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Guarani Aquifer: An unusual review on academic production

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ABSTRACT

Stretching across 4 countries, the Aquifer Guarani is one of the most important groundwater reservoirs in the world. Its waters are exploited by many daily activities from agriculture to leisure; therefore it is endangered by pollution which percolates from the surface and overuse by water utilities and companies. The great part of the academic production of the reserve focuses on geological aspects, while other topics remain not so well covered. This article brings out papers produced about environmental, technological and social facets of the aquifer, linking them and by doing so, showing how the groundwater is affected by society and remains unprotected by political and environmental conditions.

INTRODUCTION

Due to the scarcity and pollution of surface water sources, greater attention is given to the use of aquifers and groundwater as a safer alternative to the consumption of water. Niu et al. (2014), by bibliometric analysis, show that more than 60,000 articles were published between 1993 and 2012, being 59% of the production in environmental sciences and geosciences, led by the United States of America, as the largest research producer, with approximately 35% of all content produced. Meanwhile, Brazil represents only 1.4% of this academic production, despite the country’s possession of two of the biggest underground reservoirs, the Guarani Aquifer System (SAG) and the Greater Amazon Aquifer System (SAGA).

Santos and Ribeiro (2016) also verified that within the first 10 articles (listed in 3 different languages) about the SAG in academic bases, the majority addresses subjects of geosciences while other areas of study have little material in this ranking. Therefore, the objective of this article is to carry out a bibliographic survey on the content of articles about SAG that approaches perspectives closer to the daily life aspects such as pollution, agribusiness, and public management, among others on the reserve.

The article is divided in Introduction, Method, The SAG, Environmental and Economic Impacts, Modeling and Simulations, Sociopolitical Aspects and Transboundary Aquifer Management and Final Remarks.

METHODS

We have searched articles from the Science Direct, Scielo, Google Scholar and Web of Science collections, using the keywords "guarani", "aquífero", "aquifer" and "acuífero" to search for material in Portuguese, English and Spanish published between 2010 and 2017. We disregarded articles about aquifers that do not present a direct relationship to the SAG or just mention it as a reference, besides those which focus on different themes from the proposed in this article. The articles had their abstracts and methodologies read and analyzed, later being separated in topics: economic and environmental impacts of groundwater exploitation, modeling and simulations used in the management and studies of groundwater, and political and social approach in aquifer management.

The choice of the "economic", "environmental" and "sociopolitical" topics as content clusters is based on the Triple Bottom Line approach proposed by Elkington (1994), due to the simple logic of this methodology and the impact it has on current sustainability policies and future studies about SAG. It was chosen to combine the economic and environmental impacts in a chapter, and to devote a chapter to the importance of the social and political factors that impact the management of the SAG. The chapter of modeling and simulations is necessary because technological tools add more data that researchers and managers could rely on.

Finally, we opted for a bibliographic survey to deepen analysis in the articles and to bring reflections on the future of the reserve and of possible researches. It would not be at all possible in a bibliometric survey and important information could have been left aside.

THE SAG

Roughly 3% of the water on the planet is available for consumption, being nearly one-third of it is confined underground (USGS 2018). It is estimated that at least 7% of the energy consumed in the world is destined for exploitation of these waters, accounted in extraction, pumping and, treatment of groundwater and sewage produced (Hoffman 2011).

In 2002, NASA launched a mission to investigate the amount of water stored underground. Examining data between 2003 and 2013, it is concluded that of the 37 largest aquifers in the world, 21 are losing water, and of these, 13 are in a critical situation, some in the aridest regions of the world. It is possible knowing how much the reservoir is being depleted, but not how much water remains in the aquifer, raising speculations about the longevity of these areas (NASA 2015).

The SAG is one of the largest transboundary freshwater reservoirs in the world, located in the Brazilian states of Goiás, Mato Grosso, Mato Grosso do Sul, Minas Gerais, São Paulo, Paraná, Santa Catarina and Rio Grande do Sul, as well Argentina, Paraguay, and Uruguay (Cetesb 2016). It is formed by sandy sediments that by the action of the pressure, temperature and humidity have turned into sandstone, a porous rock that retains water in its interior, forming the water reservoir. In later movements, the sandstone was mostly covered by a volcanic rock of low permeability (water seeps through cracks in the rock), making the aquifer semipermeable. This feature reduces the potential for absorption and replenishment, but also helps in reducing water loss through evapotranspiration and diminishes water contamination by surface residues (Borghetti et al. 2004). At the eastern and western boundaries, there is a porous rock outcrop (narrow bands representing only 10% of the SAG's area) that are responsible for the recharge of the groundwater reserve (Rabelo and Wendland 2009).

ENVIRONMENTAL AND ECONOMIC IMPACTS

In 2007, about 90% of the water extracted from the SAG was in Brazilian territory, and 80% of the extraction was done in the State of São Paulo (Schmidt and Vassolo 2011). The growth of crops and urban areas has raised concerns on the quality of SAG's resources due to the growing use of groundwater and recharge outcrops vulnerability to various forms of contamination from agriculture, industrial and domestic activities. Some elements and substances, by infiltrating the soil and reaching its lower layers, could spread rapidly, affecting areas where they were originally not found. From economy's point of view, the exploitation of the aquifer to the maintenance of the economic activities can end up in negative variations in water recharges, reducing available resources, raising prices and searching of other sources to replace the groundwater.

In Ribeirão Preto (SP), an agribusiness city, there were no negative indicators for nitrates and heavy metals in 33 public wells between 2008 and 2009 (Sanches et al. 2010). Between 2011 to 2012, in the same city, in the Pardo River sediments, heavy metals residues were identified slightly above the limit, requiring frequent monitoring and attention to anthropic (originated by human activities) activity (Alves et al. 2014), though between 2013 and 2014, the analysis of 11 wells in the SAG's recharge area presented acceptable levels of agrochemicals (Beda, unpublished data). In Bauru (SP), the levels of substances remained within the CETESB and federal laws (Canato et al. 2014), while a different situation happened in the city of Marília (SP), where the concentration of nitrates and heavy metals exceeded the acceptable values and there was risk of contamination of other areas of the aquifers that are part of the SAG, due plausible origin in the anthropic activity of the urban region (Varnier et al. 2010, Conceição et al. 2014). The three cities present slightly acidic waters (pH < 7), which may indicate a tendency to contamination (Gastmans and Kiang 2005) by solubilization of heavy metals, such as lead and zinc, that could cause health problems (La Serra, unpublished data).

One of the major contaminants of soils and aquifers is the use of landfills. These areas, due to a large amount of organic matter in the waste decomposition, release dozens of substances that seep into the soil and finally reach the superficial levels of the groundwater. Some may be digested by microorganisms (Sheikhavandi 2015), others may accumulate in the aquifer and be transported to other areas, increasing contamination. In the former landfill Santa Madalena, in São Carlos (SP), located in an area of recharge of the aquifer, there is contamination by heavy metals. The area was deactivated in 1996 and still shows signs of contamination which points out the need for local intervention (Veloso, unpublished data, Andrade, unpublished data).

The presence of Diuron and Heptachlor, two pesticides known for their high environmental persistence, was found in São Pedro and Águas de São Pedro (SP)'s rural region, known by the citrus and sugarcane cultures. Given the time these compounds take to degrade naturally, it is believed that they may have come from other regions or originate from older applications in local cultures (Alves, unpublished data).

The presence of numerous minerals and substances in groundwater, delivered by millions of years of weathering in the surface, is one of the most important aspects of aquifers studies because above-permitted concentrations can affect the health of live beings. Bonotto and Elliot (2017) analyzed 11 wells distributed by the State of São Paulo, being 3 of them with hyperthermal waters (> 38ºC). The concentration of metals was higher in wells with higher temperatures and some had higher fluoride levels than those allowed for consumption according to the World Health Organization (WHO), as well as the presence of arsenic in one of the samples. However, the samples came from wells for recreational purposes, in this case, a pool of warm water, with probable natural origin.

During the three-year period from 2013 to 2015, in the State of São Paulo, potability standards varied considerably, albeit within the limits allowed by the Federal Government and international bodies. The presence of anthropic substances, such as nitrates and chromium, and microbiological parameters increased significantly. Nitrates and chromium hexavalent, derived from human occupation and use of pesticides, are found in very small concentrations in groundwater, but coming from industrial sites, dumps, landfills and agroindustry in large quantities, are carcinogenic. The microorganisms found may be originated from sewage treatment networks located near the wells tested or sanitary deficiency in the treatment and safety of the wells. In 2015, 106 nonconformities were verified against 36 in 2014 in the samples monitoring microbiological agents (Cetesb 2016).

The analysis of 32 wells between 2009 and 2013 in municipalities of Mato Grosso do Sul in the region of the Bauru Aquifer, one of the many formations that constitute the SAG, did not indicate contamination by copper and zinc above the allowed limits, however some wells presented residues of iron and manganese, which may have been caused by anthropic activities in local crops. Chromium concentrations above the allowed levels were found in only one year, returning to the standards in later periods, probably due to the treatment of the leather that uses the product (Uechi et al. 2017).

Processing sugarcane for ethanol production generates two industrial by-products: bagasse and vinasse (Silva et al. 2014). The first is used in the cogeneration of electricity by the plants. The second is generated in large quantities and consists of nitrogen, phosphorus, potassium, among other substances that pollute soil, surface water (eutrophication) and groundwater (Conley et al. 2009). It possesses high organic value (fertirrigation) which has been studied as a source of energy parallel to cogeneration due to its great energy potential (Pazuch et al. 2017, Cavalett et al. 2012). However, fertirrigation causes high soil salinity (Arcaro, unpublished data), solubilization of pesticides (Lourencetti et al. 2012) and pollutant infiltration (Arcaro et al. 2010, Casagrande, unpublished data), degrading the long-term soil quality.

Contamination of surface water by lead from untreated industrial waste, landfills, and sewage directly affects groundwater, as infiltration of lead into recharge areas or cracks is difficult to avoid. Studies in the Sinos River Basin in Rio Grande do Sul, an urbanized region, shows a high presence of lead, from an anthropic origin in the wells and surface waters, and arsenic, boron, and vanadium, from a probable natural origin, requiring further studies on the source (Abreu and Roisenberg 2017).

PBDE (polybrominated diphenyl ethers) are toxic substances used as flame retardants in plastics, textiles and various electronic circuits, and because of their chemical characteristics they can migrate to the environment, and now can be found in soil, animals, human tissues, and even breast milk, thus being bioaccumulative (Li et al. 2016). Samples collected in a pond in the city of Ribeirão Preto (São Paulo) on the recharge area of the aquifer pointed out traces of PBDE, reporting the risk of contamination and the need for monitoring (Souza et al. 2016, Ferrari, unpublished data).

Pharmaceutical substances, personal hygiene products, some pesticides, and medicines are also part of the residues that will end up in the sewage and contaminate soil and water (Heberer et al. 2002, Liu et al. 2010). Hormonal disrupters, for example, due to their structural similarity with natural hormones, negatively affect the health of people and animals by deregulating the metabolism, production, and transport of naturally occurring hormones produced by the body (Vilela et al. 2018). No studies on the subject were found for the SAG region, although CETESB performed measurements on estrogenic activity and did not find persistent variations in the samples (Cetesb 2016), but the importance of the treatment of pharmaceutical waste and water pollution has been studied in several regions, such as China, Spain, Singapore, Germany, among others (Sui et al. 2015).

Staggemeier et al. (2015) by analyzing the presence of adenovirus (common influenza virus, among other diseases) in dairy farms, concluded there was a higher presence of virus in the soil than in water. The feces of the animals contain pathogens that when mixed with the soil remain infectious for a longer time, and can contaminate the water courses and the aquifer, as the infiltration may contain the virus. The impact directly affects the water resources, since the pollution of rivers and groundwater will affect the health of the animals and the population that depends on these waters (Staggemeier et al. 2015). The same problem happens in the Jacutinga river basin and contiguous, in Santa Catarina, where contamination by microorganisms such as Salmonella and E. coli can impact aquifer water quality and later agricultural activity, as the region heavily depends on rural production, demanding action against contaminants and adequate treatment of waste (Comassetto et al. 2014, Viancelli et al. 2015).

The penetration of nutrients from fertilizers and pesticides into the soil is one of the main concerns about the pollution of aquifers since the depollution of these areas is difficult (Di Bernardo Dantas et al. 2011). In 81 wells in the region of the Capiibary River (Paraguay), known by the intensive use of chemicals in agriculture, the practice of not plowing and harrowing the soil, mixed weather conditions and organic activity, have been shown to reduce the mobility of nitrates in soil layers and prevent their accumulation in aquifers and rivers (Houben et al. 2015).

Due to the numerous formations that make up the SAG, some areas have a higher concentration of diluted salts, requiring the use of desalinizers (Brião et al. 2014). However, the process of obtaining desalinated water for consumption is costly, affecting the interest in investments (Anderson et al. 2010). As the depletion of superficial resources is rapidly increasing, the water treatment becomes more expensive, therefore several studies have been carried out to study how to reduce the costs and improve the supply of drinking water to the society that depends on the SAG (Lado et al. 2017, Brião et al. 2016). The future use of desalinators is a warning that abusive groundwater consumption should be controlled through effective public policies and public awareness of increasing waste and costs.

The search for cleaner energy sources has led attention to solar, eolic, hydro and geothermal alternatives. A number of studies, for example, in Central Europe (Töth et al. 2016), Turkey (Balaban et al. 2017) and China (Wang et al. 2015) have shown the feasibility and problems of using geothermal sources in the industry, agriculture, and tourism. For the SAG, the occurrence of thermal and hyperthermal waters is little studied, but there is potential for exploitation in economic activities and the need for more studies on the use as a source of energy (Arboit 2013).

The decline in oil reserves has driven the exploration of shale fields, a porous rock formation capable of storing organic material such as oil and natural gas (Pereira, unpublished data). In Brazil, the largest estimated reserves are found in the Solimões and Amazonas geological basins, and Paraná, where the SAG is located (Camargo et al. 2014), in addition to the Uruguay, Paraguay and Paraná rivers. Extraction of shale gas presents risks of environmental contamination by heavy metals and other additives, overexploitation of surface and groundwater, and huge exploitation sites to be commercially viable, culminating in land conflicts (Scheibe et al. 2014). There is a possibility of displacements or landslides of aquifer areas, causing the pollution of non-exploitable areas and possible loss of local waters, as well as leakage of flammable gases to the surface (Meroni and Piñeiro 2014).

In summary, the environmental aspects of the SAG are mostly in accordance to the standards defined by national and international regulatory bodies. But the presence of harmful substances to living beings, although within limits, is a strong warning in all articles, requiring constant monitoring of groundwater and further studies on the subject, especially on new types of pollution such as antibiotics and chemicals, and how the substances spread through the system. The economic impacts of SAG activities also need to be better studied as the long-term effects are difficult to measure and future problems can arise, for example, population health concerns and depollution of areas.

MODELING AND SIMULATIONS

Climate change, atypical rainfall cycles and pollution of surface waters have driven more attention to the responsible management of aquifers. The water crisis of 2014, which affected the state of São Paulo and led its capital to water rationing, brought a series of media speculations about the exploitation of the Guarani Aquifer (Martirani and Peres 2016; Villar 2016a). Surface water is treated differently from groundwater even though it is part of the same hydrological cycle and this difference is accentuated during periods of prolonged drought, when the solution is to exploit the underground sources, generating future deficit in the aquifers' levels, stress in the water systems and future droughts (Famiglietti 2014).

The uncertainties regarding the current water volume of the Guarani and its future availability, and of other aquifers, lead researchers to create models and scenarios that consider factors such as climate change, evapotranspiration, human consumption, balances between recharges and discharges, land use, among others (Castilla-Rho et al. 2015, Melo et al. 2015, Lucas et al. 2015, Nava and Manzione 2015).

Thus, the modeling tools are more than predictions and future scenarios, since they fundamentally aid the decision making the process of the water management in the aquifer and the superficial resources that affect it. With adequate human and financial capital and knowledge, it is possible to raise awareness of society, tackle environmental problems and promote public policies that fit local realities, optimizing the use of available environmental resources (Vasconcelos et al. 2013, Rodríguez et al. 2013).

The concept of recharge is important to estimate how much can be extracted from the aquifer without depleting it irreversibly (Döll and Fiedler 2008). Thus, the importance of the recharge level simulations is fundamental for the public and private management of the wells and the potential use of each unit, since the flow of water inside the aquifer is slow and there are variations in the recharge in each region (Coelho et al. 2017, Melo et al. 2015). Summing to that, approximately 75% of the SAG recharge area is occupied by crops (IPT, 2011), therefore it is necessary to understand how they affect the aquifer recharge, and how the density of native vegetation also influences the amount of water absorbed or infiltrated in the system.

In a simulation with data collected from local weather and land use, between 2004 and 2014, in a river basin in the central region of São Paulo, Melo and Wendland (2017) have created 10 scenarios for the period between 2081 and 2099. Climatic forecasts indicate a decrease in rainfall volume, higher temperatures, and decrease in water availability, consequently reducing aquifer recharge. The areas with eucalyptus and sugarcane crops will suffer even more from recharge reduction due to higher evapotranspiration of the plants.

Oliveira et al. (2017) studied cerrado vegetation in a pristine area in the central region of São Paulo and observed that the water infiltration decreases as the grass vegetation becomes denser as a forest. Deforestation of dense areas of cerrado for crops use may increase aquifer recharge, but this requires adequate planning, as certain cultures, like eucalyptus, can reduce the water absorption. Simulations involving frequency of rainfall, land use and volumetric variations in the water table of 23 wells between 2004 and 2014 reinforced how weather and crops interfere in the aquifer recharge (Manzione et al. 2017). Other studies have brought the need to better understand the impacts of land use and deforestation on the potential of aquifer recharge (Lucas and Wendland 2016, Dobrovolski and Rattis 2015). Natural vegetation cover also interacts with how contaminants used in agriculture will penetrate the soil and reach the aquifer, since the mobility and persistence of the substance in the environment can extend over large areas and periods of time (Alves, unpublished data, Roux et al. 1998, Salem et al. 2015).

Being formed by a system of aquifers of diverse aspects, besides the uncertainty of how these reserves connect, the SAG's hydrogeological modeling assists in the understanding of structures, geological formation, the potential of recharge and discharge of the local aquifers (Mira et al. 2013, Manzione et al. 2012). These models enable researchers to map and analyze water absorption, flow within the system, substance movement, penetration of pollutants and contaminants, land use, the extent of a given reserve, and deliver to managers greater knowledge about the area to be explored (Machado et al. 2017, Höyng et al. 2014).

For example, Araraquara, one of the largest cities in the central region of São Paulo is located in an outcrop area of SAG and consumes more than 70,000 m3 of water daily from the aquifer for public supply, which has resulted in signs of low groundwater level (Scalvi, unpublished data, Hirata et al. 2012). In a simulation up to the year 2020, consumption will grow by more 1200 m3 per day, increasing the water stress on the local aquifer (Scalvi, unpublished data).

Models simulators such as GRACE (the same used by NASA to measure aquifer levels at the beginning of this article) and other tools rely on gravitational and climate changes to measure variations in aquifer levels (Frappart et al. 2013). Atypical rainfall regimes affected the Rio de la Plata basin and the SAG recharge in the region (Pereira and Pacino 2012). On the other hand, the SAG presented little variation in water levels, even with the last rainfall improvement due to the narrow recharge zone range (Hu et al. 2017).

Vulnerability models such as GOD and DRASTIC are used to measure how exposed an area is for contamination by using a range of variables and punctuating them until the calculated vulnerability is reached. Recognized the risk that an area is under, it is possible to decide on the use and occupation of the land to reduce the environmental impact. Regarding the studies found, the vulnerability of the aquifer in the analyzed regions varies from medium to very high, indicating the need for more inclusive policies for the most vulnerable places. New Palma (Lobler and Silva, 2015), Portão and Estância Velha (Muradás et al. 2010), agricultural regions in Rio Grande do Sul, presented medium and high vulnerability. In São Paulo, Ribeirão Bonito (Santos et al. 2015), São Pedro and Águas de São Pedro (Alves, unpublished data), all in regions with a strong presence of sugarcane culture, presented high risks. In Paraguay, the Yacyretá Dam, which borders to Argentina and has a relevant agricultural activity, presented high and very high vulnerability (Musalem et al. 2015), which in a binational area, is a problem for both countries.

It reinforces the importance of modeling and simulations as powerful management tools in the better understanding and exploitation of SAG waters. In addition, the use of these tools for mapping urban and agricultural areas represents a significant factor in environmental control and the future impact that it will have on the aquifer.

SOCIOPOLITICAL ASPECTS AND TRANSBOUNDARY AQUIFER MANAGEMENT

As seen, the aquifer is exposed to many forms of contamination that can travel through the system and affect other areas. As a reservation that spans under several states and three other countries, managing such an extensive and legally diverse area is a challenge for public agents. It is important to study how society and politics affect the aquifer and understand how exploitation of the reserve will occur in the coming years.

In 2004, negotiations began on the agreement of the Guarani Aquifer System by MERCOSUR members, all of whom have some reserve of the aquifer. This was a milestone for international legislation on groundwater, as it was the first to be carried out without territorial dispute or environmental damage prior to the agreement (Villar, unpublished data).

The Brazilian Ministry of Foreign Affairs, because of an inflexible and sovereign position, played a defensive strategy by not assuming additional responsibilities and delaying the signature of the agreement up to 2010 by all the member countries. The final agreement, after several revisions, had more diplomatic and political features than really social and environmental concerns. By it, the world is informed that the aquifer is transboundary rather than international, avoiding pressure and exploitation of foreign groups in the reserve (Santos, unpublished data). Until 2017, only Argentina, Brazil and Uruguay had ratified the Agreement (Parlasul 2017), that means, the treaty is not yet in force and the lack of consensus may induce each country to legislate differently on the aquifer, increasing risk factors.

In the Agreement, there are proposals to create commissions that would coordinate the fulfillment of the environmental objectives of the treaty and would have MERCOSUR support (OEA 2009). However, from an environmental point of view, the bloc has a rather uneven policy of shared management among its members - although it is in its statutes and there is a specific group responsible for managing the environment - functioning better as a trade stimulus instrument than as an integrator of environmental actions among its members (Ribeiro 2008).

Cross-border resources need greater coordination between interested states, respecting the particularities of each. This was what the Guarani Aquifer Project intended to bring the 4 countries involved to discuss the protection and economic use of waters (Amore 2011). MERCOSUR, as well as an economic institution, could also bring clarity to the arguments of the countries, through its organs such as the MERCOSUR Tribunal, creating a common legislative regime and expanding regional integration (Confortí 2014). However, like the Guarani Aquifer Agreement, MERCOSUR still does not have sufficiently strong structures to interact as a regulatory body in the international policies of the signatory countries. An example of this position was the case of Uruguay and Argentina for the pulp and paper industries, a situation settled by the International Court of Justice and which showed that MERCOSUR does not guarantee internal conflict resolution (Kaakinen and Lehtinen 2016).

Although recharge areas are common to countries, central waters are difficult to restore due to basaltic coverage, creating the need for integrated international management to protect recharge areas and control exploitation, overtaking local authorities and institutionalizing a strong management, but the lack of cooperation and information exchange threatens the shared administration. For example, due to SAG's extension and formation, the aquifer varies from region to region and there are no common strategies for extraction and use, which can induce conflicts (Villar and Ribeiro 2011) and weaken an agreement that is not yet in operation.

According to Dietz et al. (2003), the lack of strong institutions in the management of transboundary water resources coupled with uncertainties, inconclusive decision making and different environmental agendas result in crises and conflicts that could be reduced by building shared governance.

Sugg et al. (2015) researched the opinion of 10 groundwater management experts, and according to those interviewed, the SAG needs further studies on the dynamics of reservoirs and their waters, and has several administrative jurisdictions suffering from insufficient regulation, as well conflicts over the use and allocation of strategic resources. Although the Guarani Aquifer Agreement is about the public benefit over private's, the position of the countries is sovereign respecting the portions of the aquifer in each nation, that is, there is not a single force legislating about the reserve but four stakeholders focused on self-interest. This position reflects the absence of transnational bodies responsible for regulating and controlling these waters, then empowering the national regulatory agencies of each country.

The International Groundwater Resources Assessment Center (IGRAC) has identified 592 transboundary aquifers (IGRAC 2015), 29 of which occur in South America, but most of them are little known about physical size, geological formation, water quality and exploration (UNESCO 2007). For Villar (2016b), this lack of information generates potential for technical cooperation among countries, international organizations and academic community, creating knowledge and material for international agreements, as was the case with SAG, which although it is a world example in the technical area, still lacks of political strength to be used as an example of shared groundwater management.

The incongruity of information is one of the major problems in the efficient coordination of water resources in Brazil. The country uses a management model that, although allows social participation, generally excludes it from decisions by focusing on the technical aspects and delegating the final decision to the government and major users (Sousa Júnior and Fidelman 2009). To cite international examples, for the water management in Australia, which suffers from drought cycles and shifting floods, popular participation was essential to the government and companies to implement initiatives aimed to manage sustainable consumption during the Millennium Drought (Sousa Júnior et al. 2016). When comparing Singapore's water management to the Piracicaba, Capivari and Jundiaí (PCJ) Rivers Basin Committee, the best structured in the country (Gontijo Júnior, unpublished data), Sakaguti Júnior (unpublished data) points out that the lack of articulation between society and public authorities, bureaucracy in the money transfers and low capability to launch initiatives present in the PCJ Committee would endanger the management of surface waters and groundwater.

One of the strengths of the Agreement was the importance of the knowledge generated by the researchers from all the countries that cooperated to support and secure decision making (Santos, unpublished data). In the past, knowledge of groundwater was restricted to geologists, hydrogeologists, and other professionals in the area who focused on studying the physical systems and dynamics of reservoirs. Today, engineers, systems analysts, and economists help make the use of these waters technically better. The new projects aimed at efficient management of the resources and risks involved, combining diverse sectors and policies in strategies that seek to preserve water resources (Tujchneider et al. 2013).

In this line of thought, ISARM Americas as an epistemic community has contributed to the production and dissemination of SAG's knowledge and governance of transboundary waters. It was argued that due to the lack of international law rules on water and its particularities, in addition to the few registered cases of multinational agreements for the management of shared resources, the SAG lacks a strong legal basis to guide the legislators from the countries involved. ISARM Americas disseminates technical information through a variety of means, providing data on the normative structure of the countries, helping to draw up co-joint guidelines for projects and establishing guidelines for groundwater management (Souza et al. 2014).

Broadly speaking, the Guarani Aquifer Agreement was a regulatory mark in the area of transboundary waters. Above all, closer relations between states and nations are needed to establish a transnational set of laws and institutions to regulate water use and academic cooperation, but such activities can be endangered by political and diplomatic problems, which may indicate a short-term view of the governments involved and political interests threatened, as there would be an international observation on these interactions.

FINAL REMARKS

This work sought to identify relevant studies and researches about the SAG on issues more familiar to society such as pollution and environmental impacts, exploitation of SAG waters and governmental management, for example. This bridge between academic knowledge and society is key to inform people of how daily routine can impact an important resource that is not visible to all.

Based on the researched articles, for the environmental, economic and technological points of view, more long-term studies in larger areas to measure impacts are needed, once the occurrence of a problem in a single-point area can spread to its vicinities. That said, it is recommended that public authorities, companies and research institutions collaborate to better understand the SAG peculiarities (Villar 2016b), in order to avoid future expenses with health, water treatment and drilling of new wells.

On the socio-political view, the Guarani Aquifer Agreement is emblematic because it is a model agreement on transboundary waters, though, by the selected works, it is suggested that greater integration among members and transnational regulatory institutions, simplification of bureaucracy, and academic and technical communication between researchers and research centers are absent and strongly suggested. It reinforces the need for further discussions on state, national and international hydropolitics, still lacking on the SAG and its members, and how this cooperation would help shape other cross-border water agreements (Hussein 2018, Zeitoun and Cascão, 2013).

Finally, water sustainability can be defined as the ability to use sufficient quantities of quality water on a local or global scale to meet human and environmental needs and to protect society from the hazards caused by natural or man-made disasters (Mays 2006). The water crisis from 2014 to 2016 showed that common sense of water abundance is a questionable idea. As seen, without the cooperation among society, private agents and the State, water management is a difficult task to be implemented to ensure sustainable water development.

REFERENCES

ABREU CA AND ROISENBERG A. 2018. Distribuição geoquímica de metais pesados e outros elementos químicos em águas subterrâneas da Bacia do Rio dos Sinos, RS. Pesquisas em Geociências, Porto Alegre, v. 44, n. 1, p. 63-78.

ALVES RIS, SAMPAIO CF, NADAL M, SCHUMACHER M, DOMINGO JL, SEGURA-MUÑOZ SI. 2014. Metal concentrations in surface water and sediments from Pardo River, Brazil: Human health risks. Environmental Research, v. 133, p. 149-155. DOI: 10.1016/j.envres.2014.05.012.

AMORE L. 2011. The Guarani Aquifer: From Knowledge to Water Management. International Journal of Water Resources Development, v. 27, n. 3, p. 463-476.

ANDERSON MA, CUDERO AL, PALMA J. 2010. Capacitive deionization as an electrochemical means of saving energy and delivering clean water. Comparison to present desalination practices: Will it compete? Electrochimica Acta, v. 55, p. 3845-3856. DOI: 10.1016/j.electacta.2010.02.012

ARBOIT NKS et al. 2013. Potencialidade de utilização da energia geotérmica no Brasil – uma revisão de literatura. Revista do Departamento de Geografia, São Paulo, v. 26, p. 155-168. DOI: 10.7154/RDG.2013.0026.0008.

ARCARO NP, PEREIRA SY, MIGUEL MG, AGUIAR DPO. 2010. Study of soil contaminated by vinasse applying leach test. In: XXXVIII International Association of Hydrologists, Cracóvia/Polônia, IAH 2010.

BALABAN TÖ, BÜLBÜL A, TARCAN G. 2017. Review of water and soil contamination in and around Salihli geothermal field (Manisa, Turkey). Arabian Journal of Geosciences, v. 10, n. 523. DOI: 10.1007/s12517-017-3299-z

BONOTTO DM AND ELLIOT T. 2017. Trace elements, REEs and stable isotopes (B, Sr) in GAS groundwater, São Paulo State, Brazil. Environmental Earth Sciences, v. 76. DOI: 10.1007/s12665-017-6590-0

BORGHETTI N et al. 2004. Aqüífero Guarani: a verdadeira integração dos países do Mercosul. Curitiba: Imprensa Oficial.

BRIÃO VB, MAGOGA J, HEMKEMEIER M et al. 2014. Reverse osmosis for desalination of water from the Guarani Aquifer System to produce drinking water in southern Brazil. Desalination, v. 344 p. 402-411. DOI: 10.1016/j.desal.2014.04.008

BRIÃO VB, PANDOLFO A, BRIÃO EB, FAVARETTO DPC. 2016. Economic assessment of the desalination of the Guarani Aquifer System by reverse osmosis to produce potable water in southern Brazil. Desalination and Water Treatment, v. 57, n. 42, p. 19690-19701. DOI: 10.1080/19443994.2015.1103310

CAMARGO TRM, MERSCHMANN PRC, ARROYO EV, SZKLO A. 2014. Major challenges for developing unconventional gas in Brazil – Will water resources impede the development of the Country′s industry? Resources Policy, v. 41, p. 60-71. DOI: 10.1016/j.resourpol.2014.03.001.

CANATO HM, CONCEIÇÃO FT, HAMADA J, MORUZZI RB, NAVARRO GRB. 2014. Caracterização hidrogeoquímica do aquífero Adamantina na área urbana de Bauru, SP. Ciência & Engenharia, v. 23, n. 2, p. 39-47.

CASTILLA-RHO JC, MARIETHOZ G, ROJAS R, ANDERSEN MS, KELLY BFJ. 2015. An agent-based platform for simulating complex human–aquifer interactions in managed groundwater systems. Environmental Modelling & Software, v. 73, p. 305-323. DOI: 10.1016/j.envsoft.2015.08.018.

CAVALETT O, JUNQUEIRA, TL, DIAS MOS et al. 2012. Environmental and economic assessment of sugarcane first generation biorefineries in Brazil. Clean Technologies and Environmental Policy, v. 14, n. 3, p. 399-410. DOI: 10.1007/s10098-011-0424-7

CETESB. SÃO PAULO. 2016. Qualidade das águas subterrâneas do estado de São Paulo 2013-2015. Execução Rosângela Pacini Modesto [et al..]. Colaboração Blas Marçal Sanchez [et al..] - São Paulo.

COELHO VHR, MONTENEGRO S, ALMEIDA CN, SILVA BB, OLIVEIRA LM, GUSMÃO ACV, FREITAS ES, MONTENEGRO AAA. 2017. Alluvial groundwater recharge estimation in semi-arid environment using remotely sensed data. Journal of Hydrology. DOI: 10.1016/j.jhydrol.2017.02.054

COMASSETTO V, MATTHIENSEN A, ALVES J, FAVASSA CTA, YABIKU VM, WASKIEWIC ME, BÓLICO J. 2014. Diagnóstico das águas subterrâneas na bacia do Rio Jacutinga e contíguos. In: Anais do XVIII Congresso Brasileiro de Águas Subterrâneas, Belo Horizonte, Águas Subterrâneas, São Paulo, Brasil.

CONCEIÇÃO FT, MAZZINNI F, MORUZZI RB, NAVARRO GRB. 2014. Influências Naturais e Antrópicas na Qualidade da Água Subterrânea de Poços de Abastecimento Público na Área Urbana de Marília (SP). Revista Brasileira de Recursos Hídricos, v. 19, p. 227-238. DOI: 10.21168/rbrh.v19n3.p227-238.

CONFORTÍ N. 2014. Principios en la gestión de los recursos naturales compartidos por los estados del primigenio Mercosur. Latinoamérica, Revista de Estudios Latinoamericanos, v. 59, p. 129-163. DOI: 10.1016/S1665-8574(14)71728-4.

CONLEY DJ, PAERL HW, HOWARTH RW, BOESCH DF, SEITZINGER SP, KARL E, LANCELOT C, GENE E. 2009. Controlling eutrophication: Nitrogen and phosphorus. Science, v. 123, p. 1014–1015.

DI BERNARDO L, DANTAS AD, VOLTAN PE. 2011. Tratabilidade de água e dos resíduos gerados em estações de tratamento de água. São Carlos/SP: Editora LDIBE.

DIETZ T, OSTROM E, STERN PC. 2003. The struggle to govern the commons. Science, v. 302, n. 5652, p. 1907–1912. DOI: 10.1126/science.1091015

DOBROVOLSKI R AND RATTIS L. 2015. Water collapse in Brazil: the danger of relying on what you neglect. Natureza & Conservação, v. 13, n. 1, p. 80-83. DOI: 10.1016/j.ncon.2015.03.006.

DÖLL P AND FIEDLER K. 2008. Global-scale modeling of groundwater recharge, Hydrology and Earth System Sciences, v. 12, p. 863-885. DOI: 10.5194/hess-12-863-2008

ELKINGTON J. 1994. Towards the Sustainable Corporation: Win-Win-Win Business Strategies for Sustainable Development. California Management Review, v. 36, n. 2 , p. 90–100.

FAMIGLIETTI JS. 2014. The global groundwater crisis. Nature Climate Change, v. 4, n.11, p. 945–948. DOI:10.1038/nclimate2425.

FRAPPART F, SEOANE L, RAMILLIEN G. 2013. Validation of GRACE-derived terrestrial water storage from a regional approach over South America. Remote Sensing of Environment, v. 137, p. 69-83. DOI: 10.1016/j.rse.2013.06.008.

GASTMANS D AND KIANG CH. 2005. Avaliação da hidrogeologia e hidroquímica do sistema Aqüifero Guarani no estado do Mato Grosso do Sul. Águas subterrâneas, São Paulo, v. 19, n. 1, p. 35 – 48.

HEBERER T, REDDERSEN K, MECHLINSKI A. 2002. From municipal sewage to drinking water: Fate and removal of pharmaceutical residues in the aquatic environment in urban areas. Water Science and Technology, v. 46, n. 3, p. 81–88.

HIRATA R, SANGIORGE M, WAHNFRIED I, LIMA JBV. 2012. Explotação do Sistema Aquífero Guarani em Araraquara. Geologia Série Científica USP, Revista do Instituto de Geociências – USP, São Paulo, v. 12, n. 2, p. 11-127.

HOFFMAN AR. 2011. The Connection: Water Supply and Energy Reserves. Washington DC, US Department of Energy.

HOUBEN GJ et al. 2015. The impact of high-intensity no-till agriculture on groundwater quality in the subtropical Capiibary catchment, SE Paraguay. Environmental Earth Sciences, n. 74, v. 1, p. 479-491. DOI: 10.1007/s12665-015-4055-x

HÖYNG D, D'AFFONSECA FM, BAYER P, OLIVEIRA EG, PERINOTTO JAJ, REIS F, WEIß H, GRATHWOHL P. 2014. High-resolution aquifer analog of fluvial–aeolian sediments of the Guarani aquifer system. Environmental Earth Sciences, v. 71, n. 7, p. 3081–3094. DOI: 10.1007/s12665-013-2684-5

HU K, AWANGE JL, KHANDU et al. 2017. Hydrogeological characterisation of groundwater over Brazil using remotely sensed and model products. Science of The Total Environment, v. 599-600, p. 372-386. DOI: 10.1016/j.scitotenv.2017.04.188.

HUSSEIN H. 2018. The Guarani Aquifer System, highly present but not high profile: A hydropolitical analysis of transboundary groundwater governance. Environmental Science & Policy, v. 83, p. 54-62. DOI: 10.1016/j.envsci.2018.02.005.

ZEITOUN M AND CASCÃO AE. 2013 Power, Hegemony and Critical Hydropolitics. In Transboundary Water Management: Principles and Practice. Routledge: London, p. 40-55.

IGRAC (International Groundwater Resources Assessment Centre), UNESCO-IHP (UNESCO International Hydrological Programme). Transboundary Aquifers of the World [mapa]. Edição 2015. Escala: 1:50000000. Delft, Holanda: IGRAC, 2015.

IPT (Instituto de Pesquisas Tecnológicas). Sistema Aquífero Guarani: Subsídios ao Plano de Desenvolvimento e Proteção Ambiental da Área de Afloramento do Sistema Aquífero Guarani no Estado de São Paulo [online], 2011. Secretaria do Meio Ambiente do Estado de São Paulo.

Jet Propulsion Laboratory. News. Study: Third of Big Groundwater Basins in Distress.

KAAKINEN I, LEHTINEN A. 2016. A bridge that disconnects – On shared and divided socio-spatialities in the pulp mill conflict between Uruguay and Argentina. Forest Policy and Economics, v. 70, p. 106-112. DOI: 10.1016/j.forpol.2016.06.005.

LADO JJ, ZORNITTA RL, CALVI FA et al. 2017. Enhanced capacitive deionization desalination provided by chemical activation of sugar cane bagasse fly ash electrodes. Journal of Analytical and Applied Pyrolysis, v. 126, p. 143-153. DOI: 10.1016/j.jaap.2017.06.014.

LI J, WANG C, WANG D et al. 2016. A novel technology for remediation of PBDEs contaminated soils using tourmaline-catalyzed Fenton-like oxidation combined with P. chrysosporium. Chemical Engineering Journal, v. 296, p. 319-328. DOI: 10.1016/j.cej.2016.03.118.

LIU ZH, KANJO Y, MIZUTANI S. 2010. A Review of phytoestrogens: their occurrence and fate in the environment. Water Research, v. 44, n. 2, p. 567-577. DOI: 10.1016/J.Watres.2009.03.025.

LOBLER CA AND SILVA JLS. 2015. Vulnerabilidade à contaminação das águas subterrâneas do município de Nova Palma, Rio Grande do Sul, Brasil. Revista Ambiente & Água [online], v. 10, n. 1, p.141-152. DOI: http://dx.doi.org/10.4136/ambi-agua.1390

LOURENCETTI C, DE MARCHI MRR, RIBEIRO ML. 2012. Influence of sugar cane vinasse on the sorption and degradation of herbicides in soil under controlled conditions. Journal of Environmental Science and Health, Part B, v. 47, n. 10, p. 949–958. DOI: 10.1080/03601234.2012.706562

LUCAS M, OLIVEIRA PTS, MELO DCD, WENDLAND E. 2015 Evaluation of remotely sensed data for estimating recharge to an outcrop zone of the Guarani Aquifer System (South America). Hydrogeology Journal , v. 23, p. 961– 969. DOI: 10.1007/s10040-015-1246-1

LUCAS M AND WENDLAND E. 2016. Recharge estimates for various land uses in the Guarani Aquifer System outcrop area. Hydrological Sciences Journal, v. 61, n. 7, p. 1253-1262. DOI: 10.1080/02626667.2015.1031760

MACHADO AR, MELLO JUNIOR AV, WENDLAND EC. 2017. Avaliação do modelo J2000/JAMS para modelagem hidrológica em bacias hidrográficas brasileiras. Engenharia Sanitária e Ambiental, Rio de Janeiro, v. 22, n. 2, p. 327-340. DOI: 10.1590/s1413-41522016145177

MANZIONE RL, MARCUZZO FFN, WENDLAND EC. 2012. Integração de modelos espaciais e temporais para predições de níveis freáticos extremos. Pesquisa Agropecuária Brasileira [online], v. 47, n. 9, p. 1368-1375. DOI: 10.1590/S0100-204X2012000900022.

MANZIONE RL, SOLDERA BC, WENDLAND EC. 2017. Groundwater system response at sites with different agricultural land uses: case of the Guarani Aquifer outcrop area, Brotas/SP-Brazil. Hydrological Sciences Journal, v.62, n. 1, p. 28-35. DOI: 10.1080/02626667.2016.1154148

MARTIRANI LA AND PERES IK. 2016. Water crisis in São Paulo: news coverage, public perception and the right to information. Ambiente & Sociedade, São Paulo, v. 19, n. 1, p. 1-20. DOI: 10.1590/1809-4422asoc150111r1v1912016.

MAYS LW. 2006. Water Resources Sustainability. McGraw-Hill: New York, NY, USA.

MELO DCD, WENDLAND E, GUANABARA RC. 2015. Estimate of Groundwater Recharge Based on Water Balance in the Unsaturated Soil Zone. Revista Brasileira de Ciência do Solo, Viçosa, v. 39, n. 5, p. 1336-1343. DOI: 10.1590/01000683rbcs20140740.

MELO DCD AND WENDLAND E. 2017. Shallow aquifer response to climate change scenarios in a small catchment in the Guarani Aquifer outcrop zone. Anais da Academia Brasileira de Ciências, Rio de Janeiro, v. 89, n. 1, supl. p. 391-406.

MERONI E AND PIÑEIRO G. 2014. Nuevas tecnologías extractivas para hidrocarburos no convencionales y potenciales riesgos ambientales al Acuífero Guaraní. Revista Sociedad Uruguaya de Geología, v. 19, p. 15-35.

MIRA A, DACAL MLG, TOCHO C, VIVES L. 2013. 3D gravity modeling of the Corrientes province (NE Argentina) and its importance to the Guarani Aquifer System. Tectonophysics, v. 608, p. 212-221. DOI: 10.1016/j.tecto.2013.09.034.

MURADÁS K, WOHL O, WOJAHN D. 2010. Levantamento de dados geomorfológicos e hidrogeológicos para mapeamento de vulnerabilidade de contaminação do Aquífero Guarani nos Municípios de Portão e Estância Velha/RS utilizando o método DRASTIC. Revista Ambiente & Água, v. 5.

MUSALEM K, MCDONALD MA, JIMÉNEZ F, LAINO R. 2015. Groundwater Vulnerability Mapping in Two Watersheds Affected by Yacyreta Dam in Paraguay. Tecnología y Ciencias del agua, v. 6, p. 49-61.

NAVA A, MANZIONE, RL. 2015. Resposta de níveis freáticos do sistema Aquífero Bauru (formação Adamantina) em função da precipitação e evapotranspiração sob diferentes usos da terra. Águas Subterrâneas, v. 29, n. 2, p. 191-201. DOI: http://dx.doi.org/10.14295/ras.v29i2.28402

NIU B, LOÁICIGA HA, WANG Z, ZHAN FB, HONG S. 2014. Twenty years of global groundwater research: A Science Citation Index Expanded-based bibliometric survey (1993–2012). Journal of Hydrology, v. 519 - parte A, p. 966-975. DOI: 10.1016/j.jhydrol.2014.07.064.

OLIVEIRA PTS et. al. 2017. Groundwater recharge decrease with increased vegetation density in the Brazilian cerrado. Ecohydrology, v. 10, n. 1. DOI: 10.1002/eco.1759

Organização dos Estados Americanos (OEA). Aquífero Guarani: programa estratégico de ação / Acuífero Guaraní: programa estratégico de acción.– Edição bilíngüe.– Brasil; Argentina; Paraguai; Uruguai: Organização dos Estados Americanos (OEA), Janeiro 2009.

Parlamento do Mercosul. Agência PARLASUL. Proposta de Declaração visa ratificar o Acordo sobre o Aquífero Guarani.

PAZUCH FA et al. 2017. Economic evaluation of the replacement of sugar cane bagasse by vinasse, as a source of energy in a power plant in the state of Paraná, Brazil. Renewable and Sustainable Energy Reviews, v. 76, p. 34-42. DOI: 10.1016/j.rser.2017.03.047.

PEREIRA A AND PACINO MC. 2012. Annual and seasonal water storage changes detected from GRACE data in the La Plata Basin. Physics of the Earth and Planetary Interiors, v. 212–213, p. 88-99. DOI: 10.1016/j.pepi.2012.09.005.

RABELO JL AND WENDLAND E. 2009. Assessment of groundwater recharge and water fluxes of the Guarani Aquifer System, Brazil. Hydrogeology Journal, v. 17, p. 1733–1748, 2009. DOI: 10.1007/s10040-009-0462-y

RIBEIRO WC. 2008. Aqüífero Guarani: gestão compartilhada e soberania. Estudos Avançados, São Paulo, v. 22, n. 64, p. 227-238.

RODRÍGUEZ L, VIVES L, GOMEZ A. 2013. Conceptual and numerical modeling approach of the Guarani Aquifer System. Hydrology and Earth System Sciences, v. 17, n. 1, p. 295-314. DOI: 10.5194/hess-17-295-2013

ROUX BL, VAN DER LAAN M, VAHRMEIJER T, ANNANDALE JG, BRISTOW KL. 2016. Estimating Water Footprints of Vegetable Crops: Influence of Growing Season, Solar Radiation Data and Functional Unit. Water, v. 8, n. 10, p. 473. DOI: 10.3390/w8100473

SALEM K, MCDONALD MA, JIMÉNEZ F, LAINO R. 2015. Groundwater Vulnerability Mapping in Two Watersheds Affected by Yacyreta Dam in Paraguay. Tecnología y Ciencias del agua, v. 6, p 49-61.

SANCHES SM, VIEIRA EM, PRADO EL, TAKAYANAGUI AMM. 2010. Qualidade da água de abastecimento público de Ribeirão Preto em área de abrangência do Aquífero Guarani: determinação de metais e nitrato. Ambi-Agua, Taubaté, v. 5, n. 2, p. 202-216.

SANTOS CLS, RIBEIRO WC. 2016. Sistema Aquífero Guarani em bases eletrônicas de artigos científicos. Ar@cne: revista electrónica de recursos en internet sobre geografía y ciencias sociales [en línia].

SANTOS RG, STURARO JR, MARQUES ML, FARIA TT. 2015. GIS Applied to the Mapping of Land Use, Land Cover and Vulnerability in the Outcrop Zone of the Guarani Aquifer System. Procedia Earth and Planetary Science, v. 15, p. 553-559. DOI: 10.1016/j.proeps.2015.08.099.

SCHEIBE LF, HENNING LA, NANNI AS. 2014. Aspectos territoriais da exploração do gás de folhelho (gás de xisto) por fraturamento hidráulico. In: Anais do XVIII Congresso Brasileiro de Águas Subterrâneas, Belo Horizonte, Águas Subterrâneas, São Paulo.

SCHMIDT G, VASSOLO S. 2011. Untersuchungen zu einem der größten Grundwasservorkommen Südamerikas: Der Guaraní-Aquifer in Paraguay [Investigations of a key groundwater system in South America: The Guaraní Aquifer in Paraguay]. Grundwasser, v. 16, n. 3, p. 187–194. DOI: 10.1007/s00767-011-0171-z

SHEIKHAVANDI T. 2015. Microbial Functional Activity in Bioremediation of Contaminated Soil and Water. Handbook of Research on Uncovering New Methods for Ecosystem Management through Bioremediation, Chapter: 12, Publisher: IGI global, Editors: Shivom Singh, p.286-316. DOI: 10.4018/978-1-4666-8682-3.ch012.

SILVA DAL, DELAI I, MONTES MLD, OMETTO AR. 2014. Life cycle assessment of the sugarcane bagasse electricity generation in Brazil. Renewable and Sustainable Energy Reviews, v. 32, p. 532-547. DOI: 10.1016/j.rser.2013.12.056.

SOUSA JÚNIOR WC, FIDELMAN PI. 2009. A tecnopolítica da água no Brasil. In Governança da Água no Brasil, uma Visão Interdisciplinar; Ribeiro,W., Ed.; Annablume: São Paulo, Brazil.

SOUSA JÚNIOR W, BALDWIN C, CAMKIN J, FIDELMAN P, SILVA O, NETO S, SMITH TF. 2016. Water: Drought, Crisis and Governance in Australia and Brazil. Water, v. 8, n. 11, p. 493. DOI: 10.3390/w8110493

SOUZA A, FERRARI RS, ANNUNCIAÇÃO D et al. 2016. Polybrominated diphenyl ethers (PBDEs), emerging environmental pollutants, are detected on sediment samples of a water recharge point of Guarani Aquifer in Brazil. Toxicology Letters, v. 259, p. S119-S120. DOI: 10.1016/j.toxlet.2016.07.307.

SOUZA M, SILVA CP, BARBOSA LM. 2014. Governança e difusão de normas para a gestão de aquíferos compartilhados: o papel do ISARM. Contexto Internacional, Rio de Janeiro , v. 36, n. 1, p. 261-289. DOI: 10.1590/S0102-85292014000100009

STAGGEMEIER R, BORTOLUZZI M, HECK TMS, LUZ RBL, FABRES RB, SOLIMAN MC, RIGOTTO C, BALDASSO NA, SPILKI FR, ALMEIDA SEM. 2015. Animal and human enteric viruses in water and sediment samples from dairy farms. Agricultural Water Management, v. 152, p. 135-141. DOI: 10.1016/j.agwat.2015.01.010.

SUGG ZP, VARADY RG, GERLAK AK, GRENADE R. 2015. Transboundary groundwater governance in the Guarani Aquifer System: reflections from a survey of global and regional experts. Water International, v. 40, n. 3, p. 377-400. DOI: 10.1080/02508060.2015.1052939

SUI Q, CAO X, LU S, ZHAO W, QIU Z, YU G. 2015. Occurrence, sources and fate of pharmaceuticals and personal care products in the groundwater: A review. Emerging Contaminants, v. 1, n. 1, p. 14-24. DOI: 10.1016/j.emcon.2015.07.001.

TÖTH G, RMAN N, ÁGNES R, KERÉKGYÁRTÓ T, SZCS T, LAPANJE A, ČERNÁK R, REMSIK A, SCHUBERT G, NÁDOR A. 2016. Transboundary fresh and thermal groundwater flows in the west part of the Pannonian Basin. Renewable and Sustainable Energy Reviews, v. 57, p. 439-454. DOI: 10.1016/j.rser.2015.12.021.

TUJCHNEIDER O, CHRISTELIS G, VAN DER GUN J. 2013. Towards scientific and methodological innovation in transboundary aquifer resource management. Environmental Development, v. 7, p. 6-16.

UECHI DA, GABAS SG, LASTORIA G. 2017. Análise de metais pesados no Sistema Aquífero Bauru em Mato Grosso do Sul. Engenharia Sanitária e Ambiental, Rio de Janeiro , v. 22, n. 1, p. 155-167. DOI: 10.1590/s1413-41522016142430.

UNESCO. 2007. Sistemas Acuíferos Transfronterizos en la Américas – Evaluación Preliminar, Serie ISARM Américas N°1.

USGS. O Ciclo da Água (The Water Cycle, Portuguese).

VARNIER C, IRITANI MA, VIOTTI M, ODA GH, FERREIRA LMR. 2010. Nitrato nas águas subterrâneas do Sistema Aquífero Bauru área urbana do município de Marília (SP). Revista do Instituto Geológico , v. 31, n. 1/2, p. 1-21.

VASCONCELOS VV et al. 2013. Aquifer recharge: epistemology and interdisciplinarity. Revista Internacional Interdisciplinar INTERthesis, Florianópolis, v. 10, n. 2, p. 360-409. DOI: 10.5007/1807-1384.2013v10n2p360

VIANCELLI A, DEUNER CW, RIGO M, PADILHA J, MARCHESI JAP, FONGARO G. 2015. Microbiological quality and genotoxic potential of surface water located above the Guarani aquifer located above the Guarani aquifer. Environmental Earth Sciences, v. 74. DOI: 10.1007/s12665-015-4561-x.

VILELA CLS, BASSIN JP, PEIXOTO RS. 2018. Water contamination by endocrine disruptors: Impacts, microbiological aspects and trends for environmental protection. Environmental Pollution, v. 235, p. 546-559. DOI: 10.1016/j.envpol.2017.12.098.

VILLAR PC. 2016a. Groundwater and the Right to Water in a Context of Crisis. Ambiente & Sociedade, São Paulo, v. 19, n. 1, p. 85-102. DOI: 10.1590/1809-4422asoc150126r1v1912016.

VILLAR PC. 2016b. International cooperation on transboundary aquifers in South America and the Guarani Aquifer case. Revista Brasileira de Política Internacional, Brasília, v. 59, n. 1, e007. DOI: 10.1590/0034-7329201600107.

VILLAR PC, RIBEIRO WC. 2011. The Agreement on the Guarani Aquifer: a new paradigm for transboundary groundwater management? Water International, v. 36, n. 5, p. 646-660. DOI: 10.1080/02508060.2011.603671

WANG J, JIN M, JIA B, KANG F. 2015. Hydrochemical characteristics and geothermometry applications of thermal groundwater in northern Jinan, Shandong, China. Geothermics, v. 57, p. 185-195. DOI: 10.1016/j.geothermics.2015.07.002.