (VILLAR, 2017, p. 35) [24]. Regarding the aquifer management, in the Strategic Action Program (SAP) of GASP, it can be concluded that the holder countries of the Guarani Aquifer had legal and institutional base to the development of its management and protection.

In SAP the risks of the cooperation discontinuity are emphasized. Which could cause economical losses and institutional weakening of underground waters management. In fact, since PSAG and the agreement signature, the initiatives for common projects and information trade, such as advocated in article 12 of Guarani Aquifer Agreement, are stagnant [33] [37]. According to the UN Water (2018) [43], the ability to resolve conflicts, to develop tools for sustainable management and to mobilize diverse actors are goals to be sought in the waters governance. Drieschova *et al.* (2008) [44], by handling the specific issue of water flows in agreements for hydric resources, reinforce that these documents should be flexible and easily applicable in their rules so that their adaptation to various realities is possible. The important, according to Brooks and Linton (2011) [45] is to begin to stablish governance mechanisms for water instead of focusing in and ideal final structure to the theme.

The water governance is a general concept and there is no common ground

on its definition [46] but it is understood as including processes and political, economical and social institutions through which the governments, the civil society and the private sector make decisions about the best way to use, develop and manage the hydric resources. The governance of transboundary waters has as its fulcrum the interstate relations, particularly in international agreements formation and in the creation of joined institutions.

Villar (2010) [25] stresses, about the management of Guarani Aquifer, that GASP is important, however it is not evident in his text what the project considers as local management, if it is municipal, or of the watershed scope; it is also fundamental to pose that the project conclusion does not give the proper importance to a management that would contemplate the transboundary impacts, but that the main actions of management and protection of this resource should be within the local scope, something evident in the Strategic Action Project (2009) that says, in a clear way, that the guidelines to management should be executed in each State and in cooperation with the four countries, in the region of Guarani Aquifer System [31].

In the inner scope of the countries “(...) the national policies for the aquifers protection are in embryonic stage, before the lack of technical knowledge or the institutional and legal capacity” [25]. The legislations are in different stages: Paraguay and Uruguay, only by the end of the 2000s established their national policies for hydric resources, Argentina is still decentralized and Brazil, holding 70% of the reserves, seems reticent about the matter [32].

Furthermore, the limitations of national regulatory marks transpose themselves to other levels, with the states and cities, which compromises the elaboration of an efficient management. Villar and Ribeiro (2009) [38], by analyzing the case, explain the intrinsic character between policy and risk, and that the laws to regulate the matter of the aquifer in the region were only done to render account to the most organized social sectors and international organizations that, by the time, were involved in GASP.

Finally, the sixth and final challenge it is associated to legislations and institutionality for Guarani Aquifer Agreement and the risk of privatization of water resources, especially in Brazil. According to an interview given by Scheibe (2018) [47], emeritus professor in the Geosciences Department in the Federal University of Santa Catarina in Brazil, “the meetings of the president [Michel] Temer with the leaders of companies directly interested in the billionaire business of bottled water put even in the great press agenda the possibility of privatization, specially of Guarani Aquifer itself”. This scenario would be possible, according to the professor, through the imposition of changes in the law that regulates the exploitation of hydric reserves, once the senator Tasso Jereissati (PSDB-CE) presented a proposal to alter the National Policy for Water Resources so that it is possible to create “water markets”, in this proposal, from the begging of 2018, it is recognized the possibility to commercialize the rights of water grant, especially in a scenario of shortage.

This proposal stands against various cities of the world that reversed the cycles of privatization of services related to water, like Paris, Buenos Aires, among others, seen as the remunicipalization of waters in these sites. In 2017, during the 1st Regional Forum about Guidelines for Water Rights, organized by Parlasul, the Mercosul parliamentarians' concern with cycles of waters privatization was something palpable and there was a conference in this event just to handle with Guarani Aquifer and its strategic value in for the region [48].

In this occasion was emphasized that it was necessary to approach the aquifer under the prism of human right, besides highlighting a framework of anglo-hydraulic attitudes. According to Ricardo Canese (2017) [48], a Paraguayan parliamentarian, it is extremely important that to notice that “the Guarani Aquifer serves to promote rights and boost the development of all our peoples and not to only to the big companies”.

The planning and management of water resources, which makes the geographic variables to be contemplated, besides the benefits through the physical aspects, must also be considered the environmental, socioeconomic, political and institutional aspects, all the stakeholders on these resources.

#### **4. Conclusions**

The various cases presented in this article indicate that the management of transboundary aquifers is complex. Initially it is necessary to know the aquifer in question, and its geological specificity, as well as to evaluate its potential of use, water quality and eventual possibility of recharge. This task is complex and costly. In several places, especially in Africa and Asia, it is still incomplete. In the case of GAS, it should be emphasized that the studies were deepened through international cooperation and financing, which allowed to elaborate an overview of its hydrogeological dynamics.

Despite the difficulties, an agreement was reached between the parties involved in the GAS. The initial contribution, which elected Mercosur as a forum, failed to establish itself. The classic institutional fragility involving institutions in Latin America has revealed itself once again. That is why a specific agreement was set up, an arrangement that resulted in a new order for the four countries. Its ratification demonstrates a breakthrough, but management challenges are coming, as the demand for water must keep growing.

#### **Conflicts of Interest**

The authors declare no conflicts of interest regarding the publication of this paper.

#### **References**

- [1] ISARM (2015) TBA's of the World 2015. [https://www.un-igrac.org/sites/default/files/resources/files/TBAmap\\_2015.pdf](https://www.un-igrac.org/sites/default/files/resources/files/TBAmap_2015.pdf)
- [2] Villar, C. (2015) Aquíferos Transfronteiriços: Governança das águas e o Aquífero

Guarani. Juruá, Curitiba.

- [3] FAO (2016) Groundwater Governance. <http://www.fao.org/3/a-i5706e.pdf>
- [4] Lee, E., Jayakumar, R., Shrestha, S. and Han, Z. (2018) Assessment of Transboundary Aquifer Resources in Asia: Status and Progress towards Sustainable Groundwater Management. *Journal of Hydrology: Regional Studies*, **20**, 103-115.
- [5] McCafrey, S.C. (2001) *The Law of International Watercourses: Non-Navigation Uses*. Oxford University Press, Oxford.
- [6] Villar, C. (2012) A busca pela governança dos aquíferos transfronteiriços e o caso do Aquífero Guarani. Thesis, Programa de Pós-Graduação em Ciências Ambientais, Universidade de São Paulo, São Paulo.
- [7] UNESCO (2012) Groundwater and Global Change: Trends, Opportunities and Challenges. <http://unesdoc.unesco.org/images/0021/002154/215496e.pdf>
- [8] IGRAC (2018) TWAP Programme. <https://www.un-igrac.org/special-project/twap-groundwater>
- [9] ISARM (2018) Internationally Shared Aquifer Resource Management. UNESCO/OAS ISARM Americas Programme. <https://isarm.org/unescocoas-isarm-americas-programme>
- [10] Mechlem, K. (2009) Moving Ahead in Protecting Freshwater Resources: The International Law Commission's Draft Articles on Transboundary Aquifers. *Leiden Journal of International Law*, **22**, 801-821. <https://doi.org/10.1017/S0922156509990239>
- [11] Eckstein, G.E. (2005) Protecting a Hidden Treasure: The U.N International Law Commission and the International Law of Transboundary Ground Water Resources. *Sustainable Development Law & Policy*, **5**, 5-12.
- [12] Sugg, Z., Varady, R.G., Gerlak, A.K. and Grenade, R. (2015) Transboundary Groundwater Governance in the Guarani Aquifer System: Reflections from a Survey of Global and Regional Experts. *Water International*, **40**, 377-400. <https://doi.org/10.1080/02508060.2015.1052939>
- [13] Eickstein, G. (2017) *The International Law of Transboundary Groundwater Resources*. Routledge, New York. <https://doi.org/10.4324/9781315731216>
- [14] Los Cobos, G. (2018) The Genevese Transboundary Aquifer (Switzerland-France): The Secret of 40 Years of Successful Management. *Journal of Hydrology: Regional Studies*, **20**, 116-127.
- [15] Eickstein, G. and Sindico, F. (2014) The Law of Transboundary Aquifers: Many Ways of Going Forward, but Only One Way of Standing Still. *RECIEL*, **23**, 32-42. <https://doi.org/10.1111/reel.12067>
- [16] European Commission (2008) *Protection of Groundwaters in Europe*. Office for Official Publications of the European Communities, Luxembourg.
- [17] Barraqué, B. (2003) Past and Future Sustainability of Water Policies in Europe. *Natural Resources Forum*, **27**, 200-211. <https://doi.org/10.1111/1477-8947.00055>
- [18] He, Y. (2017) China's Transboundary Groundwater Cooperation in the Context of Emerging Transboundary Aquifer Law. *Ground Water*, **55**, 489-494. <https://doi.org/10.1590/0034-7329201600107>
- [19] Nijsten, G., Christelis, G., Villholth, K.G., Braune, E. and Gaye, C.B. (2018) Transboundary Aquifers of Africa: Review of the Current State of Knowledge and Progress towards Sustainable Development and Management. *Journal of Hydrology: Regional Studies*, **20**, 21-34.

- [20] Quadri, E. (2017) The Nubian Sandstone Aquifer System—A Case of Cooperation in the Making. *Journal of Water Law*, **25**, 274-282.
- [21] Villar, P.C. (2016) International Cooperation on Transboundary Aquifers in South America and the Guarani Aquifer Case. *Revista Brasileira de Política Internacional*, **59**, 1-20.
- [22] Forti, A.W. (2013) El papel de la Defensa en una Estrategia Suramericana para el Aprovechamiento de los Recursos Naturales.  
<http://ceed.unasursg.org/Espanol/09-Downloads/Biblioteca/DEF-RRNN.pdf>
- [23] Villar, P.C. and Ribeiro, W.C. (2011) The Agreement on the Guarani Aquifer: A New Paradigm for Transboundary Groundwater Management? *Journal Water International*, **36**, 646-660. <https://doi.org/10.1080/02508060.2011.603671>
- [24] Villar, P.C. (2017) Governança Da Água Na América Latina, Unidade 3, Material Ead, Ana-Unesp.
- [25] Villar, P.C. (2010) Gestão das águas subterrâneas e o Aquífero Guarani: Desafios e avanços, V Encontro Nacional da Anppas, Florianópolis.
- [26] Organização Dos Estados Americanos (2009) Programa estrategico de acción. Edição Bilingue. Brasil.
- [27] Brasil (2017) Ação programada de desenvolvimento e proteção de águas subterrâneas no Estado de São Paulo.  
[http://igeologico.sp.gov.br/files/2017/10/Acao\\_programada\\_de\\_desenvolvimento\\_e\\_protecao\\_de\\_aguas\\_subterraneas.pdf](http://igeologico.sp.gov.br/files/2017/10/Acao_programada_de_desenvolvimento_e_protecao_de_aguas_subterraneas.pdf)
- [28] Santos, C.L.S. (2015) Aquífero Guarani: Atuação do Brasil na negociação do acordo. Dissertation, Programa de Pós-Graduação em Ciências Ambientais, Universidade de São Paulo.
- [29] Scheibe, L.F. and Hirata, R.C.A. (2008) O contexto tectônico dos sistemas Aquíferos Guarani e Serra Geral em Santa Catarina: Uma revisão. *Revista Águas Subterrâneas*.  
<https://aguassubterraneas.abas.org/asubterraneas/article/view/23794/15859>
- [30] Wolkmer, M.F., Scheibe, L.F. and Henning, L.A. (2013) A política nacional de recursos hídricos: Fundamentos e objetivos estratégicos que orientaram a estruturação do Projeto rede guarani/Serra Geral. *Campo Jurídico*, **1**, 35-56.
- [31] Amore, L. (2011) The Guarani Aquifer: From Knowledge to Water Management. *International Journal of Water Resources Development*, **27**, 463-476.  
<https://doi.org/10.1080/07900627.2011.593125>
- [32] Leite, M.L.T.A. (2018) O Acordo do Aquífero Guarani e a ótica da integração regional. Dissertation Programa de Pós-Graduação em Relações Internacionais San Tiago Dantas (UNESP, UNICAMP, PUC-SP), São Paulo.
- [33] Villar, P.C. (2018) Countdown to the Guarani Aquifer Agreement Coming into Force: Will It Be Effective in Promoting Transboundary Groundwater Governance? *International Water Law Project Blogspot*.  
<https://www.internationalwaterlaw.org/blog/2018/06/>
- [34] FAO (2010) Guarani Aquifer Agreement.  
<http://extwprlegs1.fao.org/docs/pdf/mul-143888English.pdf>
- [35] Mccracken, M. (2017) Measuring Transboundary Water Cooperation: Options for Sustainable Development Goal Target 6.5. *Global Water Partnership: TEC Background Papers*, 23.
- [36] Raffestin, C. (1980) *Pour une Géographie du Pouvoir*. LITEC, Paris.
- [37] Sindico, F., Hirata, R. and Manganelli, A. (2018) The Guarani Aquifer System: From

- a Beacon of Hope to a Question Mark in the Governance of Transboundary Aquifers. *Journal of Hydrology: Regional Studies*, **20**, 49-59.
- [38] Villar, P.C. and Ribeiro, W.C. (2009) Sociedade e gestão do risco: O aquífero Guarani em Ribeirão Preto-SP, Brasil. *Revista de Geografia Norte Grande*, **43**, 51-64. <https://www.internationalwaterlaw.org/blog/2018/06/>  
<https://doi.org/10.4067/S0718-34022009000200003>
- [39] Noschang, P.G. (2012) Gestão de águas subterrâneas e o aquífero Guarani. *Revista Eletrônica Direito e Política*, **7**.  
<https://siaiap32.univali.br/seer/index.php/rdp/article/view/5641/3041>
- [40] Ribeiro, W.C. (2001) A Ordem Ambiental Internacional. Contexto, São Paulo.
- [41] Ribeiro, W.C. (2008) Aquífero Guarani: Soberania compartilhada. *Estudos Avançados*, São Paulo, 22.
- [42] Silva, D.M. da and Pereira, M.C.B. (2018) O Aquífero Guarani e a Busca pela Gestão Integrada do Sistema de Águas Transfronteiriças: Proposta de Implementação do Acordo do Aquífero.  
[http://www.observatoriodasaguas.org/publicacoes/id725026/o\\_aquifero\\_guarani\\_e\\_a\\_busca\\_pela\\_gestao\\_integrada\\_do\\_sistema\\_de\\_aguas\\_transfronteiricas\\_proposta\\_de\\_implementacao\\_do\\_acordo\\_do\\_aquifero](http://www.observatoriodasaguas.org/publicacoes/id725026/o_aquifero_guarani_e_a_busca_pela_gestao_integrada_do_sistema_de_aguas_transfronteiricas_proposta_de_implementacao_do_acordo_do_aquifero)
- [43] UN WATER. Governance. <http://www.unwater.org/about-unwater/governance>
- [44] Drieschova, A., Giordano, M. and Fischhendler, I. (2008) Governance Mechanisms to Address Flow Variability in Water Treaties. *Global Environmental Change*, **18**, 285-295. <https://doi.org/10.1016/j.gloenvcha.2008.01.005>
- [45] Linton, J. and Brooks, D.B. (2011) Governance of Transboundary Aquifers: New Challenges and New Opportunities. *Water International*, **35**, 606-618.  
<https://doi.org/10.1080/02508060.2011.599312>
- [46] Woodhouse, P. and Muller, M. (2017) Water Governance—An Historical Perspective on Current Debates. *World Development*, **92**, 225-241.  
<https://doi.org/10.1016/j.worlddev.2016.11.014>
- [47] Scheibe, L.F. (2018) Água: De bem comum a produto mercantilizado. UHU Online, 518.  
<http://www.ihuonline.unisinos.br/artigo/7195-agua-de-bem-comum-a-produto-mercantilizado>
- [48] Parlamento del Mercosur (2017) Aquífero Guarani: Estratégico para o direito humano à água e o desenvolvimento do Mercosul.  
<https://www.parlamentomercosur.org/innovaportal/v/14047/1/parlasur/aquife-ro-guarani-estrategico-para-o-direito-humano--agua-e-o-desenvolvimento-do-mercoul.html>